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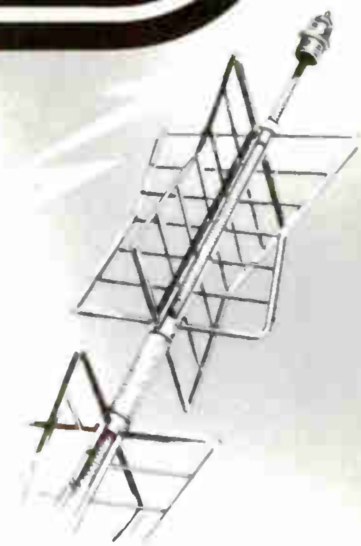
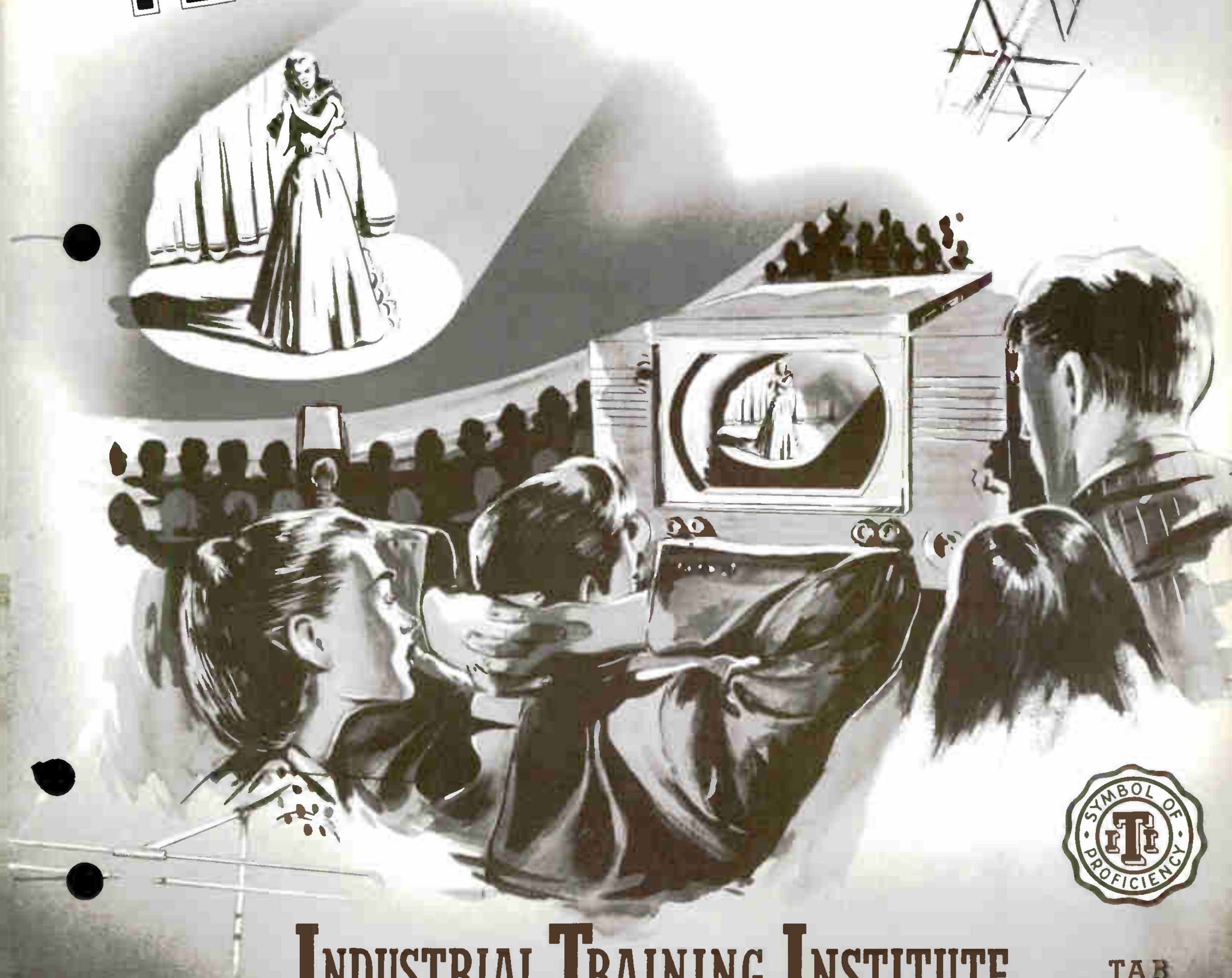


Radio and TELEVISION



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TECHNICAL TRAINING SERVICE

REVISED 1951

RADIO TELEVISION

POWER SUPPLIES

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Section 1. INTRODUCTION

All electronic circuits, including those of radio and television receivers, depend upon a source of power for their electrical energy. Since work must be done in receiving and amplifying the extremely feeble signal which strikes the antenna, a source of electrical energy is required. This source of electrical energy in a radio or television receiver is called a POWER SUPPLY.

A radio receiver power supply may take many forms, depending on the type of receiver employed, the number of tubes it contains, and the power output desired at the loudspeaker. While power supplies themselves are of varied types, they must -- as a group -- meet certain minimum requirements. A receiver power supply must provide high-voltage D-C power for the operation of the plate and screen circuits of the amplifier tubes, and must usually provide the heater or filament voltage (either A-C or D-C) for the tubes. The high D-C voltage is called the *B-supply*. The heater or filament voltage is called the *A-supply*. When these two minimum requirements are supplied, the modern radio or television receiver can be caused to operate.

Section 2. BATTERIES WERE THE ORIGINAL POWER SUPPLIES

The derivation of the terms "A" and "B" is interesting. These names were handed down to modern radio and television repairmen from the days when most radio receivers were operated from battery power sources. At that time the high-voltage battery was called the "B" battery, and the low voltage, or filament battery, the "A" battery. Even today, in portable battery receivers, this terminology is maintained. Fig. 1 is a typical portable receiver.

It is well to mention here that all modern radio receivers could be powered

Fig. 1. Portable Receiver. (Courtesy of Emerson Radio and Television.)

for operation by a battery system, if the batteries were connected in the proper way. However, as the radio industry grew, and receiver output requirements became more demanding, it was found that for many purposes the battery system was no longer adequate. Batteries wear out with use, and are subject to deterioration even when not in use. Batteries are bulky and heavy, and space must be provided for their inclusion into the receiver cabinet. Batteries are costly to replace, which makes the cost of operating a battery receiver in the home almost prohibitive.

To overcome the limitations of batteries as a source of power, the self-powered power supply was devised. By this means the user of a radio receiver simply plugs into any convenient commercial power outlet and the power supply in the receiver then delivers the proper "A" and "B" voltages. This makes for satisfactory and inexpensive operation.

Modern portable receivers still use the battery power supply. Here portability is more important than expense of operation. To enable these receivers to operate economically, special low drain tubes have been designed and the size of both the "A" and "B" batteries reduced in size and weight. The continued demand for radio entertainment at the beach and park and other places where no commercial power is available, has maintained the popularity of this type receiver.

Section 3. TYPES OF POWER SUPPLIES

Radio and Television receiver power supplies may be divided into several groups:

1. The AC-DC, or "transformerless" power supply. This is also referred to as the "universal" power supply, since it can be used directly on either A-C or D-C commercial voltages and thus is suitable for almost any location. Special emphasis will be placed on this type of power supply, since it is used in more than half of all radio receivers in operation today. It is becoming increasingly important in television.

2. The A-C power supply. The receiver containing this type of power supply can be used on A-C commercial voltage only, and with few exceptions involves the use of a power transformer which steps the "A" voltage down to the proper value and delivers a high-voltage A-C which is rectified to produce the "B" supply. This type is second in popularity only to the AC-DC power supply mentioned above. The more expensive television receivers all use this type of power supply.

3. The automobile radio, or vibrator, power supply. As the names suggest, this type of power supply is designed for use in automobiles or other mobile applications, and involves the use of a vibrator-transformer system to provide "B" voltage after rectification. The "A" voltage is supplied directly from the battery. The storage battery also furnishes the power to drive the vibrator-transformer system.

There is no reason why this system cannot also be used for automobile television receivers, but if the present trend of laws prohibiting television in automobiles continues, there is a possibility there soon will be no automobile television receivers.

4. The portable receiver power supply. This group can be further subdivided into:

a. The straight portable receiver, using batteries only.

b. The 3-way portable receiver, using a choice of: Batteries when operated outdoors, and of A-C or D-C commercial power when operated indoors.

c. The rechargeable power supply. In this case, prime power is derived from a 2.2 volt wet cell which drives a vibrator system similar to that in an automobile radio receiver. The wet cell can be kept in a charged condition by connection to commercial A-C power.

While the above power supplies all have the common ability to provide *A* and *B* voltage of the proper value, their construction and circuits differ widely. For quick and accurate trouble-shooting it is essential, therefore, for the repairman to make a positive identification of the type of power supply in the receiver under analysis before attempting any repair whatsoever.

Section 4. THE AC-DC POWER SUPPLY

Fig. 2 is a typical circuit used to provide power for an AC-DC receiver. In this diagram the "A" voltage -- to heat the tube cathodes -- is supplied to the tube heaters through a series connection of all the heaters or filaments. The pilot lamp is shunted across a portion of the power rectifier heater. "B" voltage -- for the use of

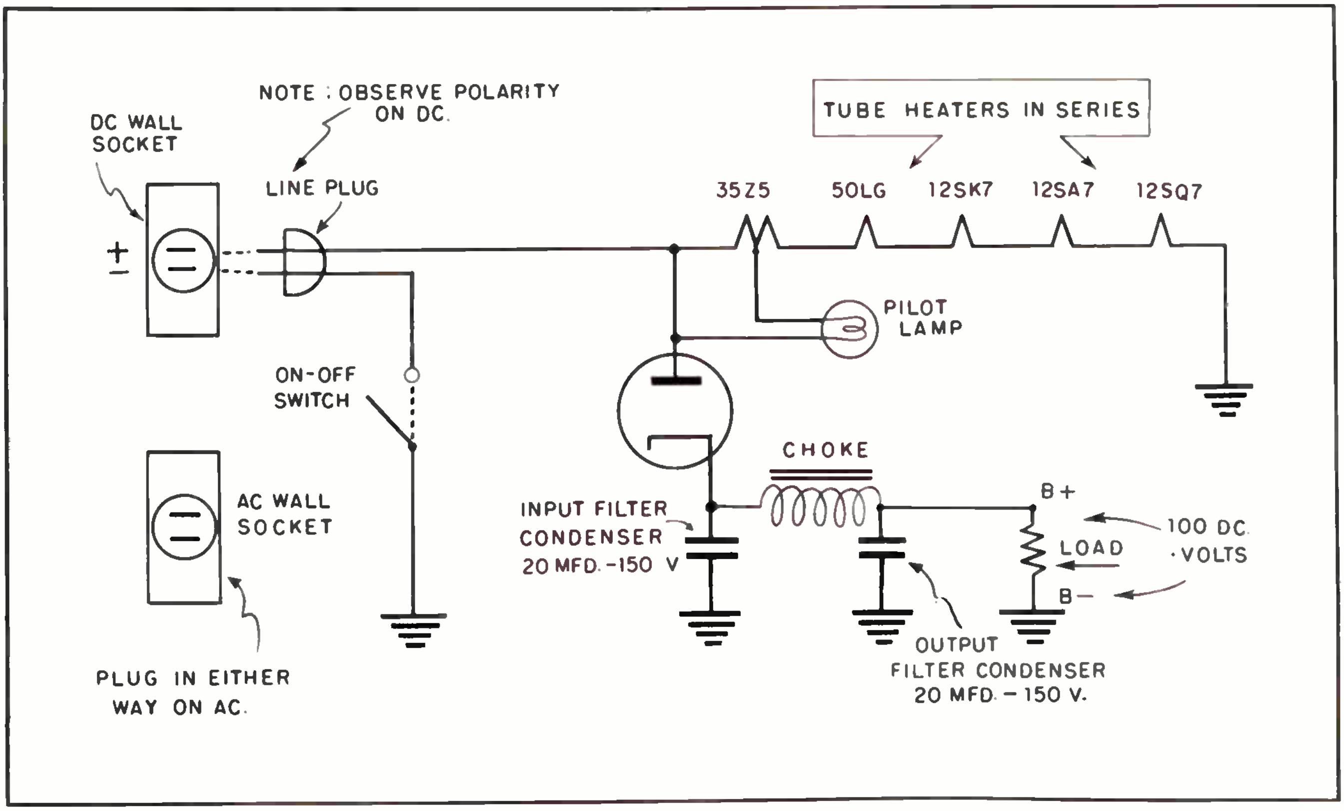


Fig. 2. AC-DC Power Supply.

the plates and screens of the amplifier tubes -- is supplied from the cathode of the rectifier, fed through the Pi-type L/C filter system, and delivered in practically pure D-C form to wherever it is needed.

Because of its greater simplicity, let us first consider the operation of the universal power supply while it is operating from a 110-volt D-C source. When the on-off switch is closed, and the power plug inserted in the wall receptacle as shown by the dotted lines in Fig. 2, current will flow through the on-off switch, through the chassis, and through the series of tube heaters to the positive side of the line. This current heats the tube heaters, which in turn bring the tube cathodes to a temperature high enough for thermionic emission to take place from the cathode surfaces.

In the meantime, after the rectifier cathode begins to emit electrons, the electrons will move toward the more positive rectifier anode, or plate, which is also connected to the positive side of the line. Electrons thus leaving the rectifier cathode will render the cathode more positive, and it, in turn, will draw more electrons through the load from ground. The filter system consists of two electrolytic condensers separated by a choke. The condensers oppose any changes of voltage across this circuit while the choke opposes changes of current in the circuit. Both effects serve to keep the voltage drop across the load constant. A steady voltage source is necessary for the proper operation of the amplifier tubes.

Pilot lamp current is a portion of the total heater current, as can be seen from the diagram.

An interesting question may well be asked here: If the system is operating from a D-C power source, why do we need either the rectifier or the filter system, since the input D-C voltage is already constant and well-filtered? The answer is that if we were certain the receiver would always be used on D-C it would not need the rectifier or filter system. We cannot, of course, be certain of this fact. To avoid limiting the use of the receiver to D-C power alone, the rectifier and filter system are included.

Now let us examine the operation of this power supply while using 115-volt A-C commercial power. The "A" voltage is supplied in the same manner as when used from a D-C power source, except that wall-receptacle polarity need not be observed. When the

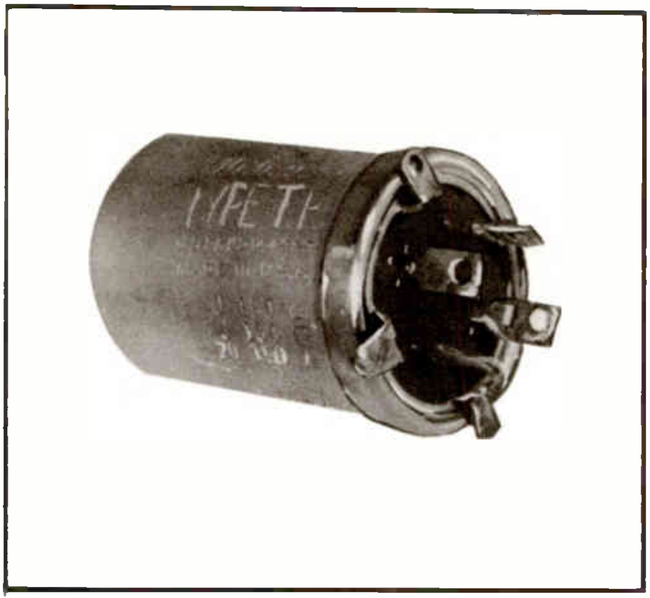


Fig.3. Electrolytic Capacitor. Two Capacitors in One Can.

on-off switch is closed, A-C current flows in the heater and pilot lamp circuit. The heaters are heated and the cathodes become ready to emit electrons. The "B" supply, however, is being powered by an alternating current, and rectification is necessary. This is done by a half-wave rectifier whose output is pulsating D-C. To stabilize the voltage across the load, the Pi-type filter comes to our assistance and smoothes out the pulses into a ripple-free D-C voltage. The Pi-type filter obtains its name from the fact a schematic drawing of its components resembles the Greek letter π.

Each of the filter condensers has a name. That nearest the cathode is called the input filter condenser, which is separated by a choke (or filter resistor) from the output filter condenser. The "B" voltage is available across the output filter condenser and is polarized to agree with the polarity indicated on the condenser. Most often, both components of a filter condenser system are enclosed within one container. See Fig. 3. There is shown the appearance of a typical common dual-section filter condenser.

Fig. 4 shows the complete schematic diagram of an AC-DC receiver, with its power supply feeding the proper voltages to all components requiring them. Test points X--X indicate where a voltmeter, on the 150 volt D-C scale, should be placed to read the output voltage. In the average AC-DC receiver, this voltage should read approximately 100 D-C volts. Some will read a little higher.

Section 5. **THE A-C POWER SUPPLY**

Fig. 5 illustrates a typical straight A-C power supply. Here the power transformer

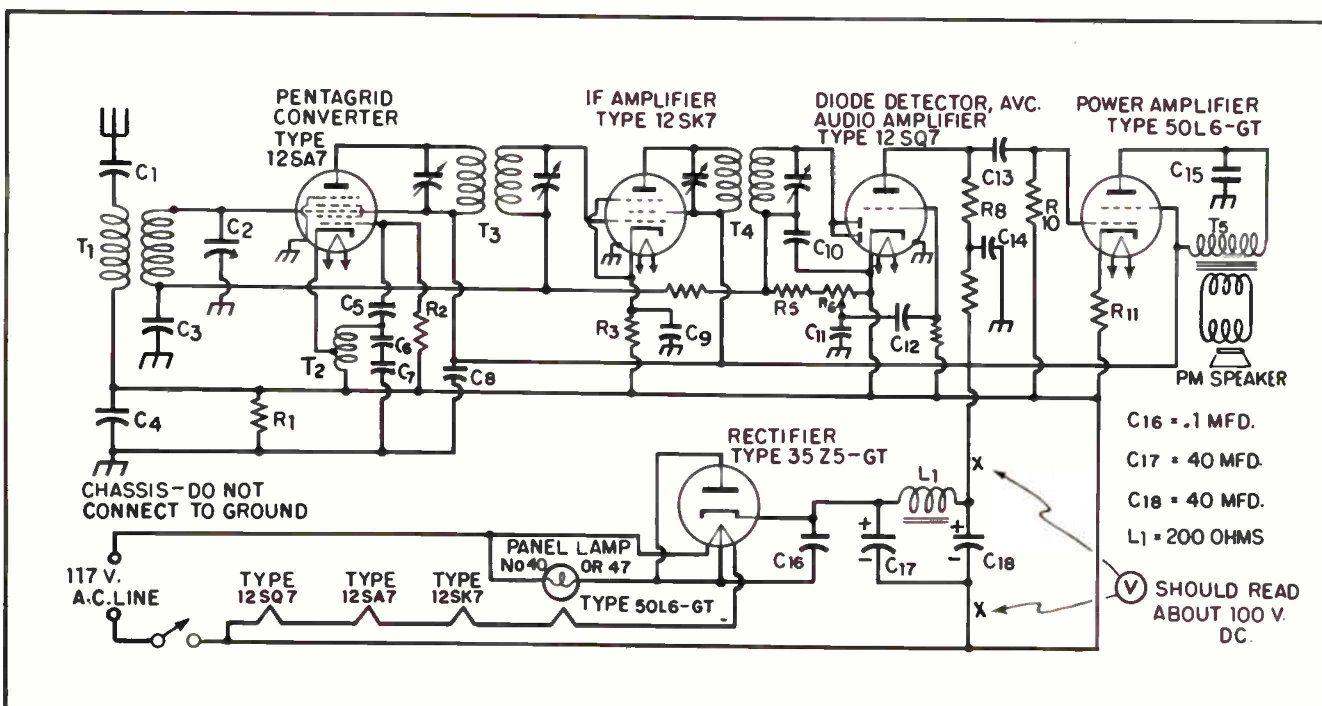


Fig.4. AC-DC Radio Receiver Schematic.

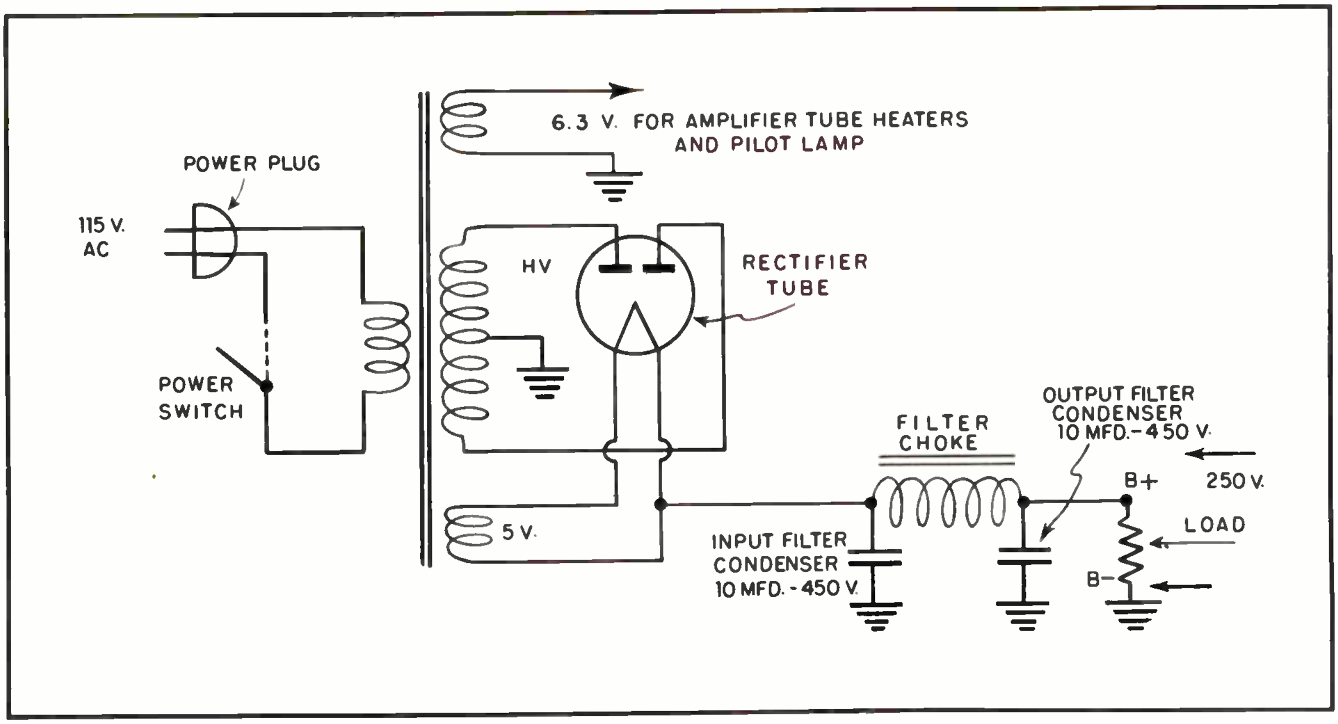


Fig.5. A-C Power Supply Using Transformer.

is used, which limits its application to purely A-C circuits of the proper voltage and frequency. In most cases, this will be approximately 115 volts, 60 cycle, to use the power supplied by the commercial power companies.

By reference to Fig. 5 we can see that when the power switch is closed, alternating current flowing through the power transformer primary induces three separate secondary voltages. These are: 6.3 volts for the amplifier tube heaters; 5 volts for the rectifier tube heater (or filament); and high voltage A-C to be rectified, filtered, and used by the plate and screen circuits of the amplifier tubes.

Under operating conditions, electrons will flow from B-minus through the load, through the filter choke, to the cathode of the rectifier. From here current will continue to flow to whichever of the two rectifier plates is positive at the time, and then proceed to B-minus through the high-voltage transformer windings. Rectification here is full-wave, in contrast to the half-wave rectification present in AC-DC receivers. Load current is stabilized in the A-C power supply much in the same manner as in the AC-DC power supply, except that filter condensers used may have smaller capacity, usually 8 or 10 mfd each. However, because the output voltage from this type power is over 200 volts, filter condenser voltage ratings should be at least 350 volts, and may be as high as 400 or 450 volts. In the A-C power supply, as in the AC-DC power supply, "B" voltage is available at the output filter condenser, from where it may be connected to any point in the receiver requiring high D-C voltage.

Fig. 6 shows a full schematic diagram of an A-C receiver. This illustrates the manner in which the required voltages are produced and distributed throughout the receiver.

Section 6. THE AUTOMOBILE RADIO POWER SUPPLY

To accommodate an occupant of a moving vehicle with radio entertainment and information, a special automobile receiver power supply has been perfected. Fig. 7 is the circuit involved. In automobile receivers the problem of heating the amplifier tube cathodes is simply solved. The tube heaters are connected through a suitable fuse and switch, directly to the 6-volt storage battery of the car.

However, the production of high-voltage D-C -- the "B" voltage -- is a less simple matter. At the heart of the method used to convert 6-volt D-C to high voltage D-C is a vibrator, samples of which are shown

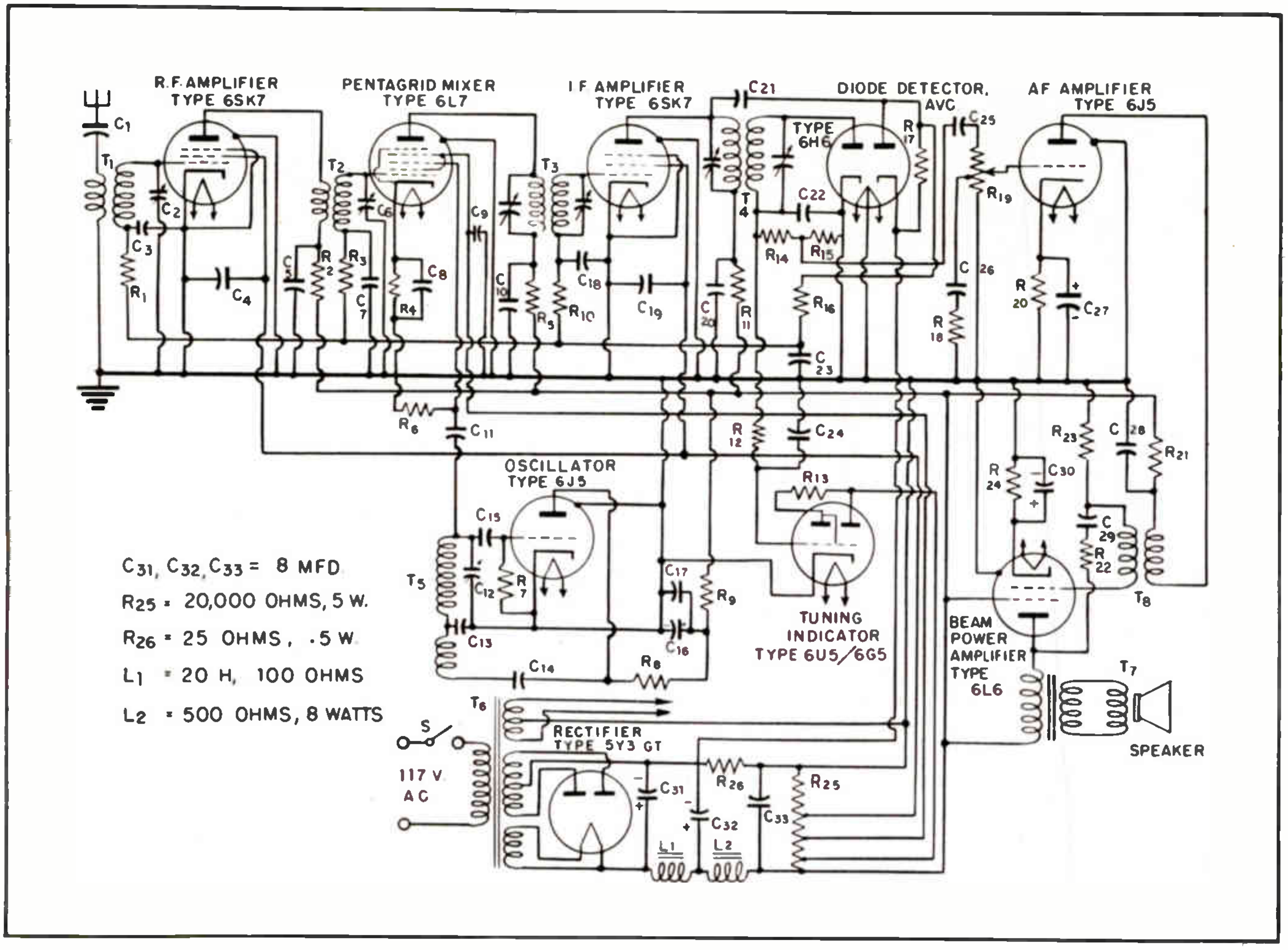


Fig. 6. Receiver Using A-C Power Supply.

in Fig. 8. It is the duty of the vibrator to break up the battery D-C into pulses which can be applied to the primary of a transformer and so induce secondary voltages for use as the "B" supply. Vibrators are similar in appearance to many electrolytic capacitors. Vibrators, however, usually plug into a socket like a tube. They are not wired.

In Fig. 7 the storage battery of the car supplies the prime power for this system. When the on-off switch is closed, current flows through the heater choke directly to the 6-volt heaters, thus supplying the "A" voltage required. At the same time, a portion of the current that flows through the heater choke splits off through the vibrator choke and continues through the upper half of the transformer primary, past contact *2* of the vibrator, until it reaches ground through the vibrator electromagnet. This current accomplishes two things: it induces a voltage in the transformer secondary, and draws the vibrator reed over to touch contact *2*. As the reed touches contact *2*, current from this point is short-circuited through the reed to ground. This de-energizes the electromagnet, releasing its hold on the reed and permitting it to swing all the way over to contact *1*. When contact *1* is touched by the reed, battery current flows through the lower half of the transformer primary to ground, inducing another voltage pulse in the secondary. The spring action of the reed assembly now adds to the pull of the electromagnet -- re-energized by the swing of the reed away from contact *2* -- to pull the reed against contact *2*, completing the first of an endless series of cycles.

The result of the action of the vibrator is that an alternating voltage is produced in the transformer secondary. The magnitude of this voltage is determined by the step-up ratio of the transformer windings, and the frequency of alternations by the natural vibrating frequency of the vibrator reed, usually 50-60 cycles per second.

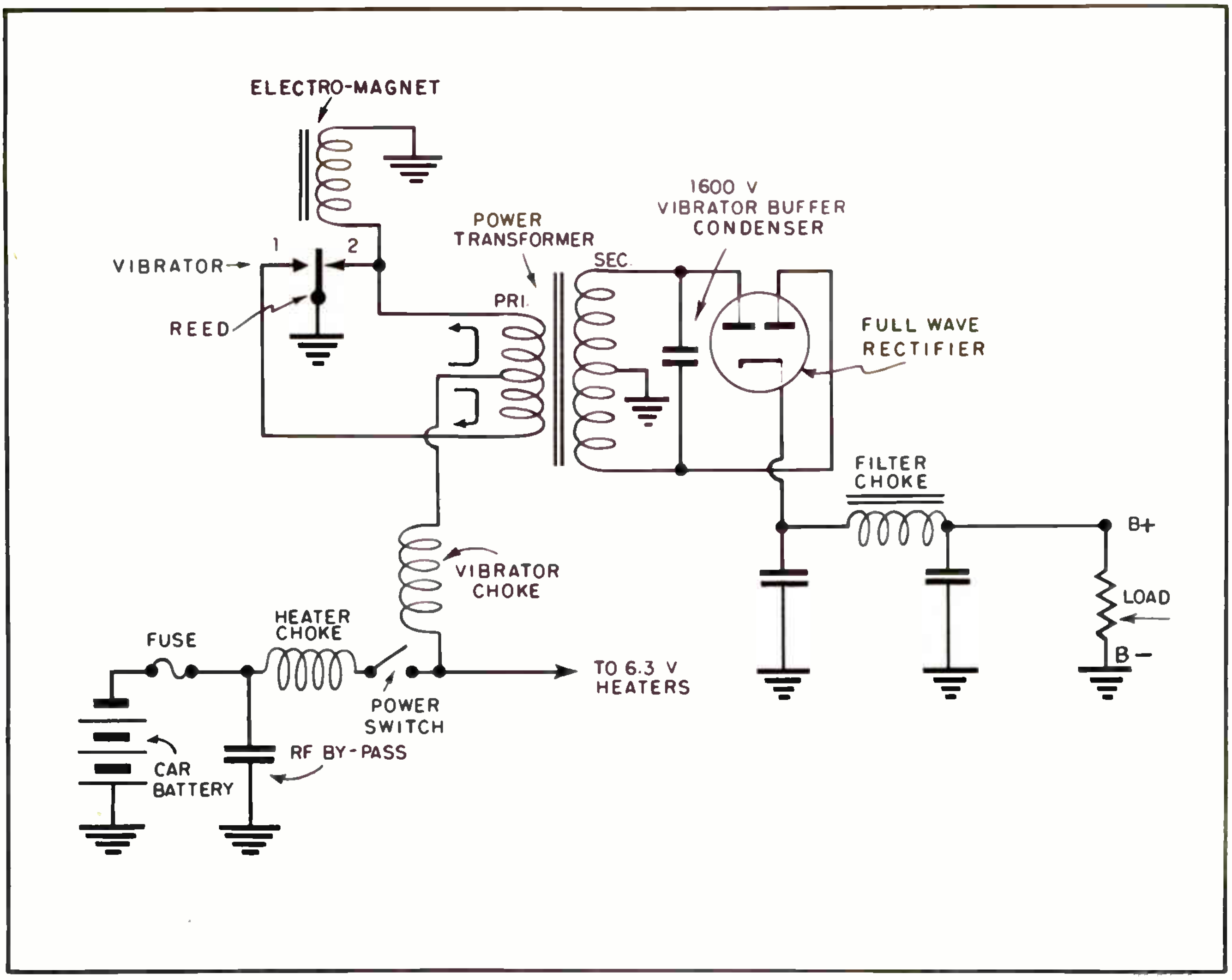


Fig. 7. Automobile Power Supply.

Fig. 9 on the page following, shows the internal construction of a typical vibrator.

With the primary current flowing on alternate half-cycles in each half of this winding, secondary voltages are induced such as to render first one plate positive, then the other, during each successive half-cycle. Notice that the ground connection is always half-way between them, being more positive than the negative plate, and more negative than the positive plate. (See Fig. 7.) When one plate is positive with respect to ground, that plate will attract electrons from the cathode of that tube. On the next half-cycle, this same plate is negative and will not attract electrons, but the opposite plate will attract them, being positive. The point is, that regardless of which plate is attracting electrons at any time the tube must draw its electrons through the load from ground (or

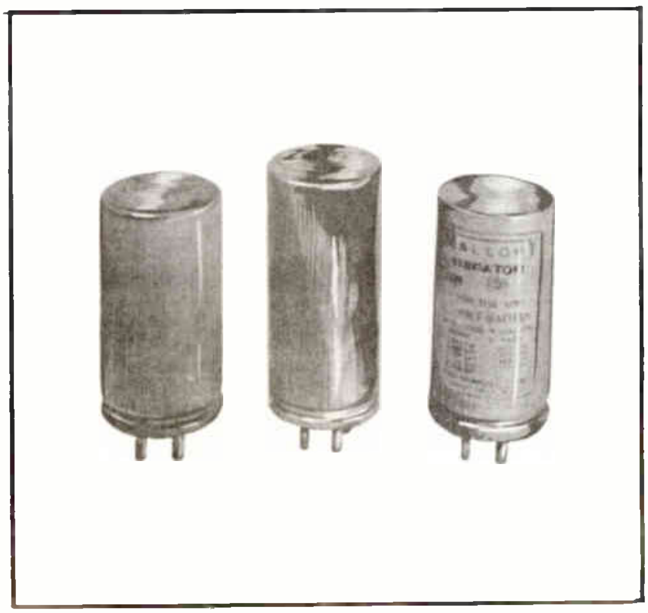


Fig. 8. Vibrators.

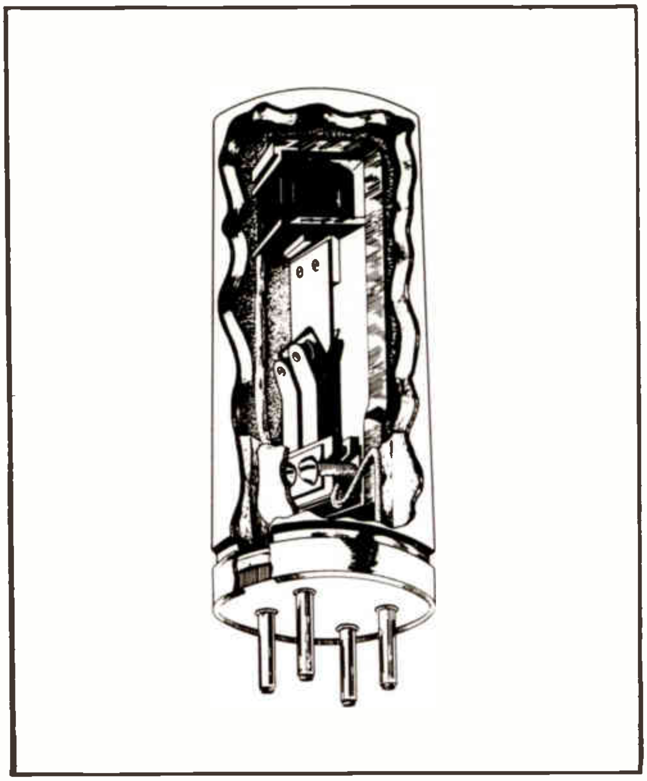


Fig.9. Internal Construction of a Vibrator.

B-minus), past the output filter condenser, through the filter choke, past the input filter condenser, to the rectifier tube cathode.

Current through the load is unidirectional. The filter choke opposes any current changes, and the filter condensers oppose any voltage changes across the load. As in the cases of both the AC-DC and the purely A-C power supplies, B-plus is available at the output filter condenser. In automobile radio receivers the B supply voltage varies between 100-300 volts D-C.

The vibrator buffer condenser, in Fig. 7, across the terminals of the transformer secondary (and also across the rectifier plates) has a high voltage rating, usually a minimum of 1600 volts. If it must be replaced, its exact capacitance should be noted since it is designed to resonate with the inductance of the transformer secondary at vibrator frequency for the purpose of maximum efficiency, and to protect the vibrator points from corrosion due to sparking.

Fig. 10 shows the schematic diagram of an automobile radio receiver.

Section 7. THE PORTABLE RECEIVER POWER SUPPLY

Portable radios employ three general systems of power supplies:

A. The "straight" battery system.
Fig. 11 is a schematic circuit of the battery portable receiver. Its power supply, as is evident from the illustration, is limited to replaceable batteries only, and hence this type of receiver needs no rectifier nor filter system. Fig. 12 shows the forms that these batteries may take, depending upon the manufacturer's choice of design.

From the circuit of Fig. 11 we can see that the on-off switch is a DPST arrangement which connects and disconnects both the "A" and "B" batteries simultaneously, leaving all other circuits intact.

B. The 3-way portable receiver system.
This type of receiver embodies features of the battery-powered radio plus those of the home radio receiver. The schematic diagram of a typical 3-way portable is shown in Fig. 13. Here the user can choose the manner of power applied to the receiver circuits by the use of the power selector switch. This has at least two positions, which are marked *AC-DC* and *Battery*.

A third position is sometimes provided and marked *OFF*. In the OFF position neither the AC-DC power nor the battery is used. Other types of receivers place the OFF switch at some other convenient position. Sometimes this switch can be manually operated at will; sometimes it will automatically make and break with the opening and closing of the receiver's front cover.

While the power selector switch is in the "Battery" position, the system operates exactly as in the case of the straight battery portable. In this case, troubleshooting is identical with that of the straight portable power supply.

However, while the power selector switch is in the AC-DC position, the rectifier-filter system is used. In the circuit of Fig. 13 this position selects connections to a rectifier tube, providing it with heater current and A-C plate voltage. At the same time the switch disconnects the batteries and, in their place, provides rectified D-C plate and filament voltages of the proper values. The filter system is also connected into the circuit.

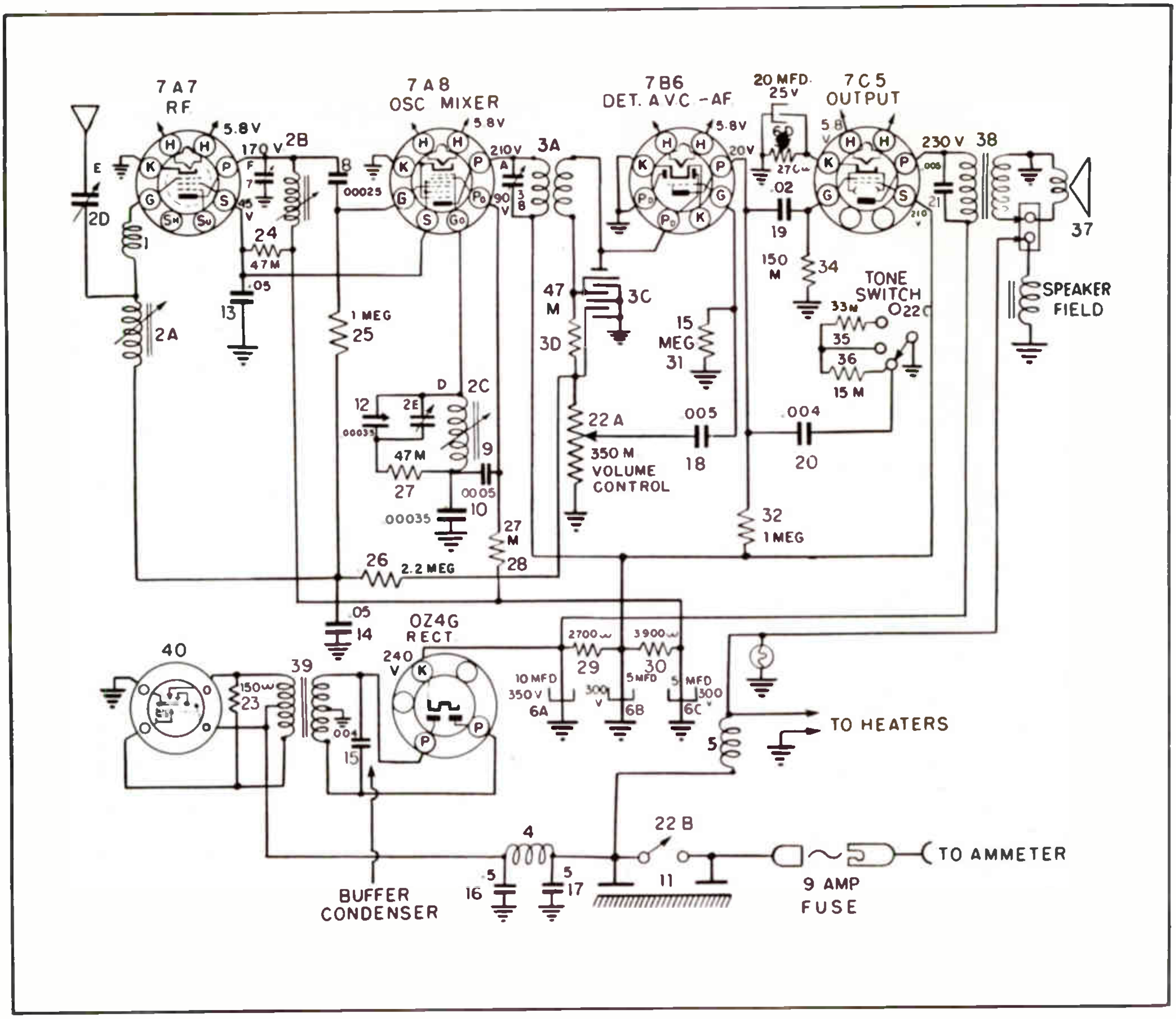


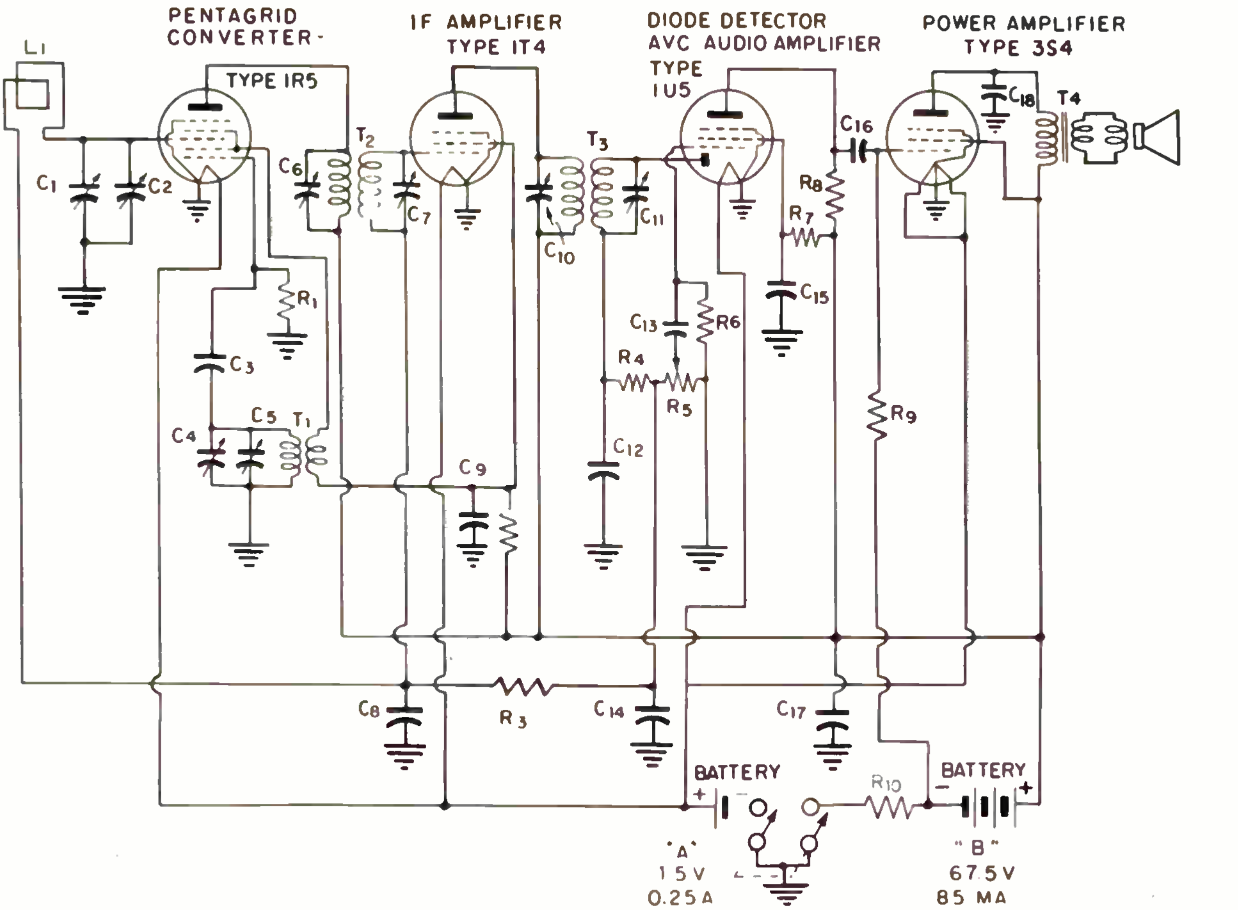
Fig. 10. Schematic of Automobile Receiver Showing Power Supply.

"B" voltage is developed in this system in a conventional manner by running load current past the output filter condenser, through the filter choke or resistor, past the input filter condenser, and thence to the rectifier cathode. The "A" voltage, in contrast to previously mentioned power supplies, instead of being A-C is now also rectified D-C. It originates at the rectifier cathode and is dropped to operating value through a special dropping resistor or ballast.

This "A" voltage must also be well filtered, since it is now being applied to directly heated filament-cathodes in the amplifier tubes. These portable tubes are directly heated since direct heating is the only method by which they can be utilized efficiently and economically. Otherwise, they would seriously shorten battery life while the system was operating on battery. The presence of a 60-cycle hum, in a portable receiver while operating on the house-power function, can be traced as often to defective "A" voltage filters as to defective "B" voltage filters.

Two separate methods of connecting the filaments of a 3-way portable receiver are utilized. They may be connected to a 1.5 volt source in parallel, as shown in Fig. 14, or they may be connected from a 6, 7.5, or 9-volt source in series, as shown in Fig. 15.

To determine which of the two methods is used, consult the battery rating of the



C_1 C_4 = Ganged tuning capacitors: C_1 10-274 μμf; C_4, 7.5-122.5 μμf.

C_2 C_5 = Trimmer capacitors, 2-15 μμf

C_3 = 56 μμf, ceramic

C_6 C_7 C_{10} C_{11} = Trimmer capacitors

C_8 = 0.05 μf, tubular, 400 v.

C_9 C_{15} = 0.02 μf, tubular, 100 v.

C_{12} = 82 μμf, ceramic

C_{13} C_{16} = 0.002 μf, tubular 150 v.

C_{14} = 33 μμf, ceramic

C_{17} = 10 μf, electrolytic, 60 v.

C_{18} = 0.005 μf, tubular, 600 v.

L_1 = Loop antenna, 550-1600 kc.

R_1 = 0.1 megohm, 0.25 watt

R_2 = 15000 ohms, 0.25 watt

R_3 R_9 = 3.3 megohms, 0.25 watt

R_4 = 68000 ohms, 0.25 watt

R_5 = Volume control, potentiometer, 2 megohms

R_6 = 10 megohms, 0.25 watt

R_7 = 4.7 megohms, 0.25 watt

R_8 = 1 megohm, 0.25 watt

R_{10} = 820 ohms, 0.25 watt

S_1 = Switch, double-pole single-throw

T_1 = Oscillator coil, tapped; for use with tuning capacitor of 7.5-122.5 μμf, and 455 kc if transformer.

T_2 T_3 = Intermediate-frequency transformers, 455 kc

T_4 = Output transformer for matching impedance of voice coil to 5000-ohm tube load

Fig. 11. Schematic of Battery Portable Receiver.

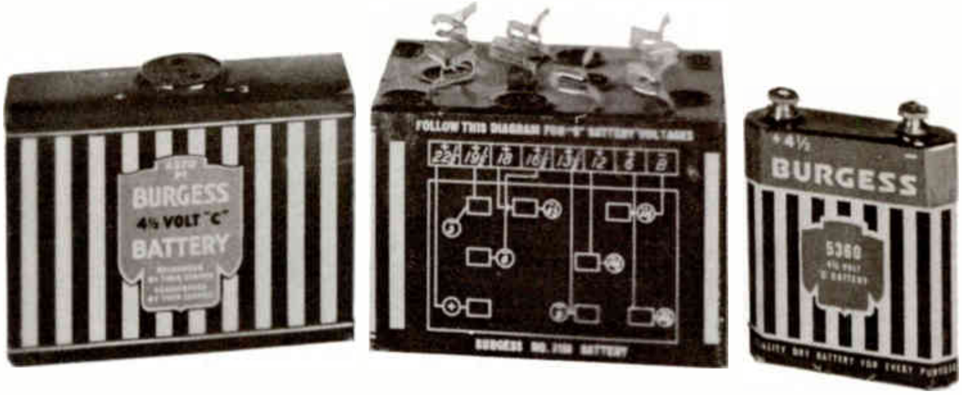


Fig. 12. Radio Batteries.

receiver. If the "A" battery is rated at 1.5 volts the amplifier tube filaments are connected in parallel on both the battery and the AC-DC functions. If the "A" battery rating is 6, 7-1/2, or 9 volts, the amplifier tube filaments are connected in series on both positions of the power selector switch. It is obvious that trouble-shooting the 3-way portable will, to a great extent, depend upon how well you understand which of these two methods is used in the receiver under analysis. The same trouble may cause different symptoms and different readings in various systems.

The power supply for a portable television receiver is very similar to those used in radio.

C. The rechargeable portable receiver power supply. This power supply system differs from the previous 3-way power supply in that it contains prime power in the form of a 2.2 volt wet cell, which in addition to furnishing filament voltage directly to the amplifier tubes also drives a vibrator-transformer system to furnish high voltage D-C to a filtering circuit for the use of the "B" supply. A typical circuit of this type is shown in Fig. 16.

While this power supply is by no means as popular as the previously-mentioned portable sets, it has the advantage of economy in operation, since its wet cell can be recharged from the 115-volt A-C line at periodic intervals. This makes battery replacement costs negligible.

The system is a cross between a battery-charger, a portable power supply, and an automobile receiver power supply, and its function switch is appropriately marked as follows, in Section 8.

Section 8. OFF-CHARGE-BATTERY-POWER

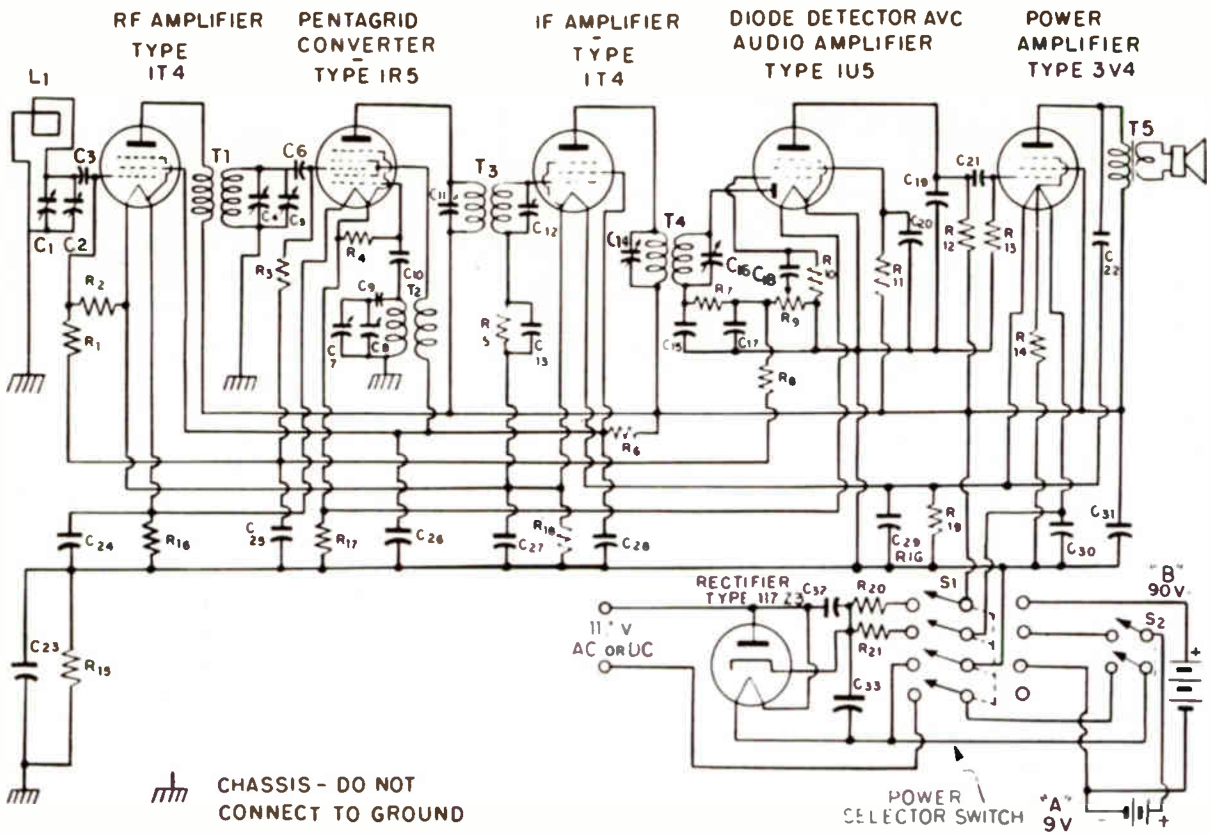
In the OFF position, all circuits are de-energized.

In the CHARGE position, the receiver does not play, but when the power plug is inserted in the A-C 115-volt line, the internal battery charger, with its step-down transformer and dry-disc rectifier, will be placed in operation. This is to charge the wet cell up to operating conditions.

In the BATTERY position the set will play, but the battery will not charge. This position is that used when the user is listening to his receiver while at the beach or park, or wherever no commercial power is available.

In the POWER position, with the power plug inserted into the 115-volt A-C line, the set will play and will at the same time maintain its battery charge. This permits listening to the receiver at home and still keep the battery charged up for future use at the park or beach.

This type of receiver should never be connected to D-C commercial power, since D-C would burn up the primary winding of the battery-charging transformer.



C_1 C_4 C_8 = Ganged tuning capacitors, 20-450 µµf

C_2 C_5 C_7 C_{11} C_{12} C_{14} C_{16} = Trimmer Capacitors

C_3 C_{10} C_{15} C_{17} = 100 µµf, ceramic

C_6 = 82 µµf, ceramic

C_9 = 560 µµf, ceramic

C_{13} = 0.01 µf, tubular, 400 v.

C_{18} C_{21} = 0.002 µf, tubular, 400 v.

C_{19} = 270 µµf, ceramic

C_{20} = 0.02 µf, tubular, 400 v.

C_{22} C_{32} = 0.005 µf, tubular, 400 v.

C_{23} = 0.1 µf, 400 v.

C_{24} = 0.05 µf, 200 v.

C_{25} C_{26} C_{27} C_{28} = 0.05 µf, 400 v.

C_{29} = 40 µf, 25 v.

C_{30} = 160 µf, 25 v.

C_{31} C_{33} = 20 µf, 150 v.

L_1 = Loop antenna, 540-1600 kc

R_1 R_2 R_{11} = 4.7 megohms, 0.25 watt

R_3 = 2.2 megohms, 0.25 watt

R_4 = 0.10 megohm, 0.25 watt

R_5 = 5.6 megohms, 0.25 watt

R_6 = 0.027 megohm, 0.25 watt

R_7 = 0.068 megohm, 0.25 watt

R_8 = 3.3 megohms, 0.25 watt

R_9 = Volume control, potentiometer, 1 megohm

R_{10} = 10 megohms, 0.25 watt

R_{12} = 0.220 megohm, 0.25 watt

R_{13} = 1 megohm, 0.25 watt

R_{14} R_{16} = 1800 ohms, 0.25 watt

R_{15} = 0.220 megohm, 0.5 watt

R_{17} = 1000 ohms, 0.25 watt

R_{18} = 2700 ohms, 0.25 watt

R_{19} = 1500 ohms, 0.25 watt

R_{20} = 1800 ohms, 10 watts

R_{21} = 2300 ohms, 10 watts

S_1 = Switch, 4-pole, double-throw

S_2 = Switch, double-pole, single-throw

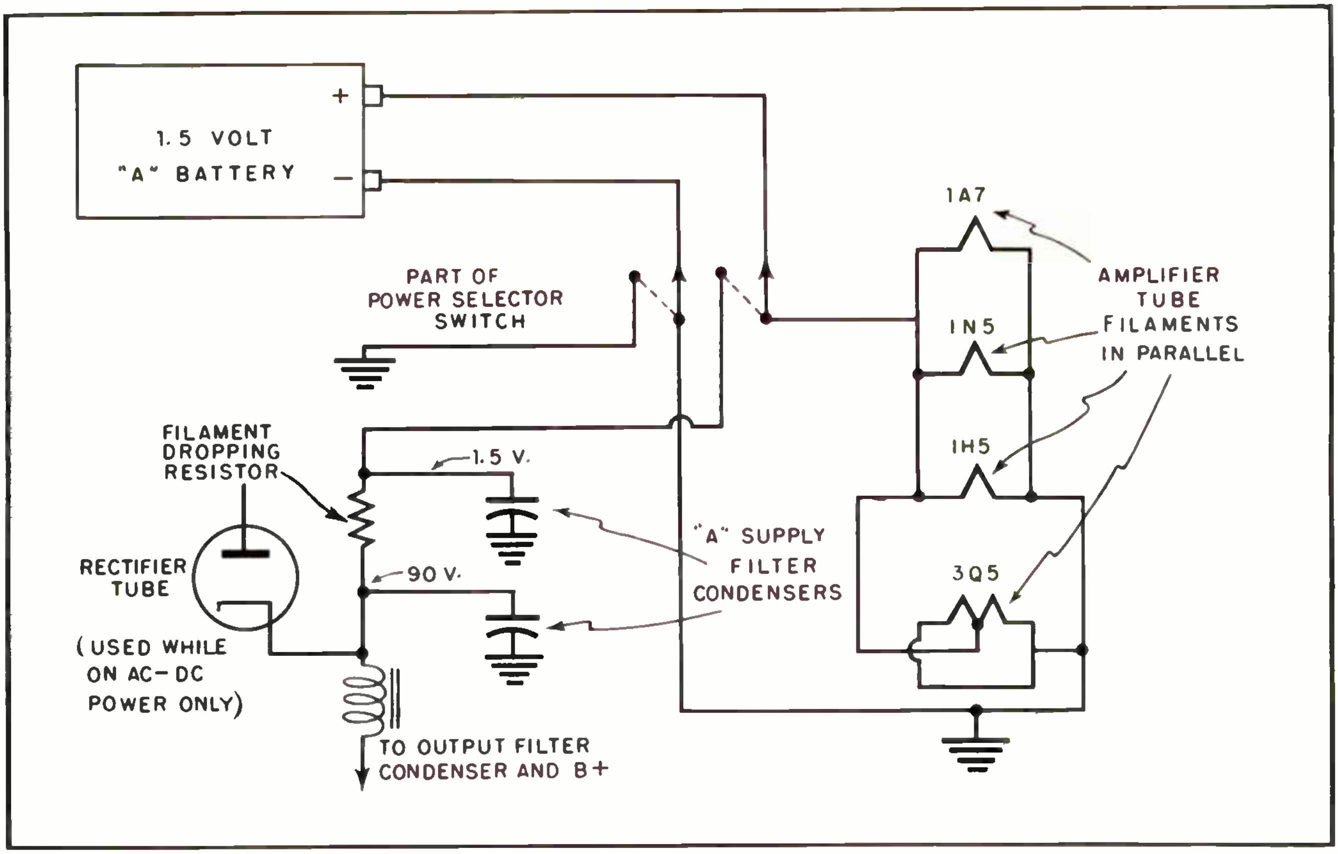
T_1 = RF transformer, 540-1600 kc

T_2 = Oscillator coil for use with a 560 µµf padder, 20-450 µµf tuning capacitor, and 455 kc if transformer

T_3 T_4 = Intermediate-frequency transformers, 455 kc

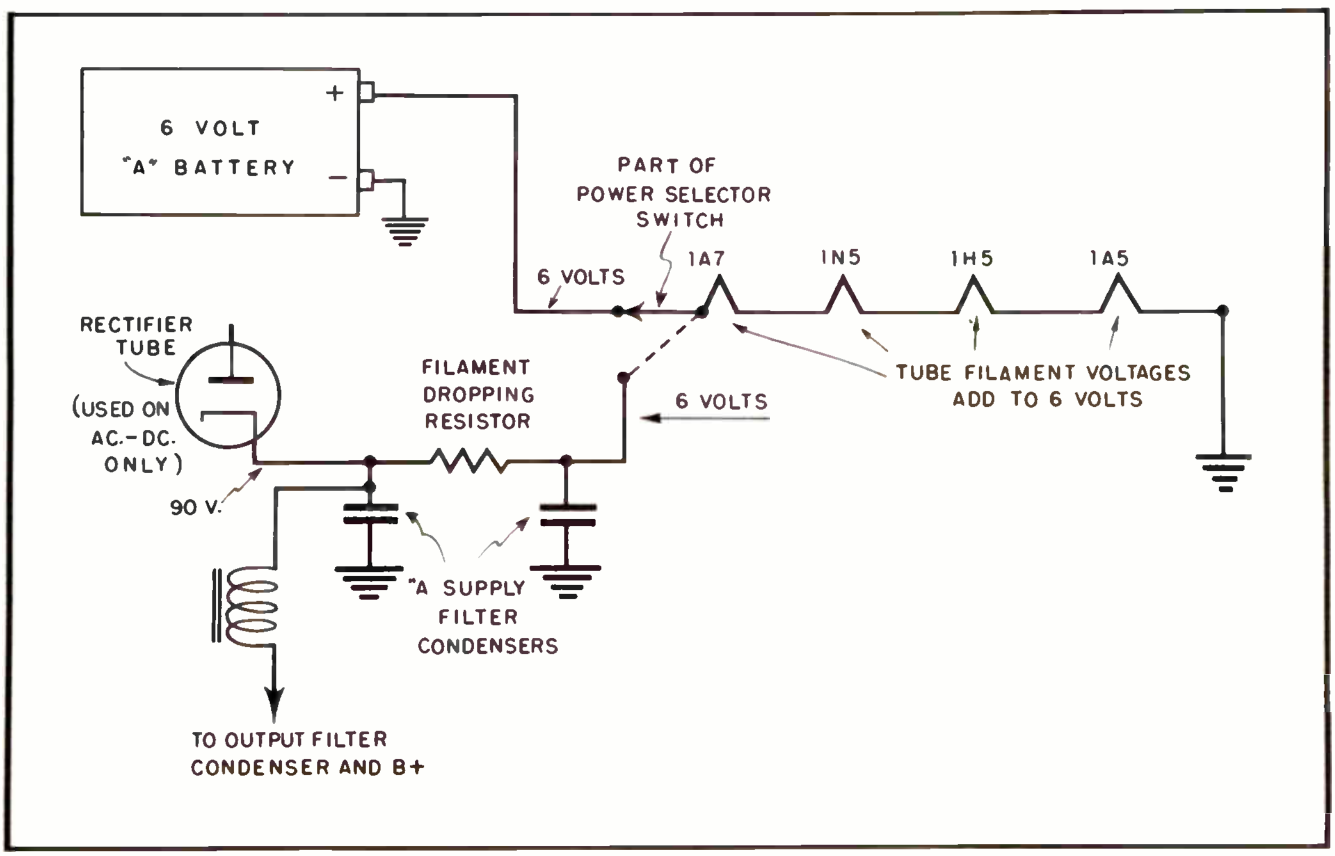
T_5 = Output transformer for matching impedance of voice coil to 10000-ohm tube load.

Fig. 13. Three-Way Portable Receiver Circuit.



1.5 VOLT
"A" BATTERY
+
—
PART OF
POWER SELECTOR
SWITCH
1A7
1N5
1H5
3Q5
AMPLIFIER
TUBE
FILAMENTS
IN PARALLEL
FILAMENT
DROPPING
RESISTOR
1.5 V.
90 V.
RECTIFIER
TUBE
(USED WHILE
ON AC-DC
POWER ONLY)
"A" SUPPLY
FILTER
CONDENSERS
TO OUTPUT FILTER
CONDENSER AND B+

Fig. 14.



6 VOLT
"A" BATTERY
+
—
PART OF
POWER SELECTOR
SWITCH
6 VOLTS
1A7
1N5
1H5
1A5
RECTIFIER
TUBE
(USED ON
AC.-DC.
ONLY)
FILAMENT
DROPPING
RESISTOR
6 VOLTS
TUBE FILAMENT VOLTAGES
ADD TO 6 VOLTS
90 V.
"A SUPPLY
FILTER
CONDENSERS
TO OUTPUT FILTER
CONDENSER AND B+

Fig. 15.

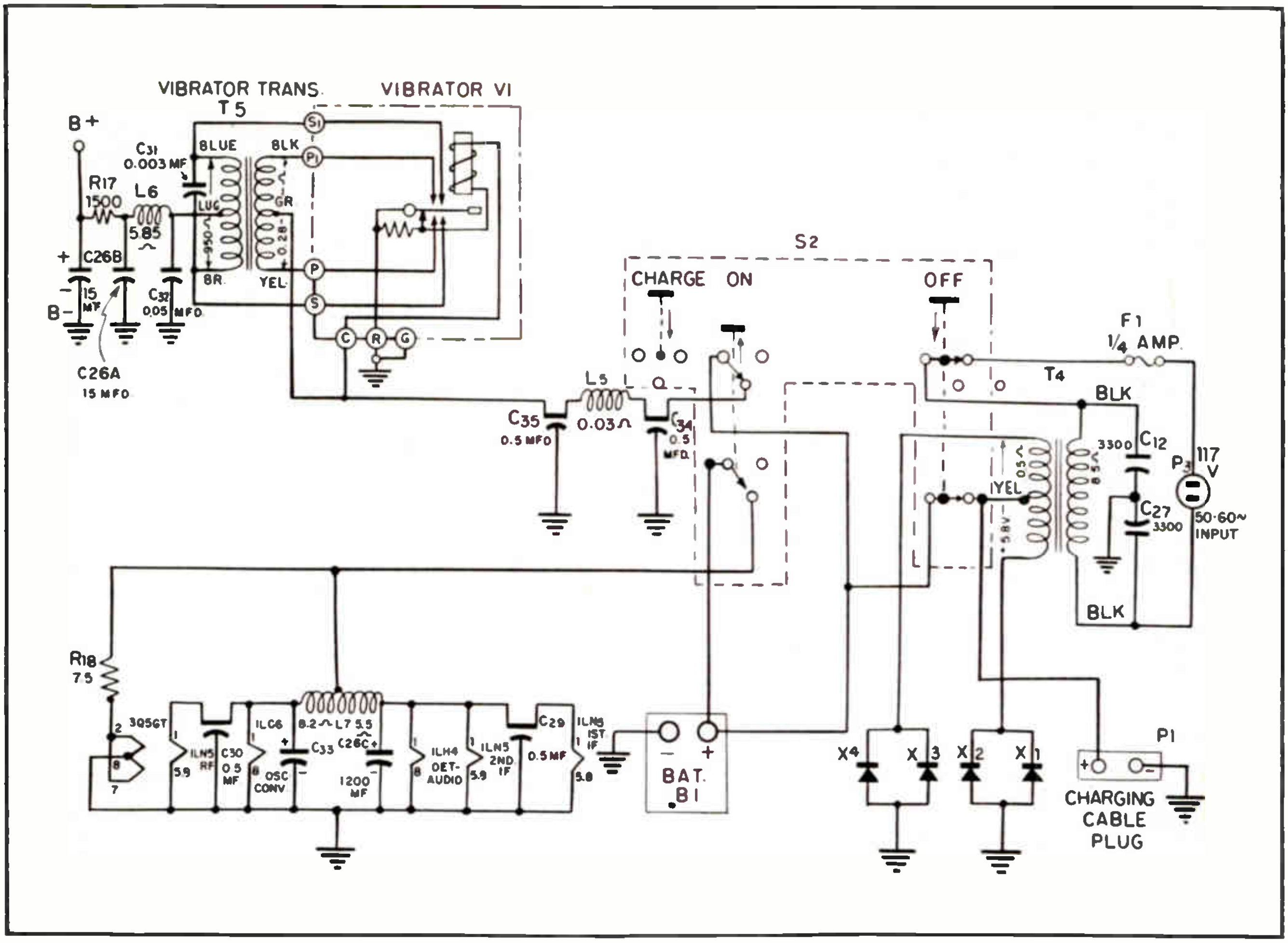


Fig. 16. Power Supply Using Rechargeable Battery.

In this system the amplifier tubes are connected with their filaments in parallel and no rectifier tube is present in the receiver. The dry-disc rectifier mentioned earlier is for battery-charging only. The plate supply voltage is rectified by the action of a synchronous vibrator which eliminates the need for a rectifier tube or another dry-disc rectifier for this purpose.

In spite of its relatively elaborate circuit, this type of power supply is rather simple to trouble-shoot.

Section 9. TELEVISION POWER SUPPLIES

Closely related to radio receiver power supplies are the special circuits used as television power supplies. While their special applications require certain differences from radio receiver power supplies, their operating principles are much the same.

Television power supplies, in addition to producing the "A" and "B" voltages required by radio receivers, must also contain provision for a third high voltage output for the final anode of the television cathode-ray tube. This is the so-called picture tube, upon the flat surface of which we actually view the picture pattern. Due to the special nature of this high voltage, its production forms a separate function of a distinct section of the television receiver. This section is known as the high voltage power supply. The fundamental circuits and operation of the "A" and "B" supplies for television have output voltages of the same order as those found in radio receivers.

In television receivers, as in radio receivers, the "A" voltage is that which powers the tube heaters or filaments, heating them to temperatures required for thermionic emission.

In television receivers, the "B" supply generates a D-C voltage which is applied to the plate and screen circuits of the amplifier tubes, to the biasing components of these stages, and to the focusing and positioning coils of the cathode-ray tube. Besides these circuits, the "B" voltage is used to drive the oscillator of the high-voltage power supply.

Fig. 17 illustrates the fundamental operation of the type of rectifier used in producing the "B" voltage of a television receiver. The inset shows the appearance of the selenium rectifier employed in this and similar circuits.

In this fundamental circuit, the selenium rectifier takes the place of the vacuum-tube rectifier. That side of the selenium rectifier marked with a plus sign can be considered the cathode, even though thermionic emission does not take place from its surface. The other side of the rectifier can be considered the plate, since it is the immediate target for electrons leaving the opposite (or "cathode") side.

It should be recalled that a vacuum tube rectifier will permit electrons to pass from cathode to plate, and prohibit the reverse movement from plate to cathode. The selenium rectifier, due to its unique uni-directional electrical abilities, displays this same characteristic. Electrons may readily pass forward (in the direction of the arrow), but are prevented from passing backward through the unit.

Referring to Fig. 17, if we assume the first half-cycle of input A-C voltage to be such as to make point *1* positive with respect to point *2*, electrons will flow from point *2* through the closed switch and divide at point *X*. Some will take the path through the primary of the heater transformer and be returned directly to point *1* at the input plug. The others will take a different path, moving towards the right to the lower side of the load, through the load, through the filter choke, through the selenium rectifier in the direction of the arrow, and finally arriving at point *1* of the power plug.

This action charges up both the filter condensers to essentially peak voltage (1.41 x effective voltage), and this charge is held on them throughout the opposite

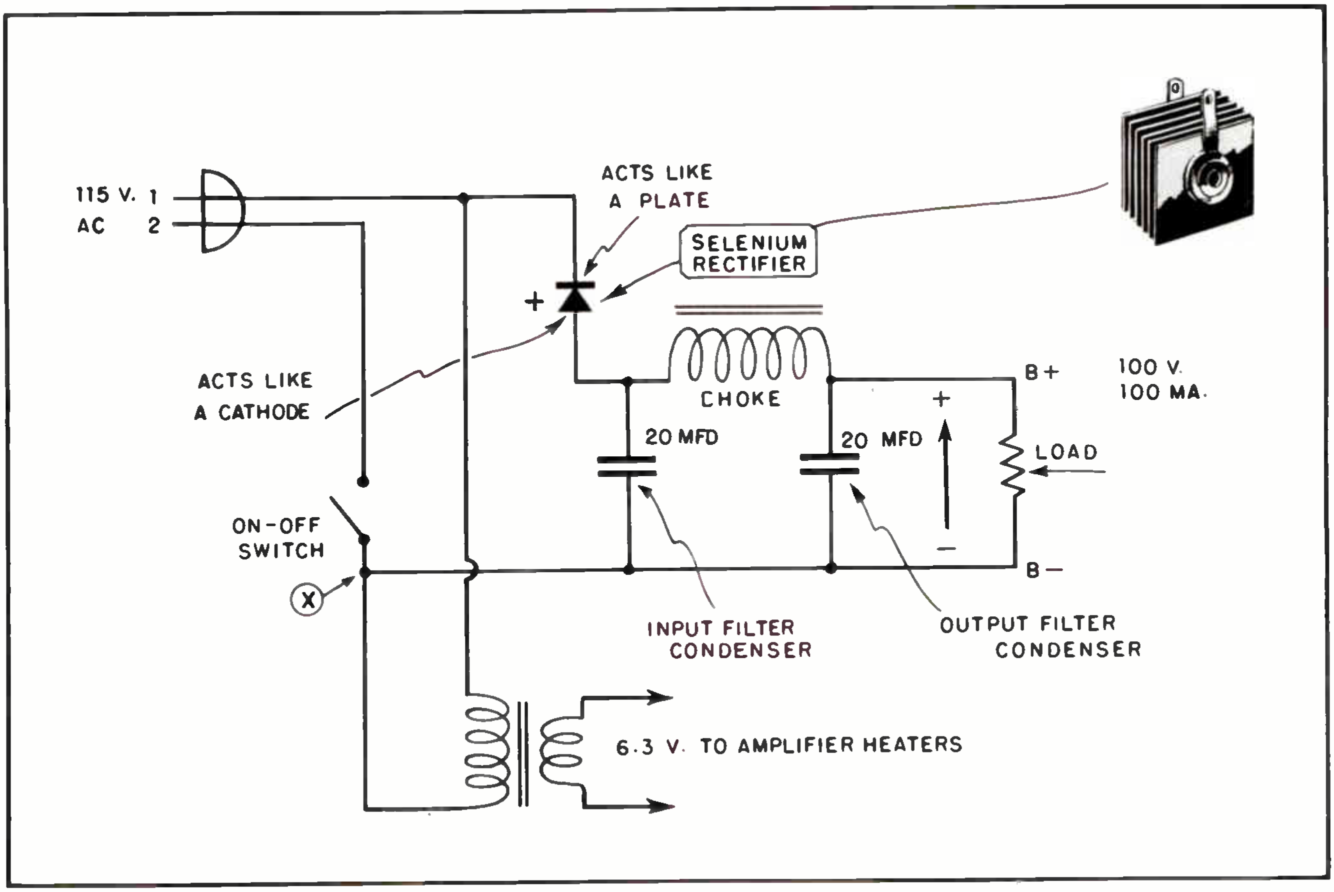


Fig. 17. Television Power Supply Using a Selenium Rectifier.

half-cycle of the input A-C voltage. The next half-cycle will make point *1* negative with respect to point *2*. Electrons will now flow from point *1* backward through the heater transformer primary. They will also try to flow backward through the selenium rectifier, but they cannot actually flow backwards. Actually, this branch of conduction will automatically reject electrons attempting to move backwards through the rectifier.

The transformer primary, being bi-directional, will permit electrons to pass both ways, resulting in the desired secondary voltages induced by primary A-C current. Current flow in the rectifier circuit, on the other hand, has now become pulsating D-C, with every alternate half-wave omitted. This, of course, is half-wave rectification, with the filter system opposing both current and voltage changes in the load and resulting in an almost pure D-C for use as the "B" voltage throughout the television receiver. The 6.3 volts A-C are fed to the amplifier heaters in parallel and are the source of heat for thermionic emission in these tubes.

Certain important points should be emphasized at this time:

What makes B-plus positive? B-plus is rendered positive by its lack of electrons. Its electrons were taken by the "cathode" of the rectifier when this "cathode" in turn, gave its electrons up to the "plate" of the rectifier. In order to replace the electrons which have been removed in this manner from B-plus, new electrons must flow upward through the load. This action, which can be compared to a hunger for electrons, makes B-plus attract them from the only available source -- B minus.

What makes B-minus negative? B-minus is rendered negative by its abundance of electrons, each of which carries a negative charge. It is important to remember that in this case, B-minus is negative only with respect to B-plus. This means that there is a greater abundance of electrons at B-minus than there is at B-plus. To counteract this condition, electrons will flow from any point on B-minus through any available path to any point on B-plus. Circuit design merely provides the proper paths for the electrons to follow so they will perform useful work while making the trip from B-minus to B-plus.

An examination of any electronic tube circuit will readily show that amplifier vacuum tube cathodes are normally connected to B-minus (which gives up electrons), and plates are normally connected through their loads to B-plus (which hungrily accepts them). When making the trip from the plate of a tube through the plate load to B-plus, the electrons are performing the work required of them, either by producing a voltage-drop in a resistive load, or creating a magnetic field in an inductive load.

What charges up the two filter condensers? The input filter condenser is charged up by the sudden removal of electrons from the side connected to the rectifier. Electrons are now fewer on the upper condenser plate; thus making it more positive by their absence. Since the opposite condenser plate is tied electrically to B-minus, and is also physically close to the upper condenser plate, electrons from B-minus gather upon the lower plate, as close to the positive upper plate as they can get, although still separated by the non-conducting dielectric. The presence of these excess electrons makes the lower condenser plate more negative. If a condenser has an abundance of electrons on one plate and a

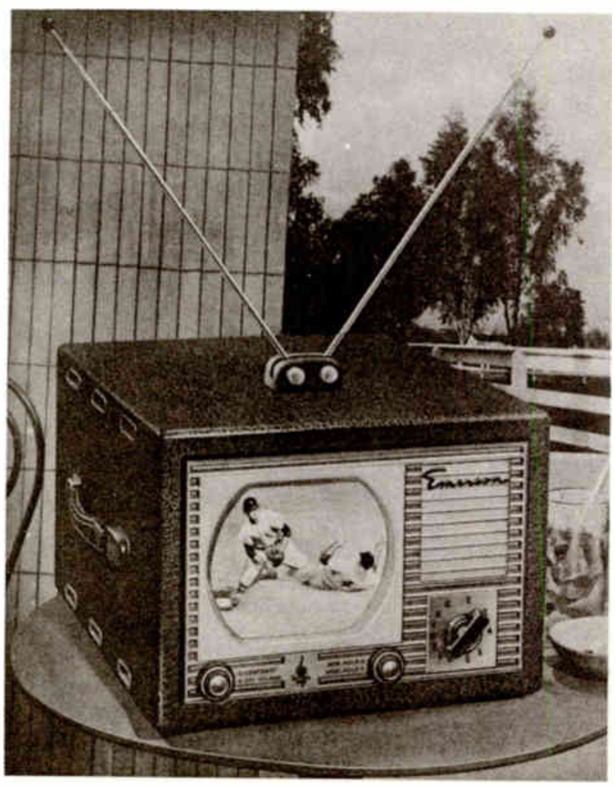


Fig. 18. Semi-Portable Television Receiver. (Courtesy Emerson Radio and Television.)

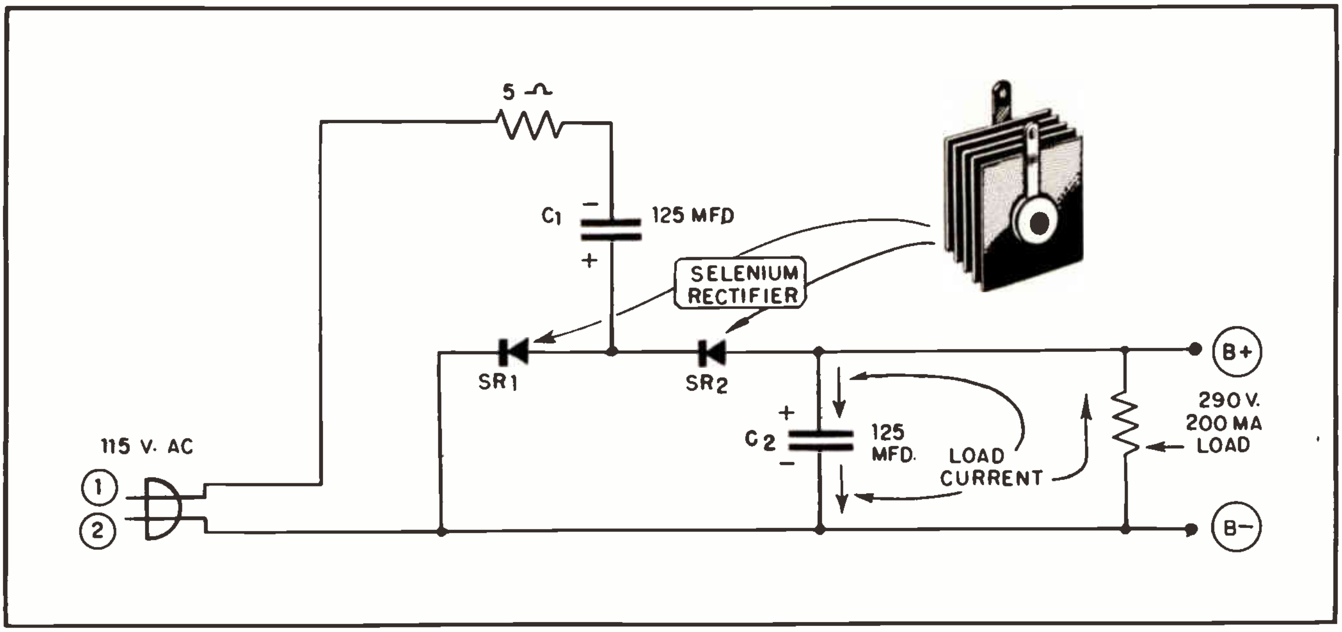


Fig. 19. Voltage Doubler Circuit.

lack of them on the other plate, it is said to be a charged condenser.

Section 10. **THE HALF-WAVE DOUBLER**

The basic principles involved in the half-wave rectifier may be easily adapted to a useful television "B" voltage supply system in the form of a half-wave doubler. As the name indicates, the half-wave doubler serves both to rectify the 115-volt A-C input and at the same time double its output D-C voltage. This method of increasing the value of B-plus voltage accounts for the higher voltage in a television receiver than would normally be available with the fundamental half-wave single-unit rectifier. Fig. 18 shows a popular television receiver employing a 10" screen to which a half-wave doubling circuit may be applied.

The circuit diagram of the half-wave doubler is shown in Fig. 19. Notice that there are two selenium rectifiers in this circuit, and two filter condensers of 125 mfd each. The five-ohm resistor is for protection purposes in case of short-circuits in the power supply. It acts to limit the current and thus protects the selenium rectifiers.

In Fig. 19, on the first half-cycle of the input A-C, suppose point *1* of the power plug is negative with respect to point *2*. At this time, electrons available at point *1* will tend to flow toward point *2* through whatever path may be available. The only available path is through the five-ohm protective resistor to the upper plate of C_1. While electrons are piling up on this plate, they repel the electrons on the opposite plate of C_1 which flow toward the electron-hungry point *2* (positive during this half-cycle). The electrons repelled from the lower plate of C_1 cannot flow backward through *SR-2* (selenium rectifier #2), but they can readily flow forward through *SR-1* toward point *2* of the power plug. On this half-cycle, therefore, C_1 is charged up in the polarity shown to the peak of the applied A-C voltage. C_1 holds this charge during the next half cycle.

The next half-cycle is such as to render point *2* of the power plug negative with respect to point *1*, which is now positive. Notice that C_2, *SR-2*, and C_1 are in series with each other across the line. If C_1 had not been charged up on the previous half-cycle, the full line voltage would be divided equally between C_1 and C_2. (Notice also that *SR-1* is useless on this half-cycle, since it blocks the path of current from point *2* to point *1* of the power plug.) However, since C_1 is holding the charge applied to it during the previous half-cycle, its voltage is now in series with the line voltage, and both voltages are applied across C_2. Their sum is twice the peak applied voltage, and when we consider the drops in the series components, we find the output across C_2 -- and also across the load -- to equal approximately 290 volts, D-C.

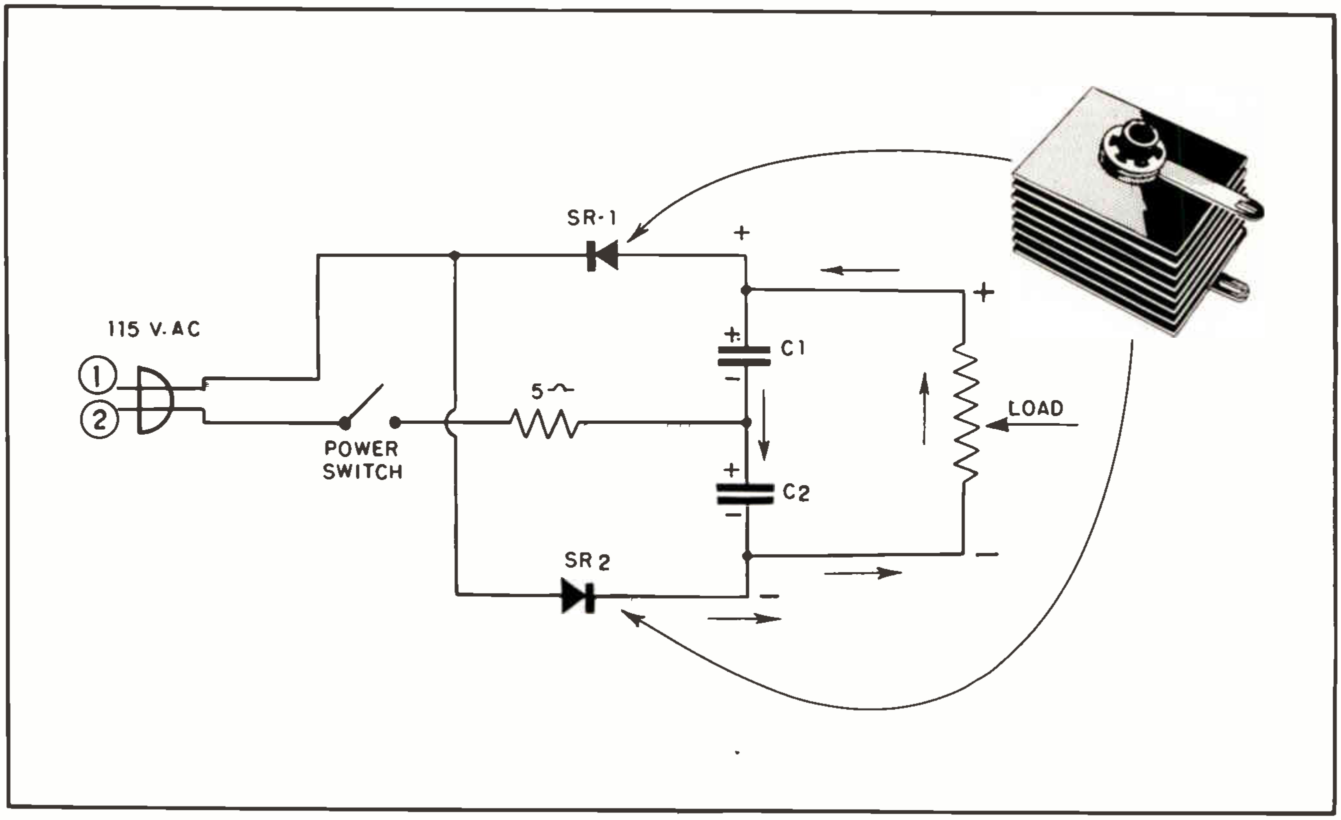


Fig. 20. Full-Wave Voltage Doubler.

Analyzing this action in more detail, on the second half-cycle of the A-C line voltage we see that the lower plate of C_1 is positive and therefore electron-hungry. The lower plate of C_2, however, being connected to what is now the negative side of the line, will have an abundance of electrons. These will force the electrons from the upper plate of C_2 through *SR-2* to the lower plate of C_1, which readily accepts them. The gathering of electrons on the lower plate of C_1 will in turn force other electrons from its upper plate toward the positive side of the line, which readily accepts them. This motion of electrons from the upper plate of C_1 toward the positive side of the line constitutes its discharge, and the polarity of this discharge is in series during this half-cycle with the applied line voltage. It is like having two generators in series with the same load, one being the applied A-C, and the other the charged capacitor, C_1.

With respect to the load, with which it is constantly in parallel, C_2 sends load current downward from its lower plate, up through the load, and downward to its upper plate. This tends to discharge C_2. But before a discharge can be completed, C_2 is again charged up to peak voltage by the action previously described. Stated somewhat differently, we might say that C_2 is recharged by the line much more quickly than it is discharged by the load.

Describing the action of a half-wave voltage doubler in briefer terms, it can be summarized as follows: C_1, charged up on the first half-cycle, discharges in series with the line across C_2 on the second half-cycle. The resulting voltage across C_2 must now be double the line voltage. The "B" voltage thus developed can be readily applied to the audio, RF, and sweep circuits of a television receiver.

Section 11. THE FULL-WAVE DOUBLER

The full-wave voltage doubling circuit, used extensively in television receivers, differs from the half-wave doubler. In this system each of the two condensers is charged up on alternate half-cycles of line A-C voltage, and they are connected so that they can discharge in series across the load.

Let us start with Fig. 20 by taking point *1* of the input power plug to be negative with respect to point *2* on the first half-cycle. If the switch is closed, electrons, leaving point *1* will be blocked in their passage to *SR-1*, but will be conducted through *SR-2* to the lower plate of *C-2*. Electrons gathering here will repel those from the other side of *C-2* toward the electron-hungry point *2* of the power plug. (The 5-ohm resistor is for protection of the rectifiers in case of a short-circuit.) *C-2* will now be charged by an abundance of electrons on its lower plate and a lack of them on its upper plate.

On the second half-cycle, with point *1* of the power plug positive with respect to point *2*, electrons will flow through the 5-ohm protective resistor, and to the lower plate of *C-1*. These will force electrons from the opposite side of *C-1* toward the positive side of the line, and *SR-1* will conduct these electrons to this point. We see that we now have a lack of electrons on the upper plate of *C-1* and an abundance of them on the lower plate, a condition which defines a charged condenser, of which the polarity is shown in the diagram.

Notice that the two filters are connected in series with each other, and that each is fully charged. They will now tend to discharge through the only available discharge path -- through the load itself. Since their charges are in series, they will act like two batteries in series, sending current through the load in the direction shown, their voltages adding together to equal about twice that of the peak input A-C voltage.

Stating the action briefly, we may say that in a full-wave voltage doubling circuit, the two condensers are charged alternately by the line and discharged in series through the load.

The "B" supply created by the full-wave doubler can, like that of the half-wave doubler, be applied to audio, RF, and sweep circuits of a television receiver, and can account for greater sensitivity than if a non-doubling circuit were employed.

Section 12. VOLTAGE TRIPLING CIRCUITS

By extending the principle of the half-wave voltage doubler to an additional rectifier and condenser branch, it is possible to achieve a D-C voltage output of approximately three times the peak A-C voltage applied to the system. The popular television receiver shown in Fig. 18 is one in which the voltage tripler may be used. The schematic circuit involved in voltage-tripling is shown in Fig. 21.

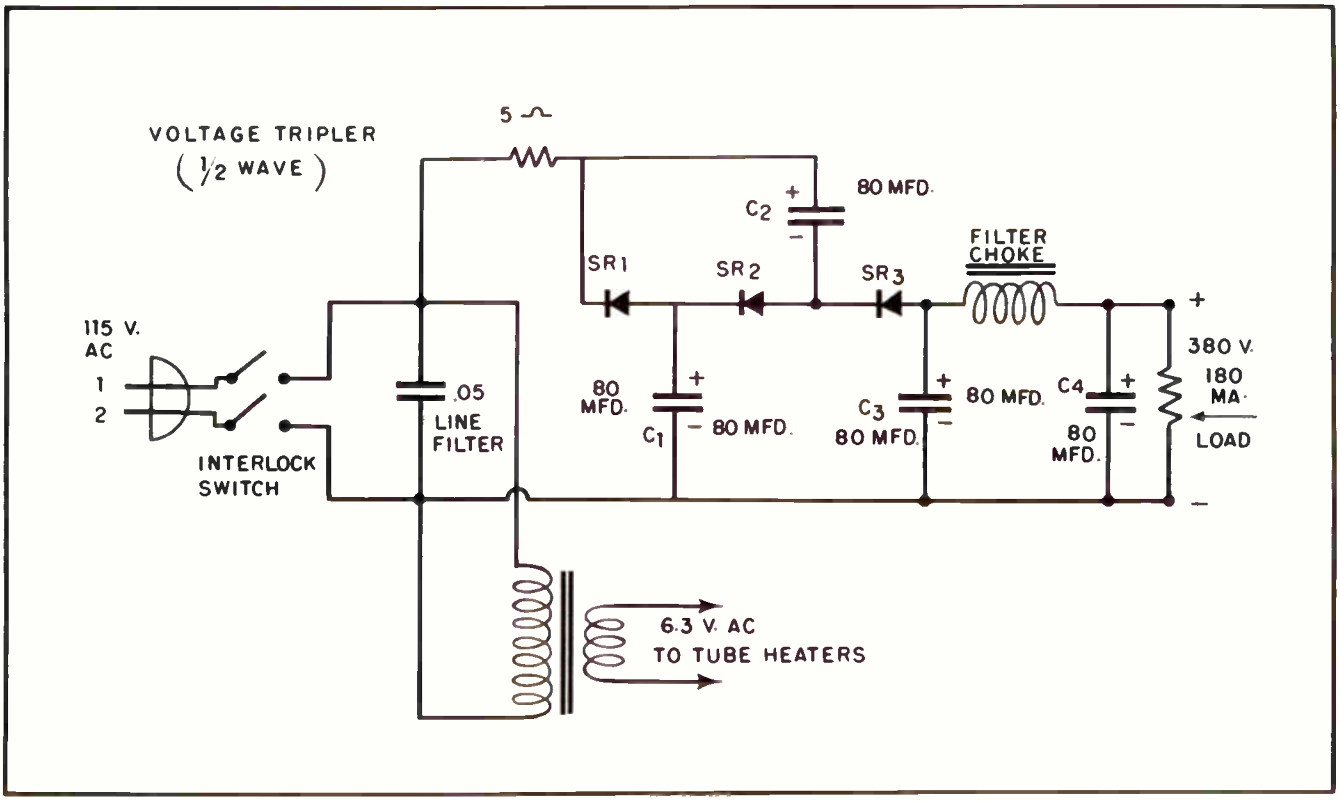


Fig. 21. Voltage Tripling Circuit.

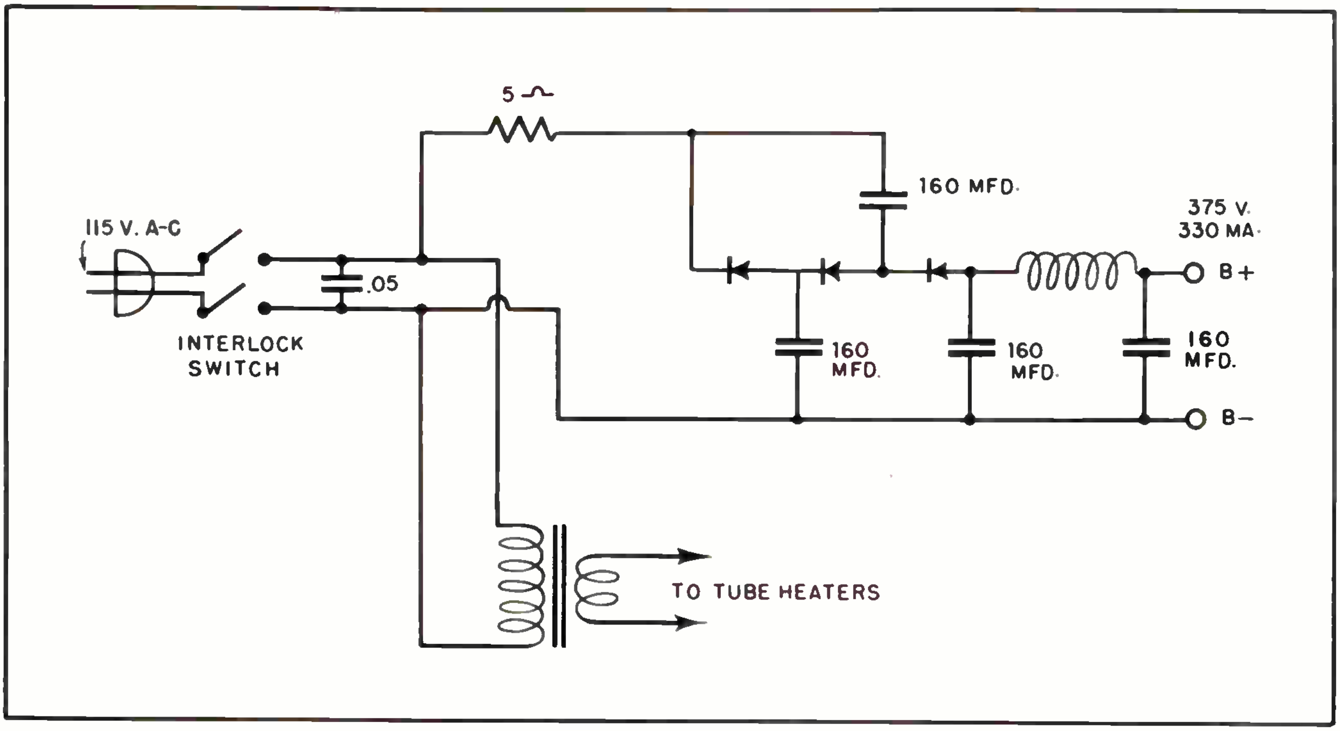


Fig. 22. Heavy Duty Voltage Tripler.

Not directly involved in the tripling circuit of Fig. 21, but associated with it are the .05 mfd line filter and the heater transformer. The former is to reduce line, or "modulation" hum; the latter is to provide 6.3 volts A-C for the amplifier and oscillator heaters. Both are placed into the circuit with the closing of the on-off switch. As in the previous examples, the 5-ohm resistor is a protective device, acting as a fuse for the rectifiers in case of short circuits.

Action begins in this tripling circuit when the switch is closed and 115-volt A-C power is applied to the system. Let us assume point *1* of the input plug to be made positive with respect to point *2* on the first half-cycle. Electrons will flow upon the lower plate of *C-1*, and their abundance at this point will repel electrons from the opposite plate of *C-1* through *SR-1* (which will readily pass these electrons), through the 5-ohm protective resistor and to the electron-hungry point *1* of the power plug. This, as we have seen, charges *C-1* up to peak voltage.

On the second half-cycle, with point *1* of the input plug now negative with respect to point *2*, the voltage across *C-1* is added in series with the line voltage and both are applied across *C-2*. This is the same action described earlier as a voltage doubler, and provides approximately twice the input peak voltage across *C-2*.

The voltage tripler goes one step further in its action. Just as *C-1* was charged to peak voltage on the first half-cycle through *SR-1*, so also is *C-3* charged to peak voltage on the same cycle through *SR-3*. (This is because they are in parallel across the same applied voltage on the first half-cycle, except for the negligible drops in the rectifiers.) Now, if *C-2* has twice peak voltage across it, and is discharged in series with the already existing peak voltage across *C-3*, the full voltage across *C-3* is three times the peak applied voltage. The filter choke and the final condenser, *C-4*, act to smooth out the pulses and provide practically pure D-C to the load.

The schematic diagram of Fig. 22 is another form of the half-wave voltage tripler, with about twice the current output as the tripler in Fig. 21. As can be seen by comparing capacitance ratings of the electrolytic condensers, this circuit contains units of 160 mfd each, instead of 80 mfd each as shown in Fig. 21. With everything else equal, doubling the capacitance of an R-C circuit will also double its time constant and, therefore, will double the discharge time of the condensers supplying the output D-C voltage. In terms of current output, this means that the system using the larger capacitance will, on the average, be capable of greater average currents to the load.

Such a feature is desirable because it permits more discharge paths for B-plus currents. This means more amplifying stages without substantially reducing the B-plus voltage level.

It should be noted here that the current-carrying capabilities of the rectifiers used in this high-current system are also greater than those of the lower-current system. In the current rating of a rectifier of this type, we are concerned with the effect that current has in creating heat within the rectifying unit. In other words, a rectifier should be so used in a circuit that its current rating is never exceeded. This is because the I^2R losses in the rectifier may damage it, or impair its characteristics. The manufacturer of the rectifier of course, will be the authority for the amount of current permitted through it without subjecting it to possible damage. Thus, when a manufacturer rates a rectifier at 100 mils of current, do not try to pass more than 100 mils through it, nor try to replace it with another rectifier having a lower current rating.

Section 13. MULTIPLE POWER SUPPLY FOR TELEVISION

Many of the larger television receivers use a multiple system of power supplies with as many as eight or ten selenium rectifiers. A system of this type is shown in Fig. 23. As can be seen from the diagram, the uppermost system is a half-wave doubler and is used to provide an isolated "B" supply for the audio stages of the receiver. The middle system is a tripler supplying an isolated 390 volts at 100 mils for the sweep generating and amplifying stages.

The bottom arrangement is actually two power supplies tied together, with B-minus and C-plus connected together and to one side of the input A-C line. The "B" section of this double-system supplies the R-F stages with plate and screen voltages, while the "C" section powers the bias and focus circuits of the television receiver. It is interesting to note that due to the fact that each of the sections of this multiple

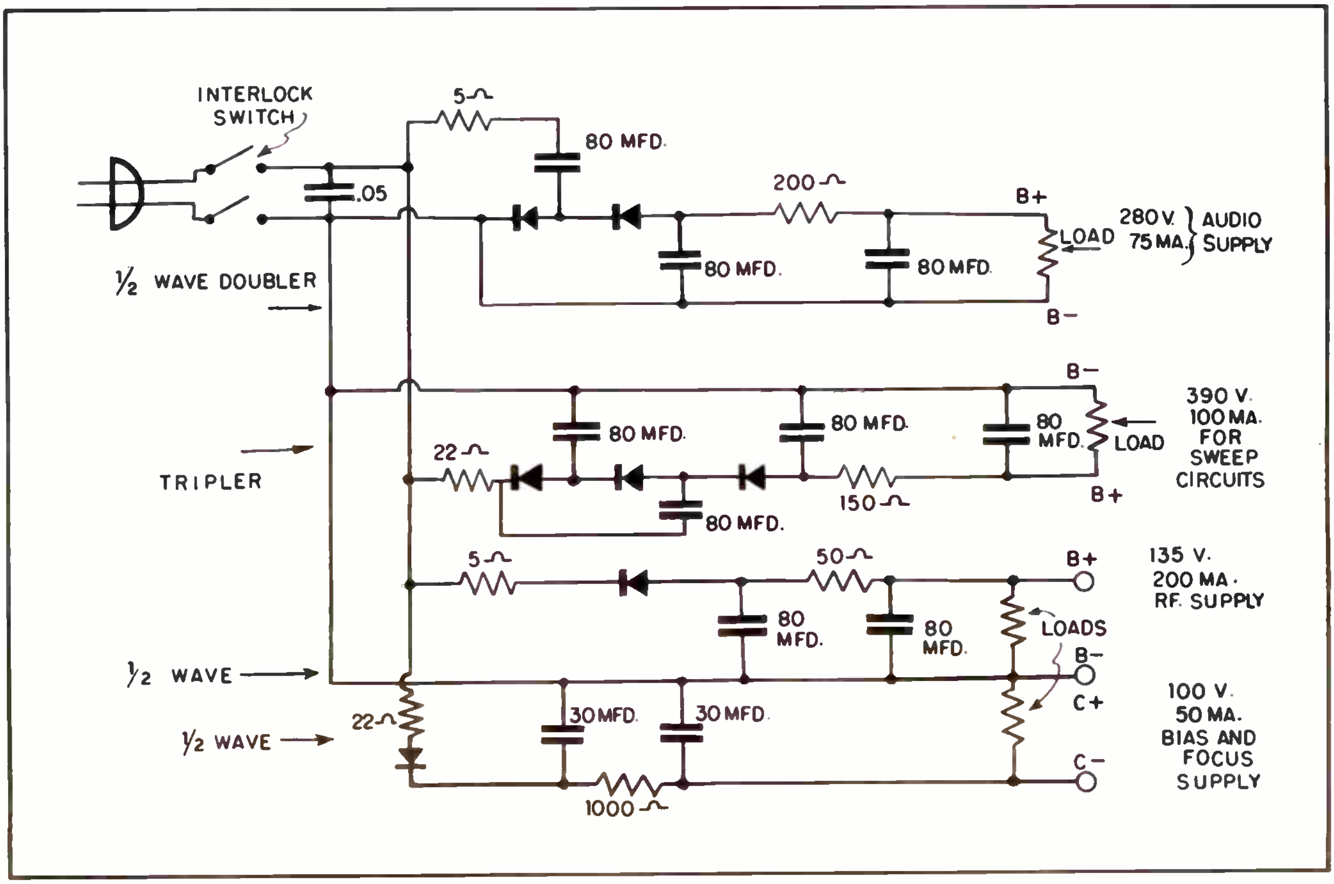


Fig. 23. Multiple Power Supply for Television Receiver.

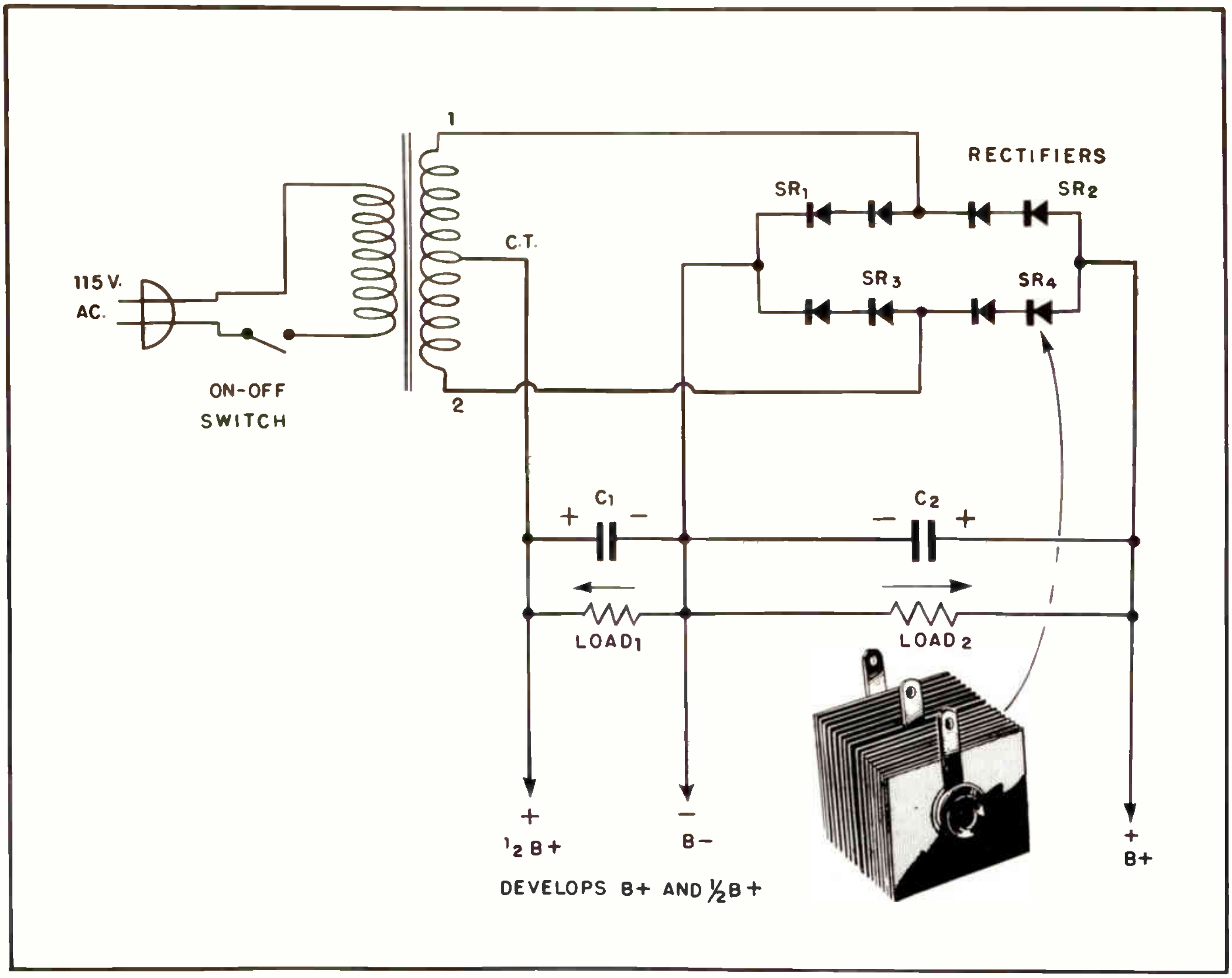


Fig. 24. Full-Wave Bridge Type Television Power Supply.

power supply has a specialized function to serve, the comparatively small current drain from each of them permits R/C -- rather than L/C -- filter systems. This makes for compactness, lightness, and less cost in the finished product.

Section 14. THE FULL-WAVE BRIDGE RECTIFIER

Another useful television power supply is that shown in the schematic diagram of Fig. 24. It is known as a full-wave bridge type. When point *1* of the transformer secondary is negative with respect to point *2*, and the center tap is midway in potential between these two extremes, current will leave point *1* and flow through *SR-1* to B-minus. At this point, current will now divide, some flowing leftward through load *1* to the transformer center-tap (which on this half-cycle is more positive than point *1*), and the other part flowing rightward through load *2*, through *SR-4* and arrive at point *2* of the transformer. Each portion of this split current charges up the two filter condensers to peak A-C voltage.

On the second half-cycle when point *1* is positive with respect to point *2*, and the center-tap halfway between them in potential, current flows from point *2* to B-minus through *SR-3*. One portion of this current passes leftward through load *1* to the center tap, while another portion passes rightward through load *2*, through *SR-2*, and arrives at point *1* of the transformer.

Notice that on both half-cycles, current flowing through each load was in the same direction, and that each condenser maintains the charge upon it by the charging current, with polarities as shown. The advantage of this type of circuit is that almost any D-C value of voltage can be determined by the transformer ratio, and that a value of 1/2 B-plus can be taken from the transformer center-tap and applied to those elements in the television receiver employing a diminished value of plate or screen voltage. Voltage dividers external to the power supply are therefore rendered unnecessary.

Fig. 25 illustrates the full-wave bridge rectifier as applied to a mobile television receiver. Here the supply voltage, instead of the usual 115-volt A-C, is a 6-volt vehicle battery, and the use of the transformer is virtually mandatory. Full output here, as in Fig. 24, is filtered by the condensers shunting the two loads, with 1/2 B-plus available at the transformer secondary center-tap for circuit components requiring a diminished plate or screen supply voltage.

The circuit of Fig. 26 is also a mobile television power supply, but differs from the circuit of Fig. 25 in that the step-up transformer is equipped with a double primary winding; this necessitates the use of a double set of vibrator points. Where the number of stages in the television receiver demand a higher output from the power supply, this method may be used.

Another interesting variation of the doubler circuit applied to a step-up transformer arrangement for a high value of B-plus which can be subdivided is shown in Fig. 27. Here the secondary voltage from the transformer is applied to a series of three electrolytic condensers, with B-minus taken from the junction between *C-2* and *C-3*. Current flowing up the 33-ohm resistor gives us a 3-volt drop across *C-3*, while a difference of 165 volts is present across *C-2*, and a difference of 350 volts across *C-2* and *C-3* combined. This, as can be seen, supplies two values of B-plus and a negative biasing supply as well.

Fig. 28 is a schematic representation of a typical power supply for the AC-DC television receiver. The system operates on the half-wave principle, and shows the destination of the output voltages as applied to the various television receiver component sections. Note the H.V. (high voltage) oscillator, which is provided with B-plus by the low-voltage power supply. The H.V.

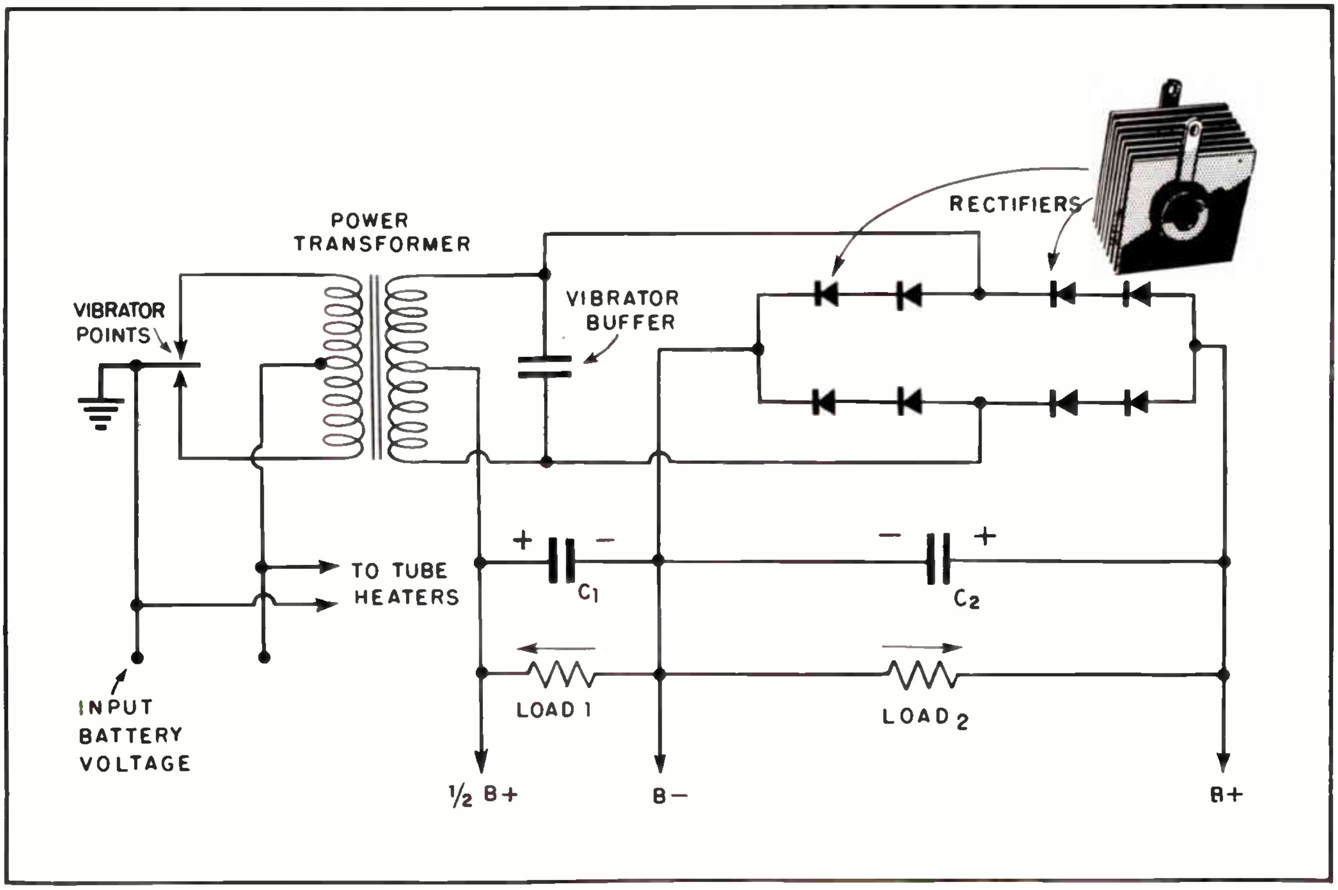


Fig. 25. Full-Wave Bridge Rectifier for a Mobile, Battery-Operated Television Receiver.

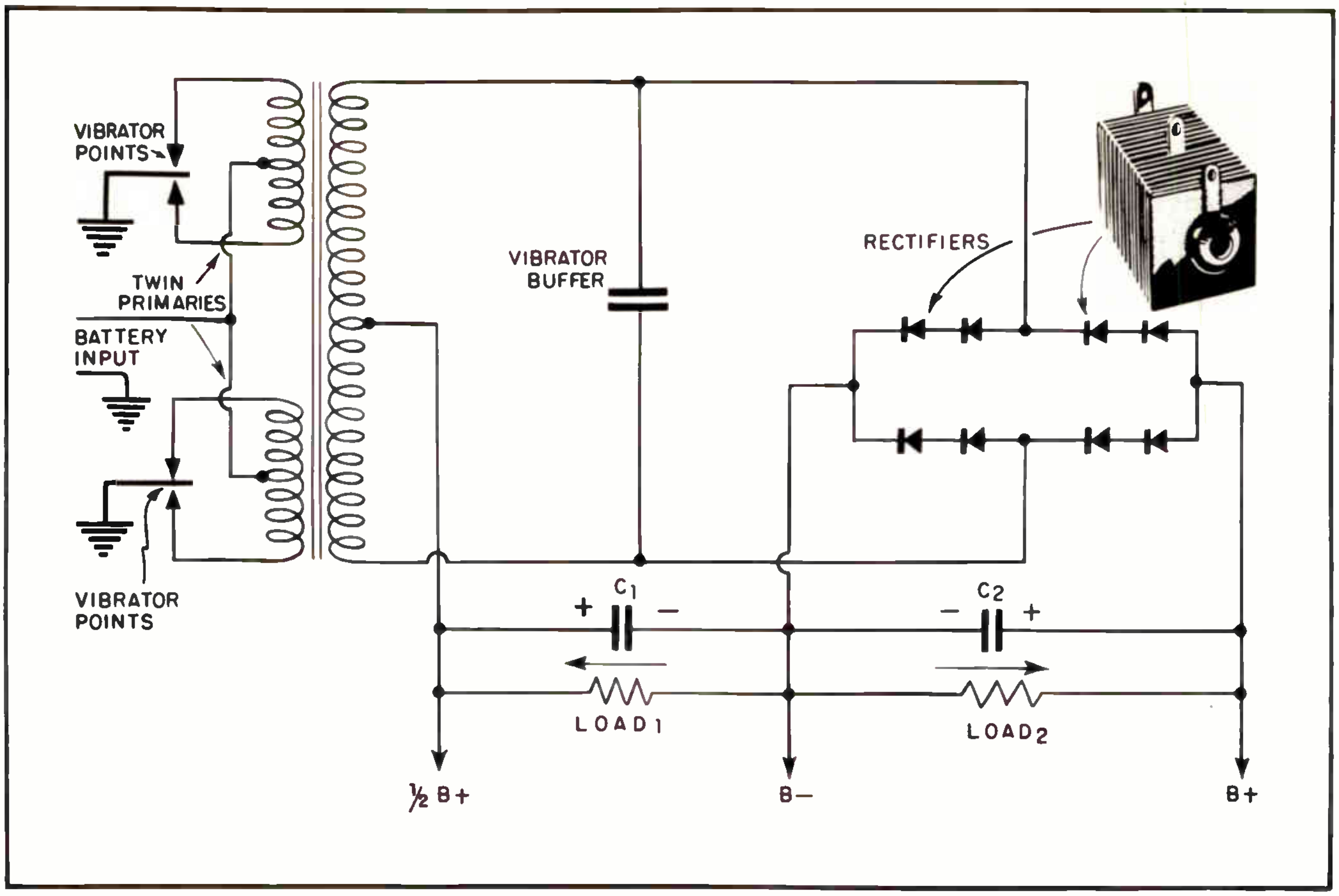


Fig. 26. Heavy Duty Power Supply for Mobile Television Receiver.

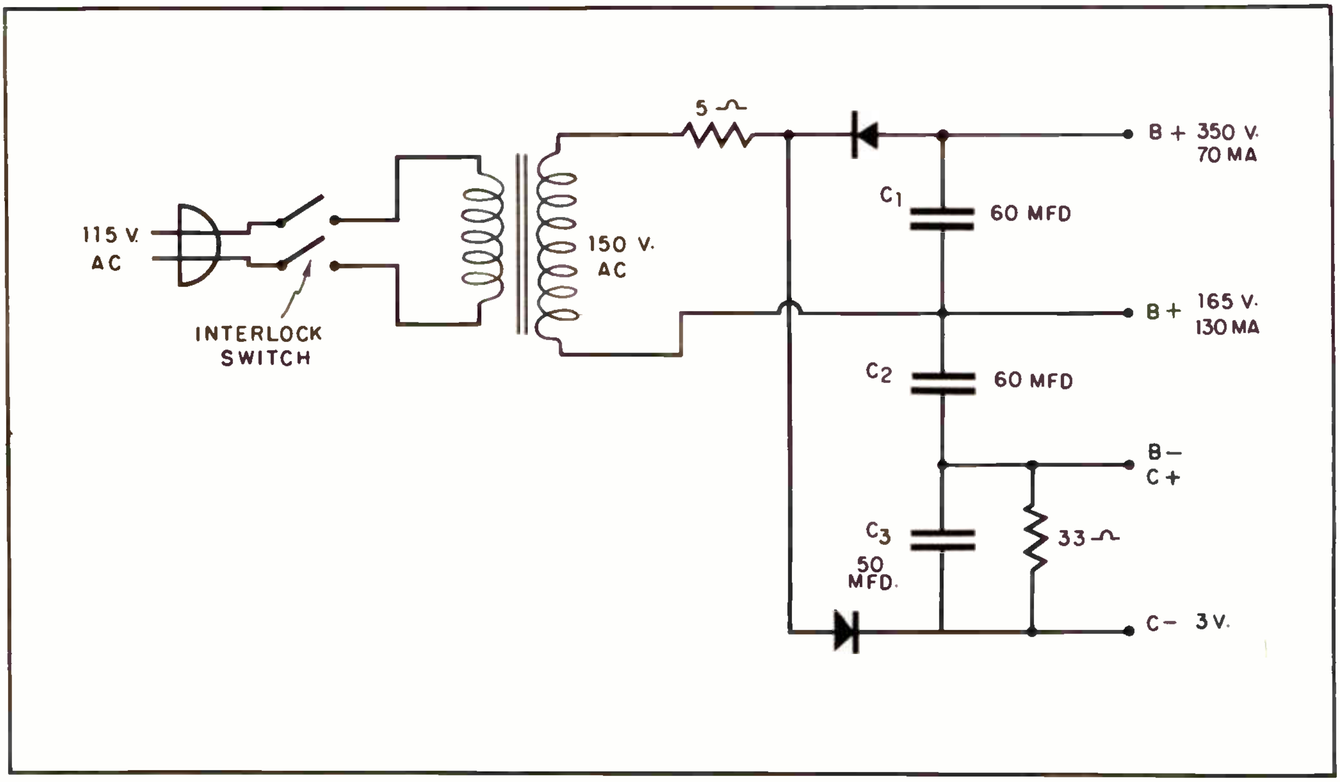


Fig. 27. Voltage Doubler with a Transformer.

oscillator operates at a high frequency with an extremely high step-up transformer ratio. The output is rectified by a vacuum-tube rectifier tube and is finally delivered to the picture tube in the form of very high D-C voltage, and there applied to the final anode. A part of this high output voltage, 600 volts, is fed to the vertical sweep amplifier as plate and screen supply.

The vacuum tube heater circuit is not shown in the diagram of Fig. 28, but it consists of several strings of series-connected tube heaters, with the various strings connected in parallel across the input voltage.

as part of the filter systems, stabilizing the voltage across their respective loads.

The table given in Fig. 29 applies both to diagram *A* and diagram *B*, and shows the output current with various kinds of selenium rectifiers.

Section 15. **THE DYNAMOTOR**

A dynamotor is a rotating electrical device used to convert low voltage D-C to high voltage D-C. The term "low-voltage" is meant to describe the 6-, 12-, or 24-28 volt storage battery source found in a vehicle, boat, or plane. By "high-voltage"

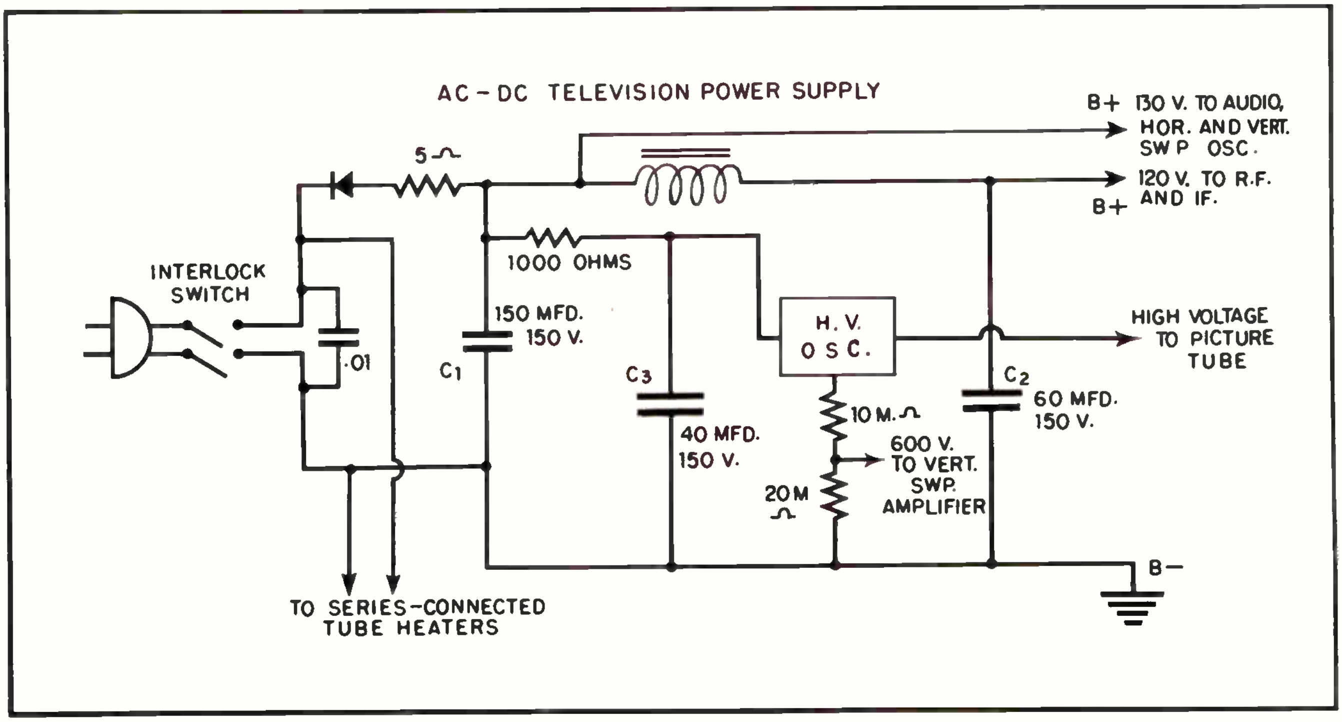


Fig. 28. AC-DC Television Power Supply.

Two similar power supplies for providing focus coil current and for energizing the ion trap in the picture tube of a television receiver are illustrated in Fig. 29. Both are of the half-wave type, using a single selenium rectifier. The manner of tapping off bias voltages for the audio and the R-F stages is illustrated in circuit *A*, while circuit *B* shows the system without these biasing voltage taps. (The ion trap is a magnetic field within the neck of the picture tube, and reduces the tendency toward blurring of pictures due to the action of the free ions within the highly evacuated picture tube.) In both of these circuits, the inductance of the coils serves

we refer to a voltage equivalent to that produced in a conventional manner by the "B" supply of a communications unit, and suitable for use on the plates and screens of the amplifier tubes. Fig. 30 shows two dynamotors, and serves to illustrate the various sizes that this type of voltage-converting unit may take.

It should be remembered that a receiver operating in a mobile unit usually develops its "B" voltage through the use of a vibrator-transformer system in conjunction with a rectifier. Where power output demands are high, such as when transmitters are used, a vibrator-transformer system may be

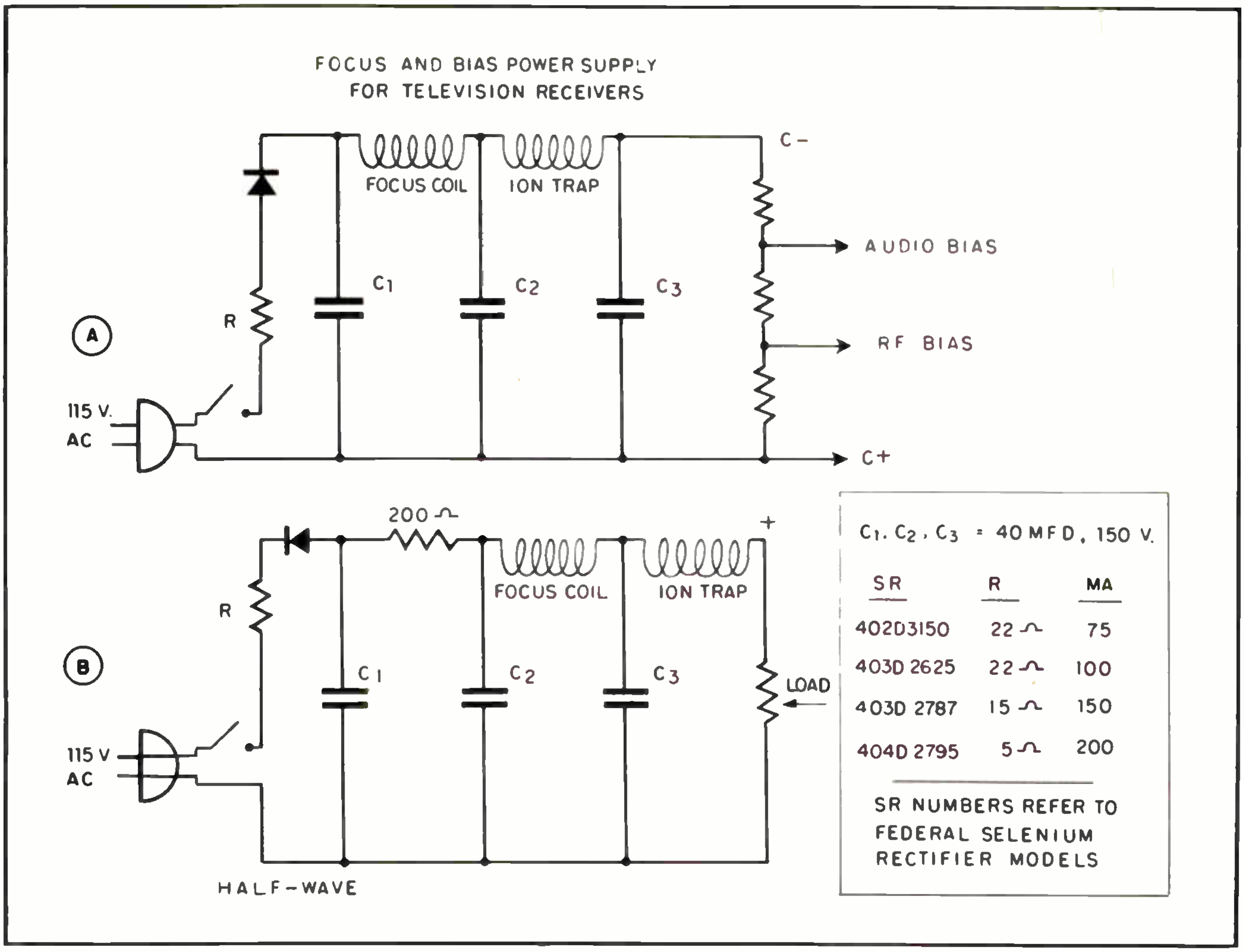


Fig. 29.

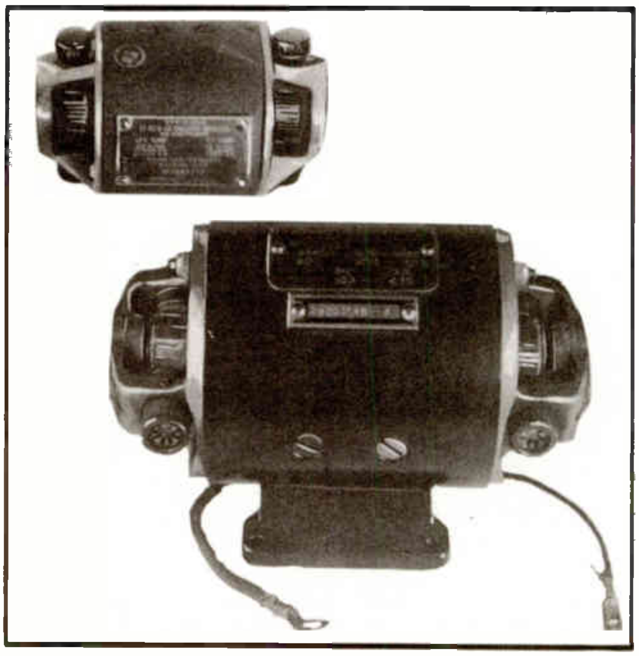


Fig. 30. Dynamotors.

inadequate. To accommodate the "B" supply needs of a large receiver, a transmitter, or a P.A. system in a mobile unit, the dynamotor can be used to advantage. Television pick-up camera trucks for picking up programs at points remote from the transmitter usually employ a number of dynamotors.

In essence, the dynamotor is a double unit, consisting of a D-C motor and a D-C generator. Characteristic of the dynamotor in comparison with other motor-generator sets is the fact that the dynamotor contains a single field winding and two separate armature windings.

Fig. 31 shows the basic principle of a D-C generator. A rotating armature winding turns counter-clockwise through the magnetic field. This induces voltages in each separate turn of the winding, and since all the turns in each half of the winding are in series their voltages are additive, the upper turns adding together to deliver a

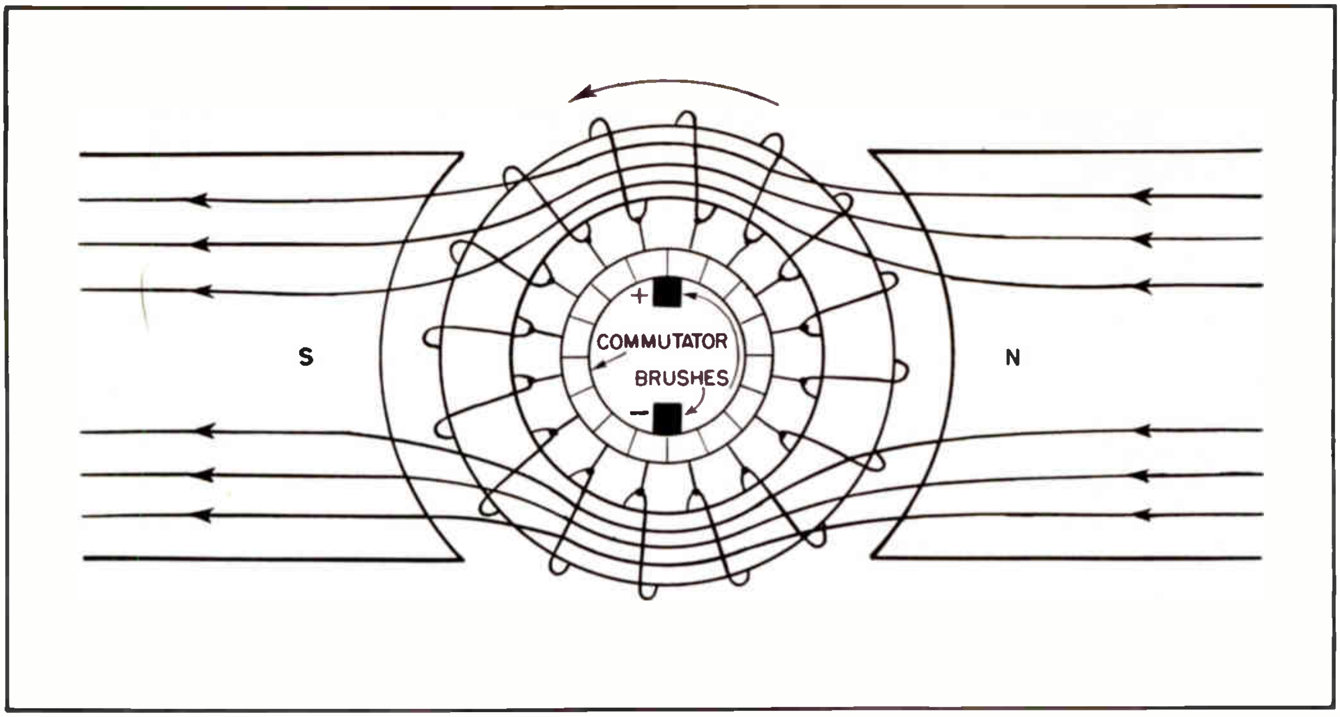


Fig.31. Brush Connections for a D-C Generator.

potential to the upper commutator brush, and the lower windings adding together to deliver the opposite polarity of voltage to the lower commutator brush. This opposition of polarity can be better understood when we consider that the upper windings are cutting the lines of force in one direction, while the lower windings are cutting lines of force in the opposite direction.

With respect to the commutator, to which the windings are permanently attached, the induced voltage within each turn is A-C. This is because each turn passes first through the field from right to left, then swings downward and rotates from left to right. However, with respect to the brushes, each winding delivers its voltage through the sliding contact just at the right time to agree with the polarity of the voltage induced by the previous commutator segment as it was passing over the brush. This is likewise true of the other brush. Each brush has impressed upon it a potential corresponding to the polarity induced in the winding to which it is then connected.

The result is that the upper brush of Fig. 31 will be constantly positive, and the lower will be constantly negative. The amplitude of this D-C voltage will depend upon the speed of rotation as well as upon the number of turns in the winding.

The functional schematic diagram of a dynamotor is shown in Fig. 32. At the extreme right is the prime power source, a low voltage battery. Connected in shunt to the battery are the low voltage armature winding (drawn in heavy lines) and a field which is common to both armature windings. The commutator at the right distributes to its windings the current necessary to create torque between the low voltage armature winding and the field, causing mechanical rotation. The left commutator, connected to the high voltage armature winding (and

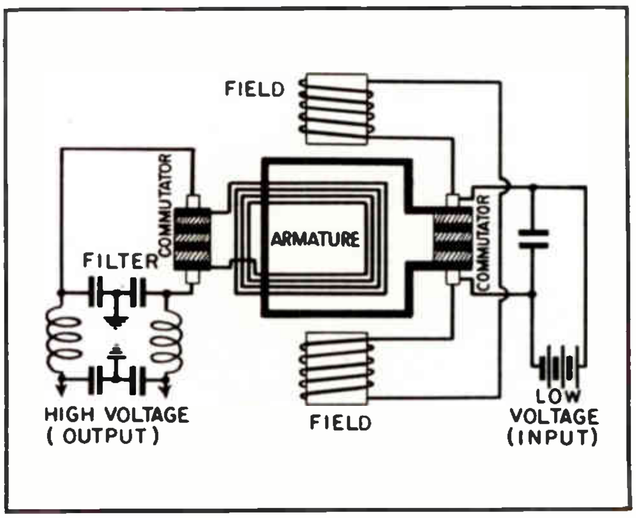


Fig.32. Schematic Diagram Showing the Wiring of a Dynamotor.

drawn in light lines) rotates with the armature through the common field. The voltage induced in this winding is then collected as D-C by the commutator and sent from the brushes as the high-voltage D-C output. This output is next fed to a filter system to smooth out the commutator ripple and the transient effects due to brush sparking. The final output of the dynamotor is therefore made extremely stable and can be readily used as the "B" supply for mobile communications equipment.

NOTES FOR REFERENCE

Power supplies supply power for operating the tubes in Radio and Television Receivers.

Power can be obtained from batteries or from commercial power sources.

AC-DC power supplies do not use transformers. Receivers using such a power source can operate from alternating current or from direct current.

Portable receivers operate from batteries. Some have special circuits which permit them to also operate from commercial power sources.

Voltage Doublers and Triplers are able to multiply the normal power line voltage to higher values than are supplied directly from the line.

Vibrators make it possible to step-up low voltages to high values.

Selenium Rectifiers are widely used with Television power supplies.

NOTES

NOTES

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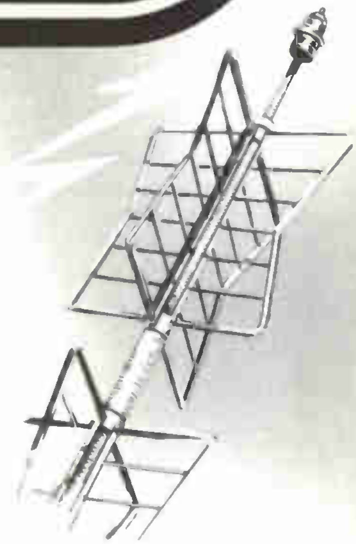

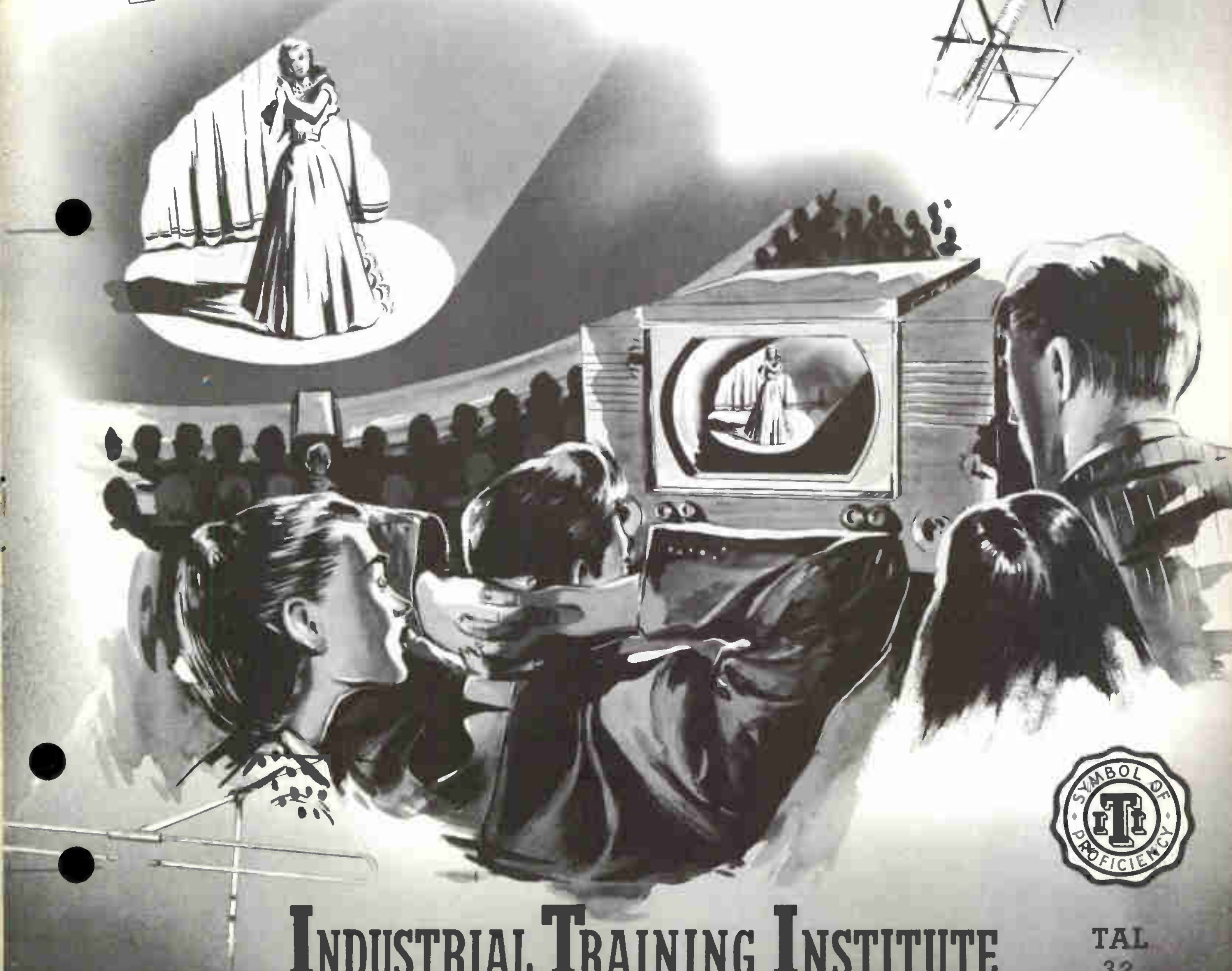

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RADIO TELEVISION

TROUBLE-SHOOTING POWER SUPPLIES

Contents: Introduction - Identification of Power Supplies - The Purpose of Each Part in a Power Supply - Transformer Troubles - Vibrator Troubles - Bleeders - Filter Resistor - Ballasts - Battery Troubles - Selenium Rectifiers - Notes for Reference.

Section 1. INTRODUCTION

We have already discussed many of the circuits, and the modes of operation, of power supplies found in radio and television receivers. We are now ready to approach them from the point of view of service and repair. Our aim now will be to trouble-shoot power supplies, verify our analysis, and test our corrections.

The first step in trouble-shooting a power supply is to positively identify the receiver under examination as to type. This must be done in a manner which will leave no room for doubt. This may seem like saying "make sure the water is wet", or some other equally obvious remark. Actually it is not. Once the power supply has been properly identified much of the trouble-shooting work will have been completed.

Section 2. IDENTIFICATION OF POWER SUPPLIES

To identify an *AC-DC power* supply, look for any one (or more than one) of the following:

A half-wave rectifier tube. (35Z5, 35Z4, 35Y3, 35Y4, 35W4, etc.). One or more tubes whose individual heater ratings are 12.6 volts.

Tube heaters connected in series.

The absence of a power transformer.

Any tube whose heater rating is 25 volts or over, in a set not containing a voltage doubler. (A voltage doubler cannot be used on D-C, and can be identified by a direct external connection between one of its cathodes and the opposite plate.) (See Fig. 2.)

To identify a purely *A-C power* supply, look for any one (or more than one) of the following:

A power transformer as shown in Fig. 1.

Tube heaters connected in parallel with each other and with the pilot lamp.

A full-wave rectifier tube. (80, 5Y3, 5Y4, 5Z3, 5Z4, 6X5, 84-6Z4, 7Y3, 7Y4, etc.).

A pair of push-pull output tubes such as 6V6's, 6F6's, 6K6's, etc.

To identify an automobile radio receiver power supply, look for:

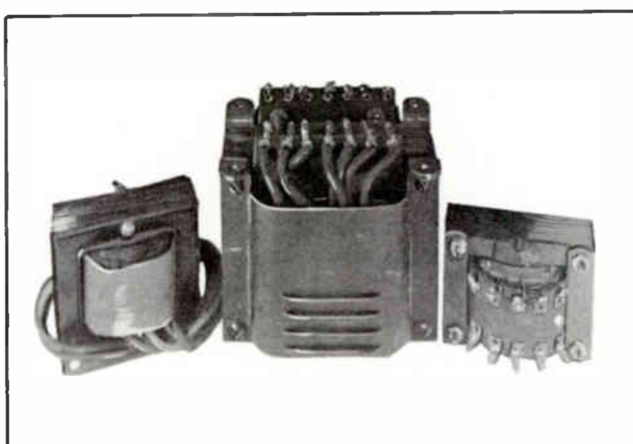

Fig. 1. Power Transformers.

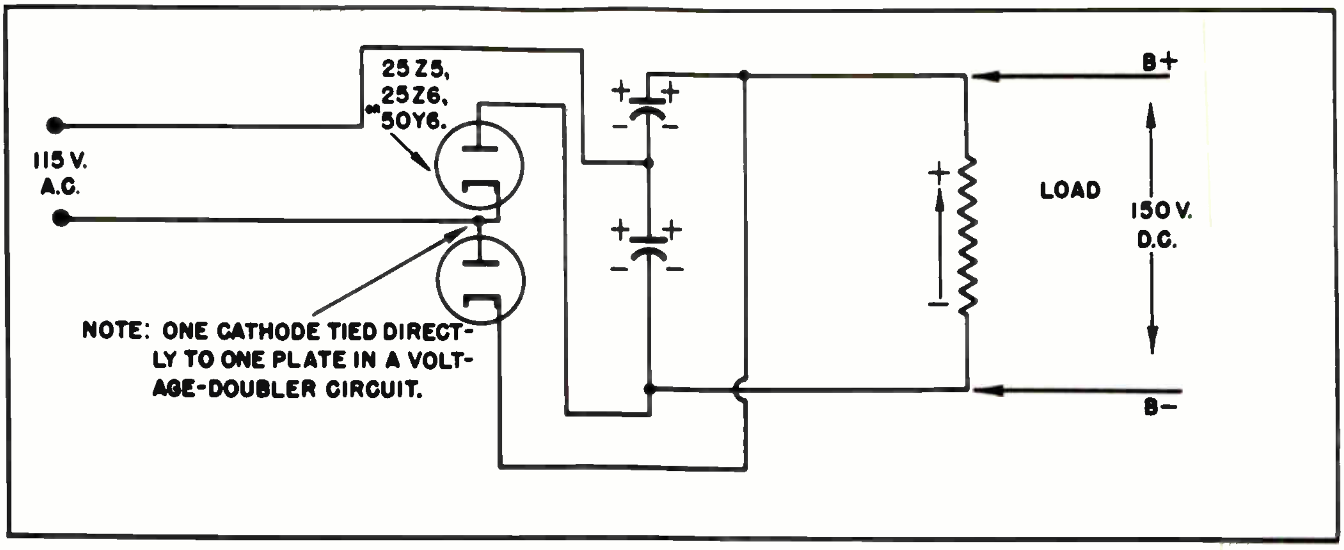

Fig.2. Voltage Doubler Circuit.

A vibrator, rated at 6 volts.

A metal case or cabinet, suitable for automobile installation.

A full-wave rectifier (0Z4, 6X5, 84-6Z4, 7Y4, etc.) whose plates are fed from a single-secondary high-voltage transformer and whose heater (if present) is fed from the 6-volt storage battery source. (The 0Z4 rectifier needs no heater voltage, since it is a cold-cathode mercury tube).

To identify a portable receiver, look for:

Batteries contained in its case, or provision for batteries in the form of battery plugs.

If it contains dry batteries and a power cord, it is a 3-way portable receiver.

If it contains either a rectifier tube or a dry-disc rectifier, in addition to batteries, it is a 3-way portable.

If it contains a wet cell, and a power cord, it is a re-chargeable portable receiver.

If it is contained in a case which is obviously portable, and if a low buzz is heard when it is turned on, it is a re-chargeable portable receiver. (On opening the rear cover, it will be found to contain a wet cell.)

The identifying features described above are meant to assist you in being certain of what type power supply you may be repairing or trouble-shooting. In many cases, such as the auto radio receiver, the power supply type is obvious from the outward appearance of the set. Moreover, it is wise for the repairman to check the receiver nameplate, which almost always identifies the type of power supply used.

Where the nameplate is illegible or absent, certain identifying features and their recognition must be resorted to for quick and accurate trouble-shooting.

Our discussion of power supplies has led us to discover marked differences among them. This is true in their circuits as well as in their modes of operation. While a keen understanding of these differences is essential to successful power supply trouble-shooting, we can avail ourselves equally well of a thorough knowledge of their striking similarities. Consequently, we may formulate our recognition of these similarities by listing the function, or purpose of each component part contained in power supplies. This list, following presently, can be used for two purposes. First, it can be used to learn the purpose of a component part of a power supply; second, it can be used to locate the source of a trouble when its outward effects are observed.

Section 3. THE PURPOSE OF EACH PART IN A POWER SUPPLY

The rectifier is used to convert A-C to pulsating D-C. If there is an *open* circuit no "B" voltage will be present, and no sound of any kind will be heard in the speaker. If *shorted* there will be no "B" voltage, but the power transformer in an A-C set may be hot.

Check for tube shorts and tube emission on a tube checker. In some cases, the rectifier of an AC-DC, or 3-way portable, may be of the dry-disc type. See the special note on this subject at the end of this lesson. If a rectifier tube checks weak, replace it; if it checks questionable, replace it; if it checks good, and low volume in the set cannot be directly traced to any other part, temporarily replace the rectifier tube and test the set. In auto receivers, a weak 0Z4 rectifier may check good on the tube-checker and still be defective. In this case, the signal will fade in and out at random intervals. It may even be normal, except while the car motor is running. Where no signal of any kind is heard, and B-plus is absent, make a careful check of the rectifier.

The input filter condenser is employed to keep B-plus at a high value, and to oppose the 60- or 120- cycle hum inherent in rectifier systems. If it is open or deteriorated, B-plus will be below normal and a hum will be present. If it is short-circuited B-plus will be absent and neither a hum nor a signal will be heard. In A-C receivers, rectifier tube plates will become red-hot. In AC-DC receivers, a shorted input filter will probably destroy the rectifier tube.

Check for an *open* or deteriorated input filter condenser by shunting it with an equivalent. Check for a short across this component by the use of an ohmmeter. (See Fig. 3.)

The output filter condenser justifies its use by opposing the change of voltage across the load; in this way it minimizes ripple-voltage (hum) and an effect called "motor-boating". If it is open or deteriorated, the receiver will hum or motor-boat, depending upon the degree of deterioration. B-plus, however, will be normal. If shorted, it will result in the absence of B-plus, and, like the input filter condenser, will cause the plates of the full-wave rectifier tube to become red-hot. Check for an "open" (or deterioration) by shunting with an equivalent condenser. Check for a short across this component by the use of an ohmmeter. (See Fig. 4.)

The purpose of the filter choke, Fig. 5, is to oppose a change of current in the load, and thus minimize hum voltages. If this choke is also used as the speaker field, as in Fig. 6 an open in this circuit will cause the loss of B-plus everywhere except at the cathode of the rectifier, and the simultaneous loss of speaker field magnetism. To check for an open choke, turn the power off and measure the choke resistance with an ohmmeter. Short circuits

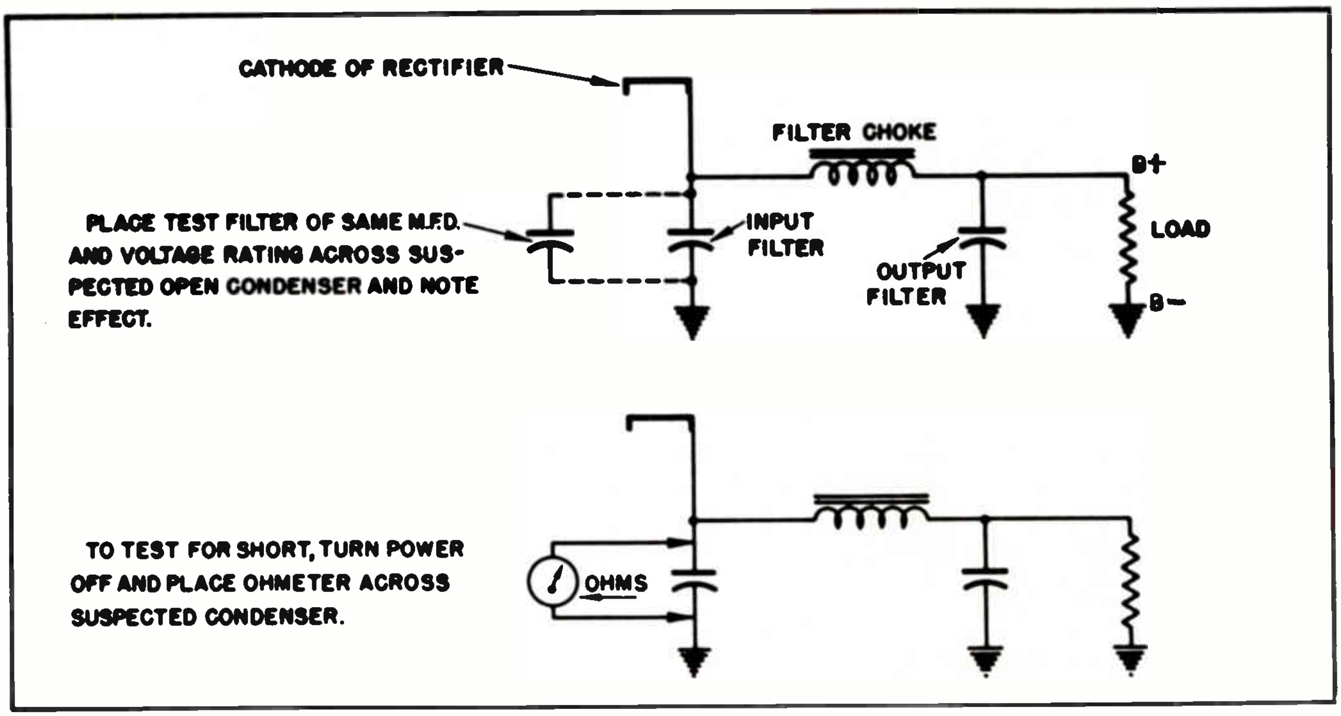

Fig.3. Test for Defective Input Condenser.

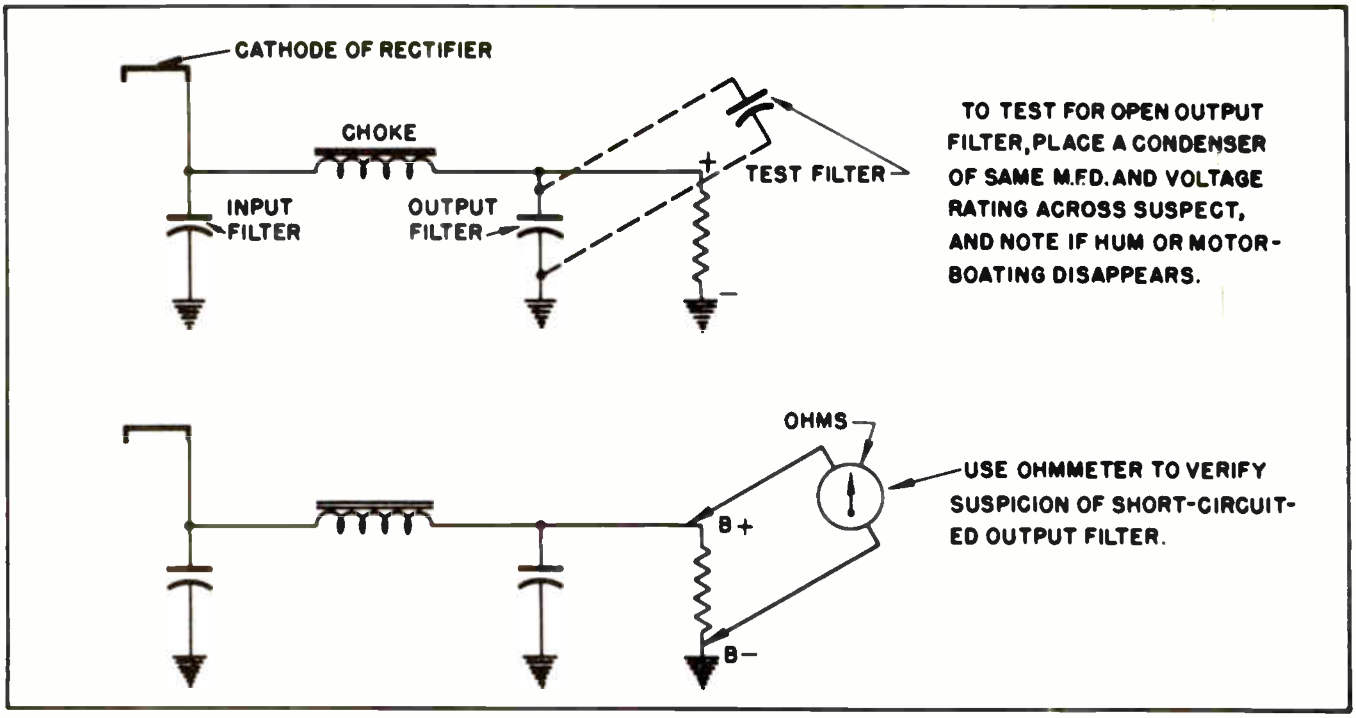

Fig. 4. Tests for Defective Output Condenser.

seldom occur in filter chokes. However, an ohmmeter check, with the power turned off, will verify any suspicion of this condition. If the choke is shorted to ground or B-minus, an unlikely possibility, the effects created will be identical with that of a short-circuited filter condenser. The average filter choke should show an ohmic resistance reading of 200-1200 ohms.

Section 4. **TRANSFORMER TROUBLES**

The high-voltage transformer is used to step up a low primary voltage (either pulsating D-C through a vibrator or 115-volt A-C) to a higher value for use, after

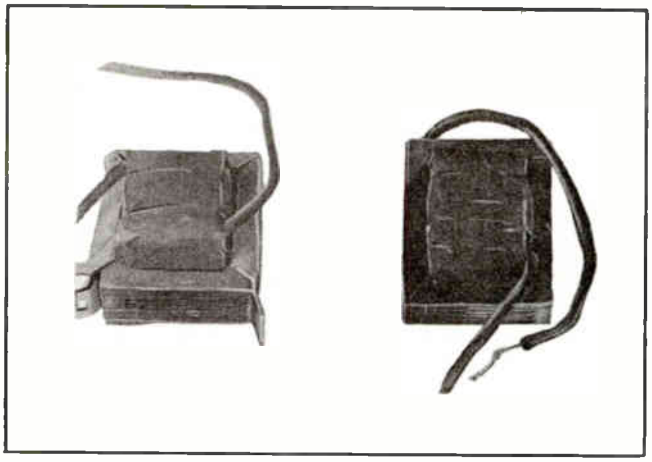

Fig. 5. Filter Chokes.

rectification and filtering, as the "B" supply. Most high voltage secondaries are normally center-tapped to ground or B-minus to permit full-wave rectification.

In the purely A-C set, primary voltage usually is 115-volts A-C, and primary resistance of the transformer around 15 ohms. The step-up ratio is usually 1:3 for each half of the secondary, making it 1:6 for the entire end-to-end H.V. secondary. End-to-end resistance for this secondary approximates 300 ohms, with ground at 150 ohms from either end. If measured with an A-C voltmeter, total end-to-end voltage should read about 700 volts, with ground at 350 volts from either end.

If one-half of the secondary is open, B-plus will drop somewhat and a distinct and excessive hum will be audible in the speaker. This condition can be verified by an ohmmeter check with power turned off. If one-half of the secondary is shorted, either to ground or by internal winding faults, B-plus will drop considerably and the transformer will become excessively hot, sometimes even reaching the "frying" stage.

This condition can be determined by an end-to-ground voltmeter check with an A-C meter and the power turned on. Voltages from either end to ground should be exactly equal, as should also their resistances.

In the A-C receiver, two additional secondaries are provided, in modern sets a 5-volt secondary for rectifier heater (or filament) supply, and an amplifier tube heater supply (6.3 or 2.5 volts).

If either of these is shorted, the transformer will become very hot, and no heater supply voltage will be fed from the defective secondary. This will mean either the rectifier tube will not light up, or the entire set of amplifier tubes will not light up. The exact symptoms will depend upon which of the two low-voltage windings is shorted. Check this condition with the low-voltage scale of an A-C voltmeter with power turned on the transformer. The defective winding will not deliver its rated voltage.

If the primary of this transformer is open, no power of any kind will be delivered to the set. If shorted, the system will probably blow the supply fuse when turned on. If it does not blow the fuse the transformer will become excessively hot.

In the automobile radio high-voltage secondary, the step-up ratio is about 1:35, enabling the 6-volt primary current to induce a secondary voltage of around 200 A-C volts between center-tap and either end. Primary resistance is but a fraction of an ohm. Secondary resistance, end-to-end is approximately 300 ohms.

Opens and shorts in an automobile radio transformer are almost identical with those in the purely A-C power supply transformer, with one notable exception. This exception involves the use of the vibrator buffer condenser described earlier. The purpose of this buffer is to prevent damage to the vibrator points due to arcing. If this condenser shorts out, the result will be a complete loss of the "B" supply voltage and, of course, of the signal as well. The transformer will become hot, but due to the metal shielding of this unit, such a rise in temperature may not be immediately evident. The supply fuse will, in most cases, blow when the buffer is shorted.

In checking, we will find no measurable A-C output from the secondary. This can mean, among other things, that the rectifier tube is internally short-circuited, that the vibrator buffer is shorted, or that the transformer secondary is shorted. Verify these possibilities as follows:

1. Check the rectifier tube on the tube-checker.

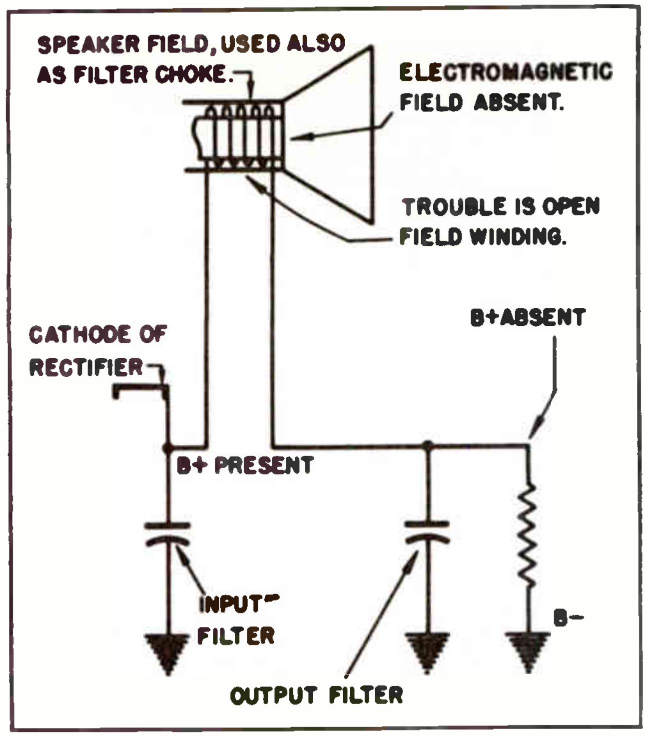

Fig.6. The Speaker Field Being Used as a Filter Choke. A Common Practice.

2. Disconnect one end of the buffer condenser and measure its resistance with an ohmmeter; it should be infinite.

3. Measure the resistance of the transformer secondary after turning off power to the set; it should be about 300 ohms.

If the primary of an automobile radio transformer is open, no power will be delivered to the "B" supply, but tubes will light. If shorted, the supply fuse will blow.

Due to the fact that the heaters of the tubes in an automobile radio are supplied directly from the storage battery, the power transformer contains no low-voltage secondary windings. There is only one secondary winding on an automobile radio transformer.

Section 5. VIBRATOR TROUBLES

The purpose of the vibrator is to chop up the low D-C voltage at the power transformer primary and induce a high A-C secondary voltage.

Receivers using vibrators are limited to those drawing power from a low-voltage re-chargeable battery, such as the automobile radio and the re-chargeable portable, as well as certain models of "farm type" receivers.

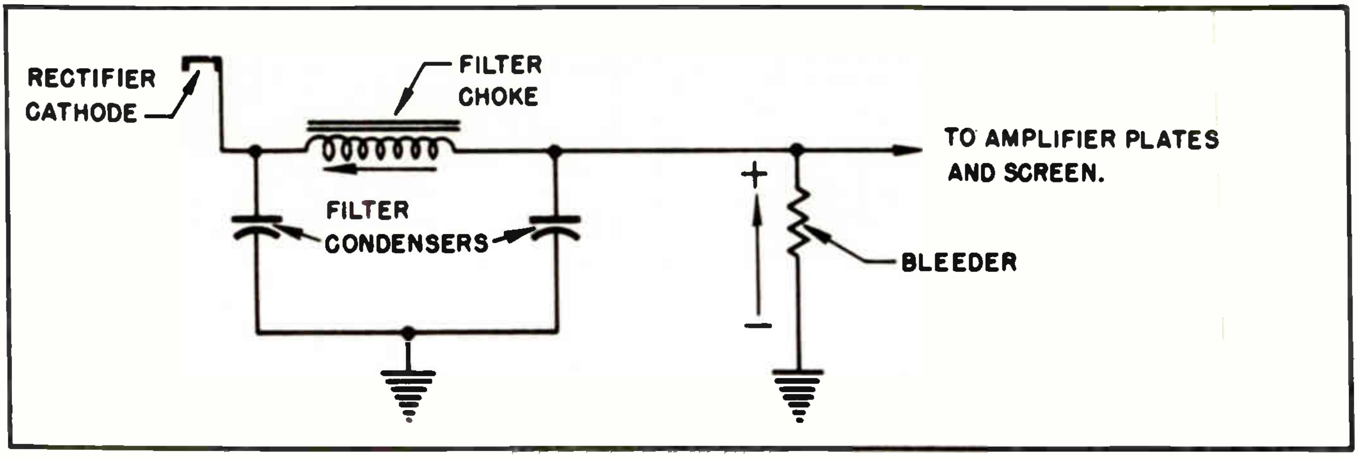

Fig.7. How a Bleeder is Connected to the Filter Choke.

A short-circuited vibrator is one in which the points are stuck against a permanent contact. In this case, the supply fuse will blow at once. To verify this condition, pull the vibrator out of its socket, and apply power to the set. If the fuse does not blow now, then the vibrator must be shorted. If the fuse blows even with the vibrator out of its socket, look for trouble in either the rectifier tube or in a short-circuited buffer condenser, as explained above.

If open, the vibrator will not issue its characteristic "buzz" (also described as a low hum) when power is applied. An open vibrator is one in which the points make no contact whatever, or in which the electromagnet winding is open. If no vibrator buzz is heard see if the tubes light up. If they do, then the vibrator is at fault, and should be replaced with its exact duplicate. If the tubes do not light up in the absence of a vibrator buzz, see if the fuse is blown. Also check for an open in the power switch, which may cause these symptoms.

It may not be necessary to check the vibrator itself for opens or shorts. As the foregoing discussion indicates, easier analysis, and fully as accurate, can be accomplished by the tests mentioned. However, if a vibrator must be tested for a short, proceed as follows: Apply 6 volts D-C through a 20 amp. fuse to the 6-volt input terminals of the vibrator. If the fuse blows before the characteristic buzz is heard, we can be certain of an internal short circuit. A similar check for an open vibrator is as follows: Apply input voltage to the input terminals, and if no buzz is heard we can be certain of an open within the vibrator. In either case, replace the vibrator with its exact duplicate. The input terminals to a vibrator may be found in any one of the many vibrator guides published by manufacturers and available at radio supply houses. Lacking specific data on a given vibrator, 6-volts D-C can be tried on all possible combinations of two terminals until either the line fuse blows or until we are convinced that no combination of terminals will produce the buzz.

Other vibrators, rated at D-C input voltages other than 6 volts can be tested in the same way. However, it is essential that any test voltage applied should correspond to that with which the vibrator is rated.

In ordering vibrators for replacement, it is advised that the repairman mention the make and model number of the vibrator.

Supply houses are provided with cross-references to duplicate the vibrator of one manufacturer with that of another, and still maintain the same physical and electrical characteristics. It is seldom worthwhile to attempt to repair a vibrator.

Section 6. **BLEEDERS**

The purpose of a power supply bleeder, shown in Fig. 7 is to make the filter choke more efficient by keeping current flowing through it at all times. Generally the bleeder will draw about 1/10 the current drawn by the plates and screens of all the tubes combined. In the previous schematic diagrams, for the sake of simplicity, the bleeder resistance was indicated only as a part of the load, with which it is normally in parallel. The bleeder system, either a series of resistances or a single resistor

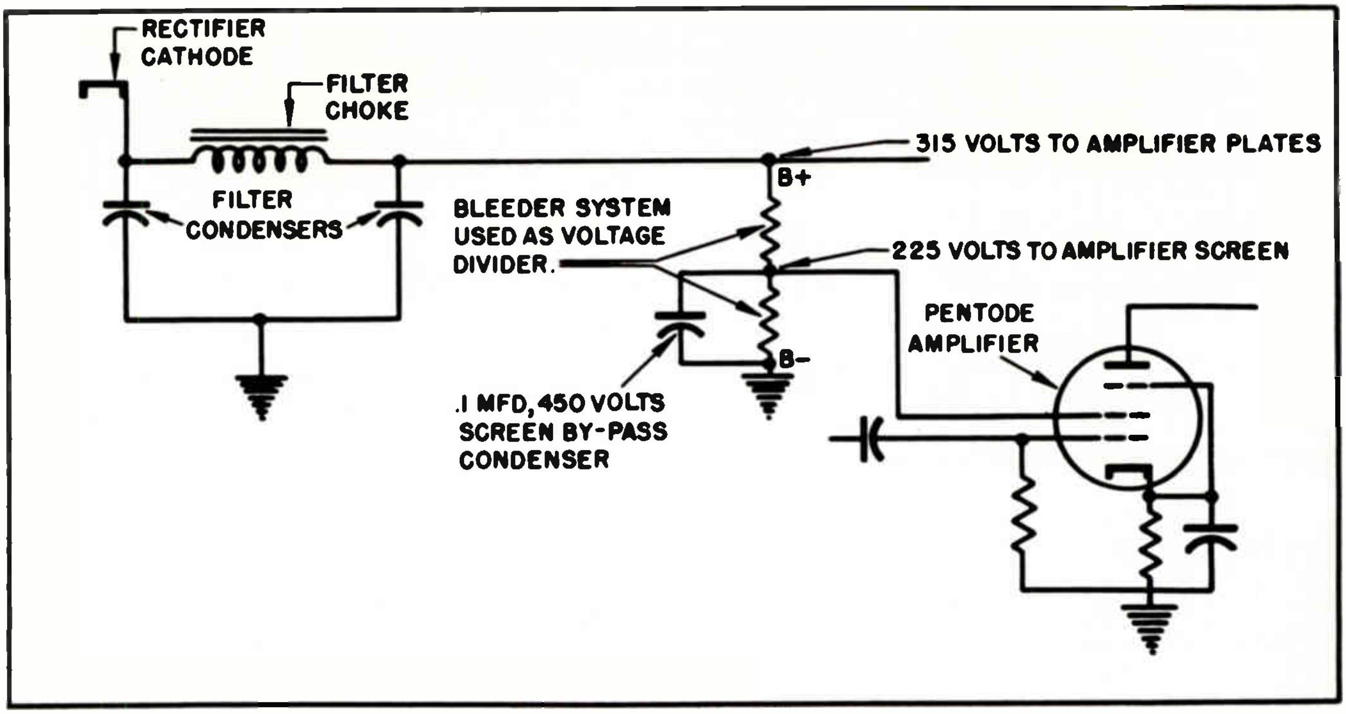

Fig. 8. How a Bleeder Can be Used as a Voltage Divider.

across the "B" supply, can also be used as a voltage divider to provide lower B-plus values to those plates and screens which operate below the output B-plus value.

A typical voltage divider bleeder system is shown in Fig. 8. Since some tubes, such as the 6V6 output tube, when operating with a plate potential of 315 volts will need no more than 225 volts on their screen grids, the bleeder voltage-divider is ideally suited to develop this voltage difference and supply it to wherever needed. If the bleeder resistance is untapped for

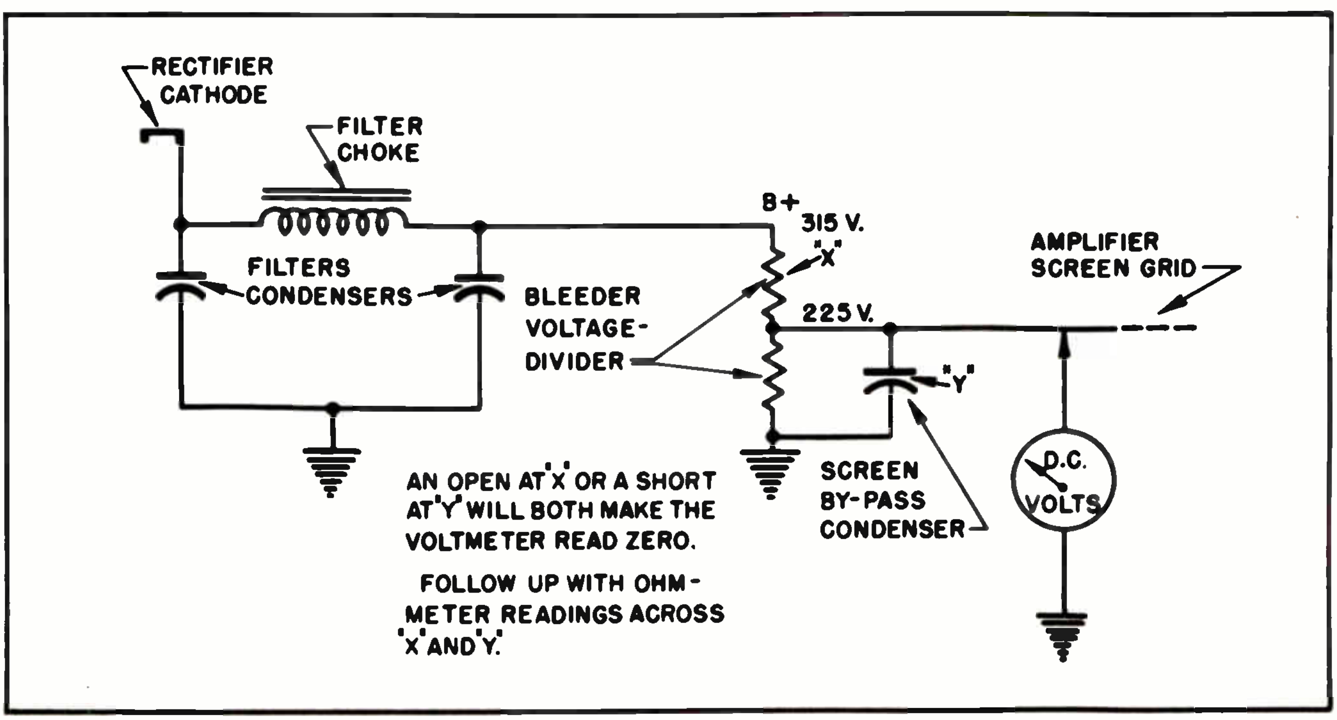

Fig. 9. How an Ohmmeter Check Supplements the Readings of a Voltmeter.

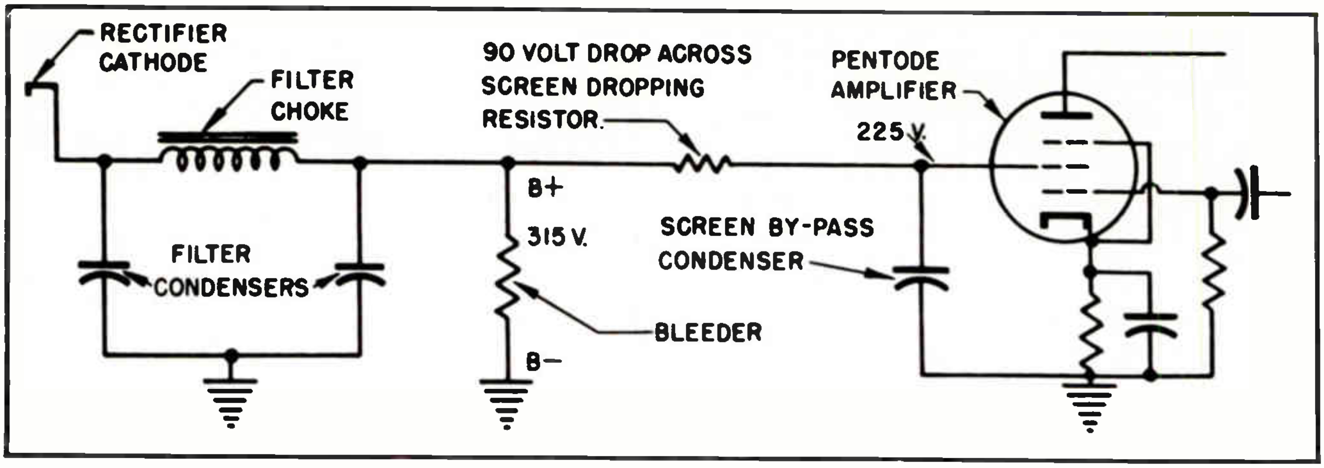

Fig. 10.

voltage division, an open will result in somewhat more hum in the receiver speaker. However, where the bleeder is also used to provide reduced screen grid voltage, an open will result in one or more free-hanging screen grids. This will usually suppress the signal, or render it extremely weak. Verification can be made by a voltmeter check on suspected bleeder components, as well as on the screen grids themselves.

Follow this voltage test with an ohmmeter check, with power turned off, between screen-grid and ground. Fig. 9 indicates why this should be done. If such a resistance reading should indicate a short between screen and ground, then the screen must be at ground potential and will therefore read zero D-C volts with respect to ground. Note that an open bleeder section can also indicate this same zero reading of voltage between screen and ground. It is wise to use the voltmeter reading as a preliminary test for either an open bleeder or a shorted screen by-pass condenser. The verifying final test would be the ohmmeter check, as described.

Fig. 10 shows another method commonly used to drop the screen grid D-C voltage where required. In this case, the dropping resistor is not part of the bleeder system, but forms a series path through which the screen current flows to produce the required drop. By-passing at the screen is necessary to avoid degeneration and motor-boating.

Both the dropping resistor and the by-pass condenser should rightfully be considered components of the power supply. If the resistor opens up, the screen will be free-hanging and will result in either the complete or partial loss of signal volume. An ohmmeter check across this resistor will reveal such an open circuit. If the by-pass condenser opens up, the screen will not be free-hanging, but the stage may now be degenerative, or it may motor-boat, or both. Verify this possibility by placing an equivalent condenser across the suspected one, and note if the undesirable symptoms disappear.

If the screen by-pass condenser shorts out, several observable symptoms will result; the screen dropping resistor will heat up, causing it to smoke and char; the signal will be completely lost; and the rectifier plates (in an A-C receiver) will become red hot. To check this possibility, measure the voltage at the screen, and examine the screen resistor for high temperature. If the resistor is hot, complete the analysis by measuring resistance, with power turned off, between screen grid and ground. If it reads zero resistance, then we can be certain the by-pass condenser is shorted.

This leads us to an interesting, and not too uncommon, type of trouble peculiar to receivers containing by-pass condensers. (In AC-DC receivers, screen voltages are rated at full B-plus and therefore need neither dropping resistor nor screen by-pass condenser.) Let us note that if the screen by-pass condenser shorts out, current can flow directly from ground through the short to B-plus. This heavy current will pass through the dropping resistor on its way to B-plus. Since the screen resistor normally has a low wattage rating the overload of current will heat the resistor, and if this current is sustained for any length of time the resistor will burn itself open. We now have two troubles where we had only one before. If we replace the resistor, it will only burn open like the first one. Obviously, we must find the original source of the trouble, the shorted screen by-pass condenser. This can be done, as explained above, with an ohmmeter placed between the screen and ground. Wherever a hot or burned screen resistor is found, look for a short circuit in the condenser by-passing this screen to ground. Replace the condenser with an equivalent, and then replace the damaged resistor.

Section 7. FILTER RESISTOR

The filter resistor, shown in Fig. 11 replaces the filter choke in many small receivers where space and weight must be considered. In these receivers, using four or five low-current amplifier tubes, the power supplies are either AC-DC or three-way portables. To avoid drawing too much current through the filter resistor, the output stage plate circuit is connected through its load directly to the cathode of the rectifier. This is shown in Fig. 11. This filter resistor, in case the output filter condenser shorts out, will become very hot and may even burn open. This would also be true if any other "B" supply short occurred which lies beyond the output filter toward the amplifier tube loads, but would not be true if the input filter were to short out. In the latter case, the rectifier tube would be damaged and would need replacement (after correcting the short-circuit), but the filter resistor would be intact. The average value of filter resistors is about 600-1200 ohms; that is, about the same ohmic resistance as presented by a filter choke in the same circuit.

Section 8. BALLASTS

The ballast is a resistor used to drop the applied voltage to the proper value for heating the cathodes, or filaments, of series connected tubes. A ballast, which may take many forms, is essentially a dropping resistor. However, it may look like, and be installed like, a tube. Or it

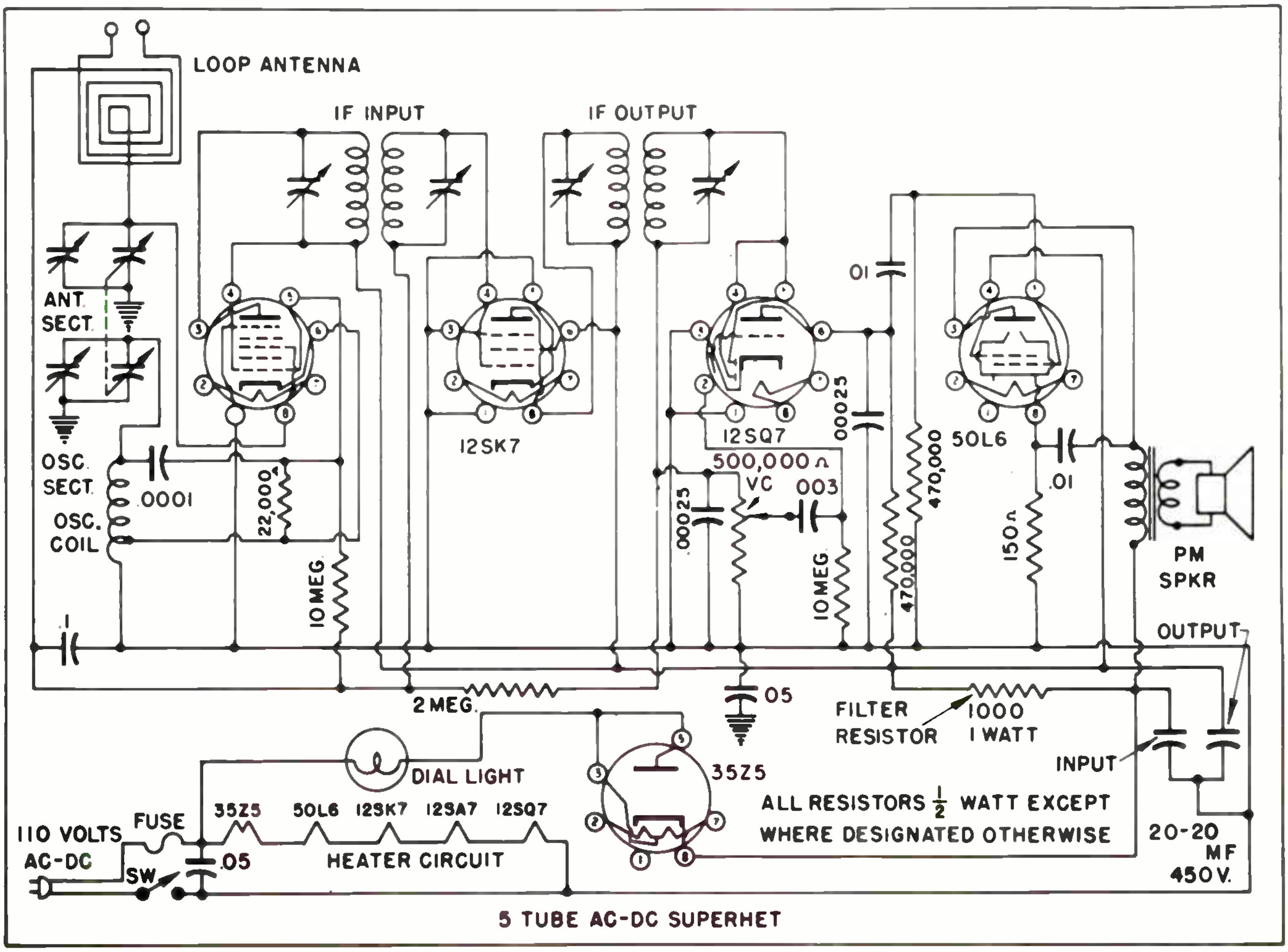

Fig.11. 5-tube AC-DC Superheterodyne Receiver Using Filter Resistor Instead of Filter Choke.

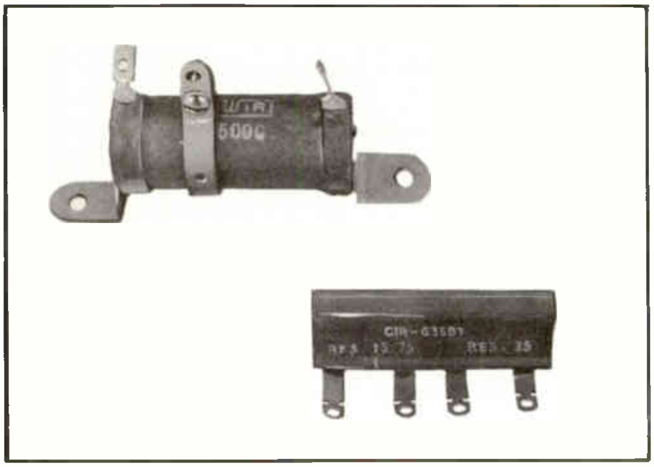

Fig.12. High Wattage Resistors Such as Can be Used for Ballasts.

may be a special type of high wattage resistor. (See Fig. 12.) Ballasts are found only in AC-DC, and 3-way portable receivers.

Due to advances in tube manufacturing techniques, the ballast has become less and less popular. Fig. 13 shows a circuit employing a ballast in series with the tube heaters in an AC-DC receiver. Fig. 14 illustrates a more modern AC-DC receiver not using a ballast, and illustrates why the ballast is not needed in the more modern type of AC-DC receiver.

In the 3-way dry-battery portable, the ballast is essential for the operation of the "A" supply while on the AC-DC position of the power switch. As illustrated in Fig. 15, this ballast drops the D-C voltage from the cathode of the rectifier to the proper heater voltage of the set. Notice that the ballast is also used as a filter resistor in this portion of the circuit, being connected at either end to the "A" supply filter condensers.

The ohmic resistance of the ballast used here is determined by whether the amplifier tube filaments are connected in series or parallel. The resistance will be that required to drop the rectifier output to the voltage needed for operation of the filaments of the amplifier tubes in accordance with Ohm's Law.

If the ballast opens up, none of the amplifier tube filaments will heat up, but

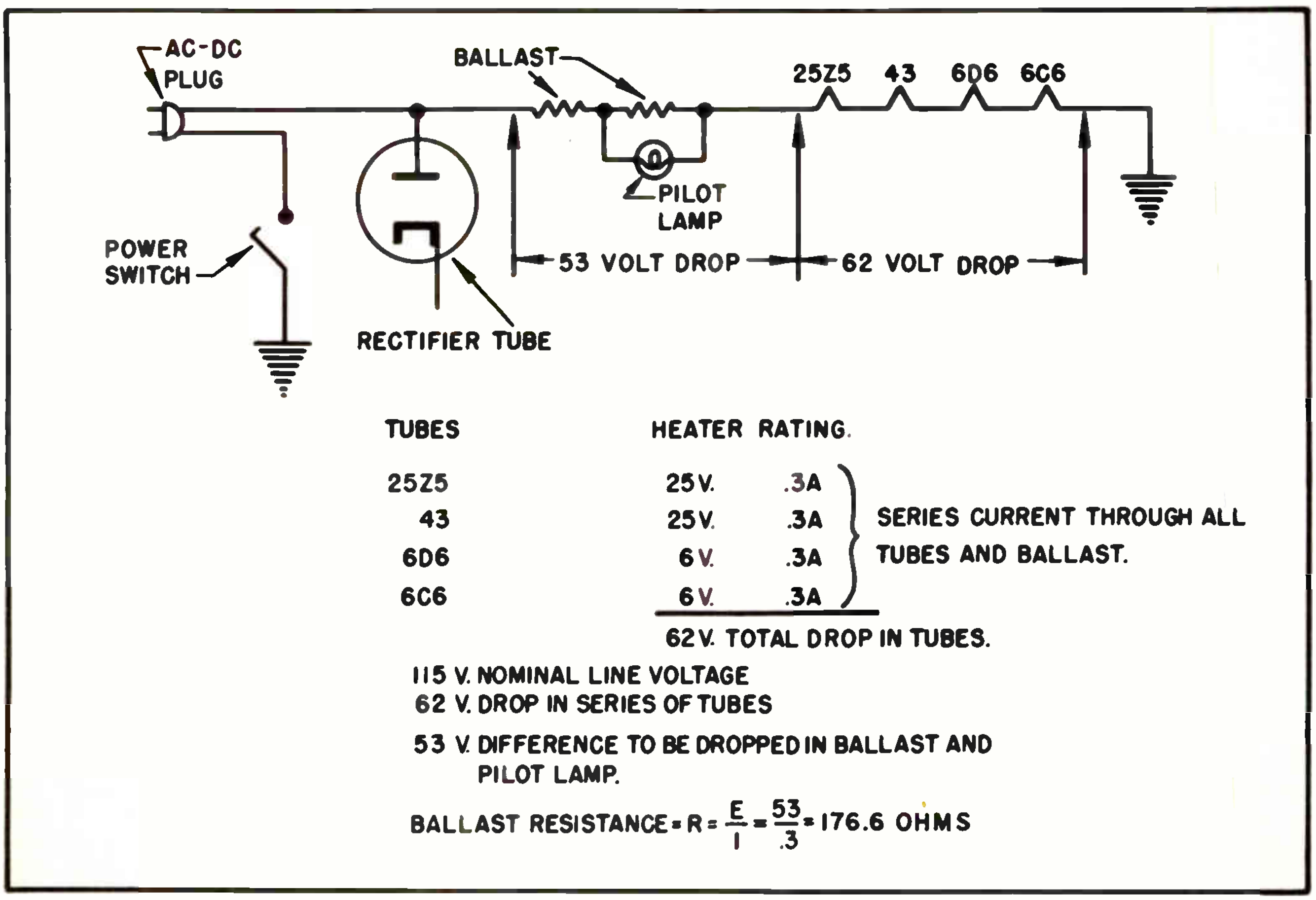

Fig.13. Using a Ballast in an AC-DC Receiver.

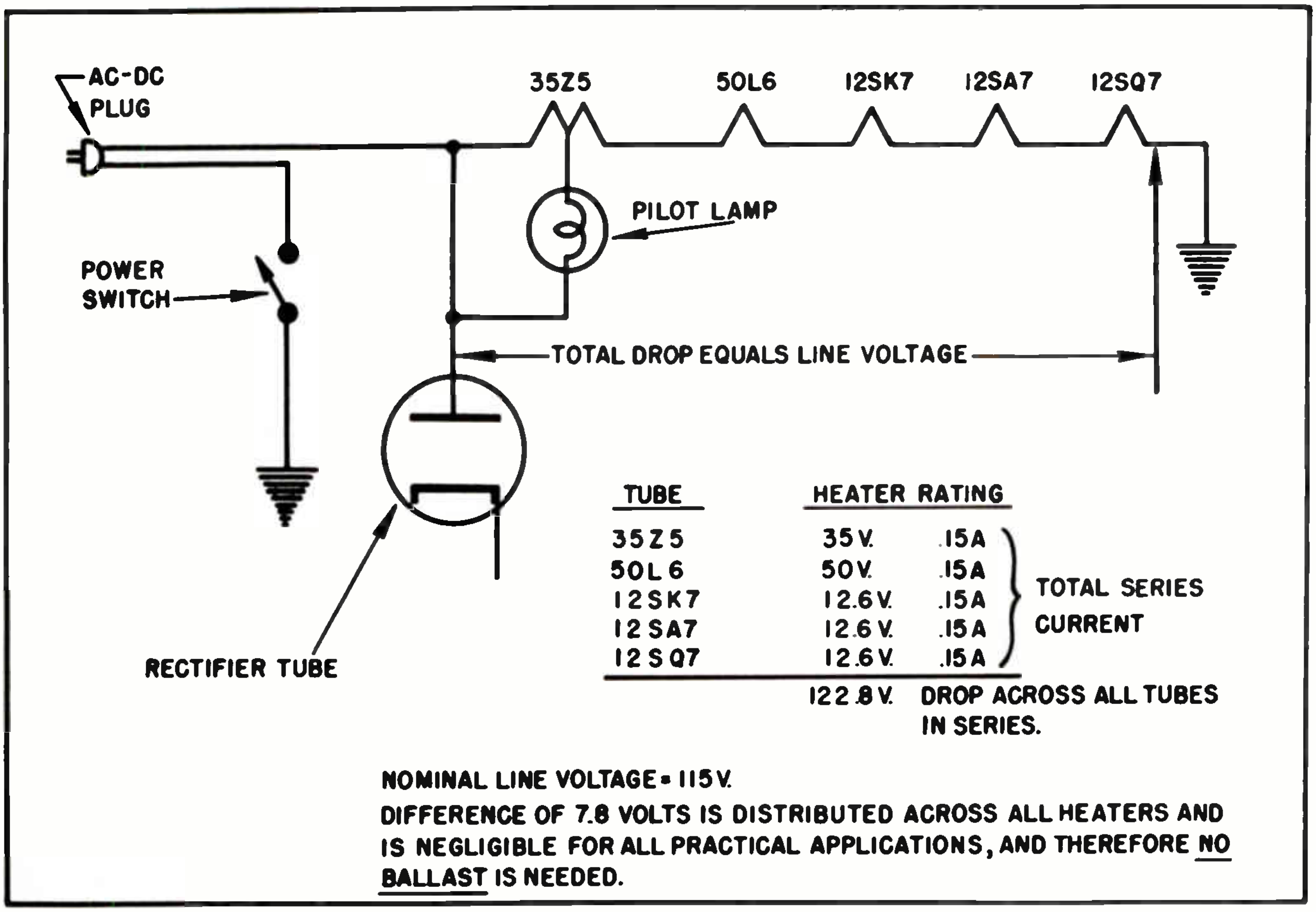

Fig.14. Circuit of a Modern AC-DC Receiver Which Does not Need a Ballast.

the rectifier tube, being supplied with heater voltage from the external power source, will still light. In such a case, the receiver will play properly on battery power but not on AC-DC power, since the ballast is not used on battery operation.

Measuring filament voltages for an open ballast resistor can be done in the following manner: If the ballast is open, none of the amplifier tubes will have filament voltage at the socket, regardless of whether these tubes are connected in series or parallel. If any one of the amplifier tubes shows the presence of filament voltage, then the ballast must be in operating condition.

An important point to be remembered will be useful here: The 1.5 volt amplifier tubes in portable receivers will seldom appear to light; therefore looking to see if they are lighted or not is not a good test. The best method of determining this is to see if filament voltage is supplied to the tube socket. If so, check the tube filament for continuity. If the filament is continuous and proper filament voltage is available to the socket, then we can safely assume that the tube heats up when power is applied.

If the ballast in a portable receiver is short-circuited to ground it will, as a rule, become very hot and no filament voltage will be present. If the ballast shorts out to ground in an AC-DC receiver, the supply fuse will blow. Ballast shorts are not so common as open circuits in these components.

In an AC-DC receiver an open ballast will be indicated by the fact that the tubes all check good, but do not light when power is applied to the set. In this case no B-plus will be present and, of course, no sound in the speaker. Fig. 16 illustrates these symptoms and their cause, in an AC-DC receiver. Note that to verify this condition, and to rule out the possibility of an open switch or power cord, the ballast should be tested with an ohmmeter. Information on ballast connections and ohmages is available in standard manuals available at radio supply houses. In ordering ballasts for replacement specify the type and model number to insure exact duplication.

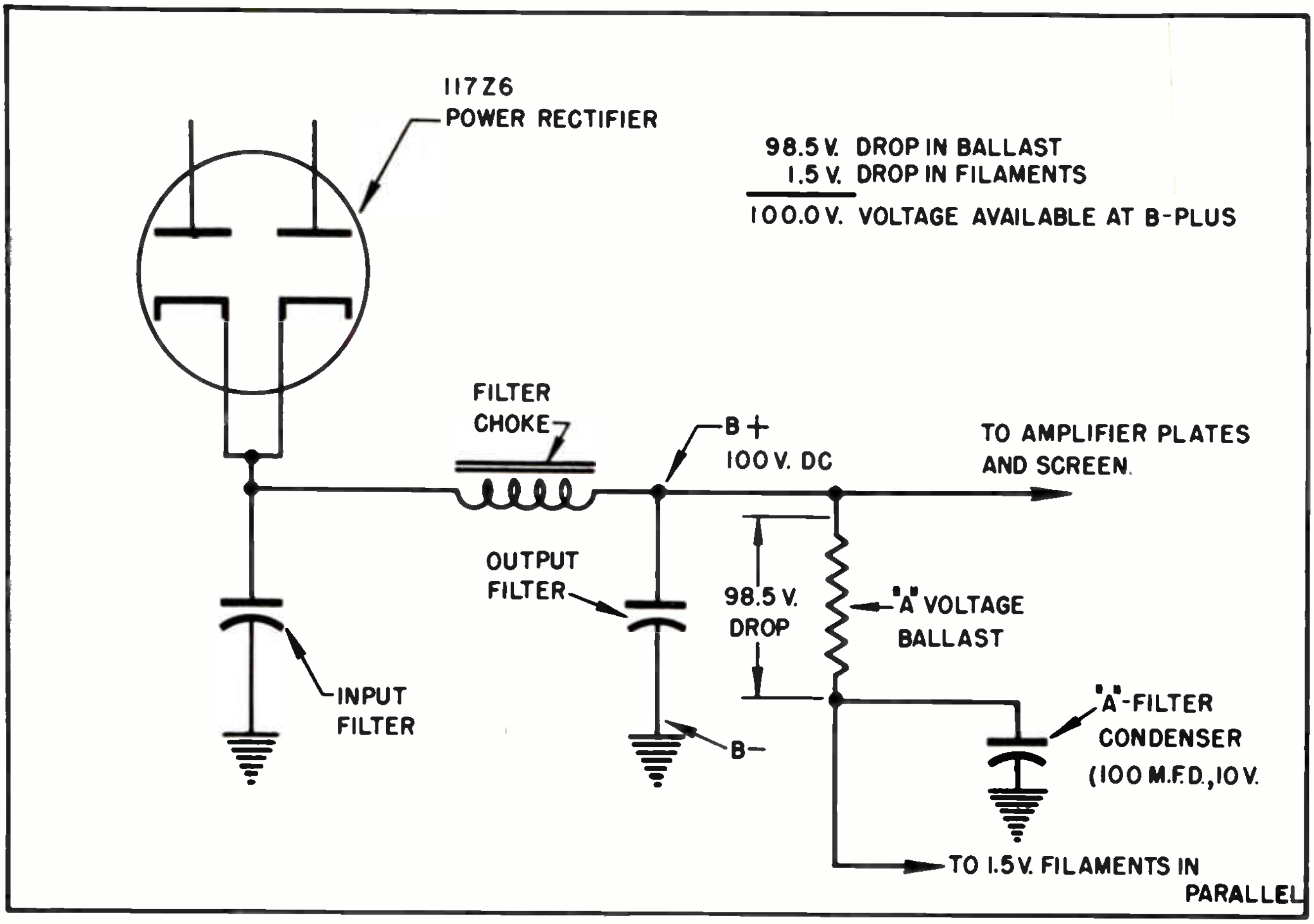

Fig. 15. Using a Ballast for the "A" Supply in a Portable Receiver.

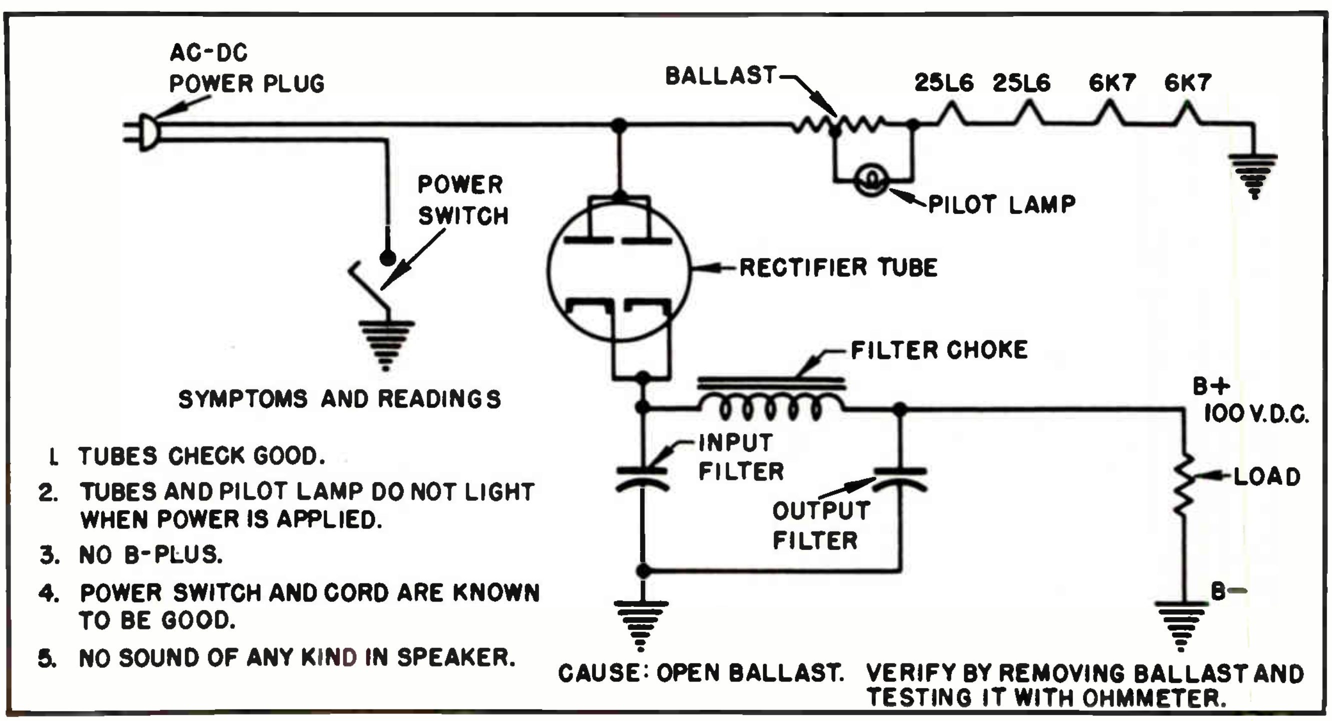

Fig. 16.

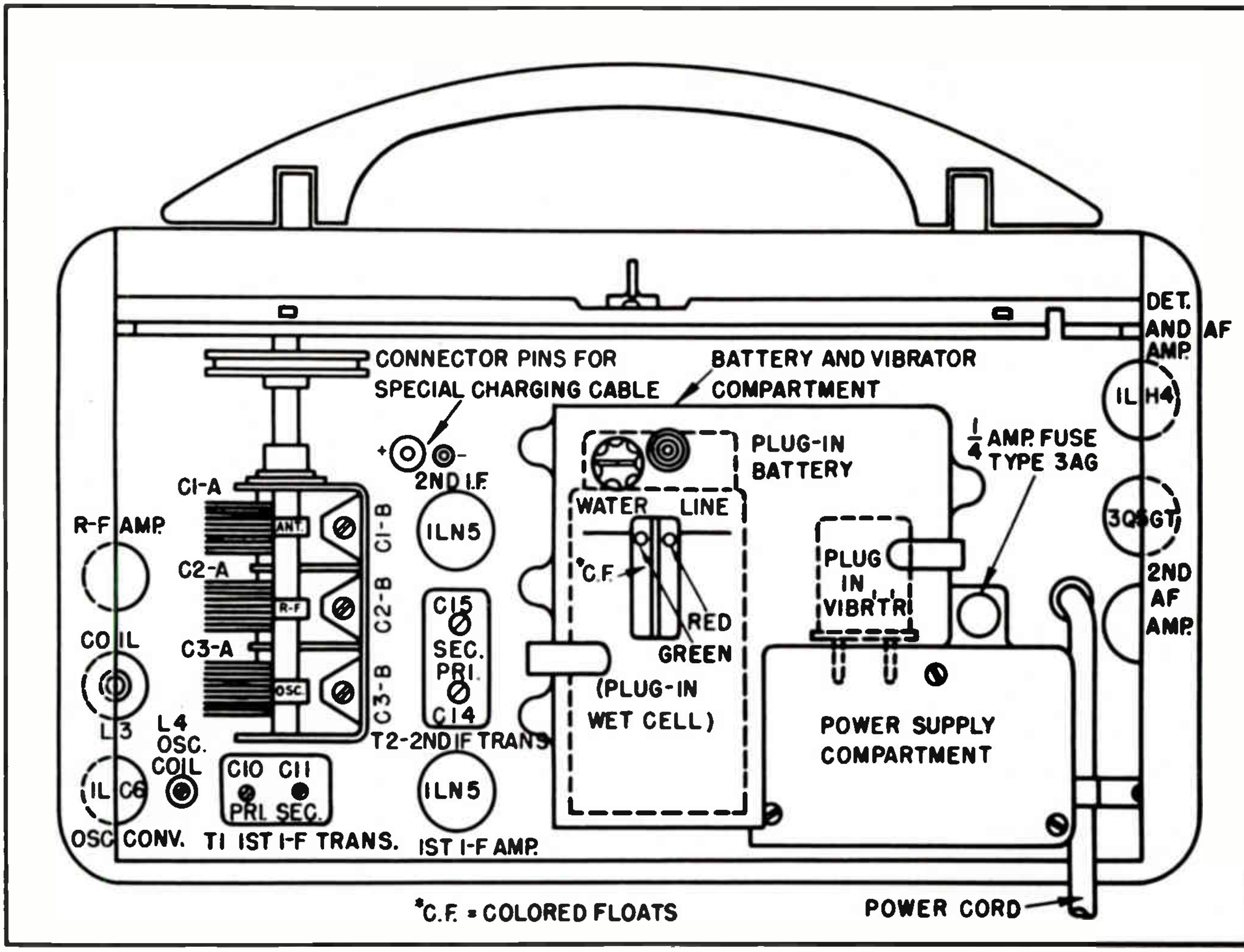

Fig. 17. The Red and Green Colored Floats Indicate the State of Charge of the Battery.

Section 9. **BATTERY TROUBLES**

Dry batteries are used in 3-way portables and straight portables, their purpose being to supply transportable power to any location where the receiver is to be used. In portable receivers employing them, dry battery troubles are by far the most common fault, the chief one being deterioration through normal use.

If a portable receiver does not play on its own batteries, the first step is to determine their state of charge. Remember to check batteries only while they are under load. While disconnected from its load, a battery may check good. This method is misleading and therefore time-consuming. A D-C voltmeter, set on the proper scale and applied to the battery terminals while under load, will read battery output voltages accurately. Replace the batteries when needed. If the batteries of a portable receiver (or a 3-way portable on battery operation) test good, and the receiver does not play, then check for trouble elsewhere, especially in the tubes, tube-sockets, or switch. A careful visual inspection of the battery plugs and their leads would also be in order.

When replacing dry batteries, order by name and model number. Radio supply houses, provide cross-reference information so the exact electrical characteristics of the batteries will be duplicated. Of equal importance, the same physical dimensions will be duplicated. Most portables have limited space for batteries, making it necessary to conform to rigid battery dimensions.

Wet batteries, found in re-chargeable portables and used by automobile receivers, provide low D-C power for direct consumption by the tube heaters or filaments, and a driving power to the vibrator-transformer system for the "B" supply voltage. Their obvious advantage is that they may be re-charged, offering operational economy.

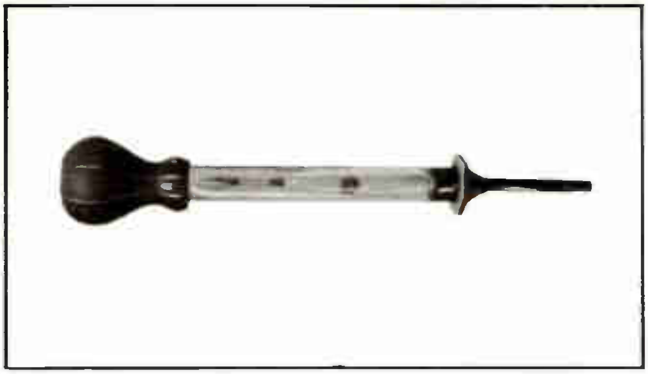

Fig. 18. A Hydrometer Used for Checking the Conditions of Storage Batteries.

The 2.2 volt wet battery employed in rechargeable portables seldom need testing with a voltmeter, since, as illustrated in Fig. 17, the state of charge can be determined by inspecting its colored floats. In rare cases where the floats are stuck, measure the voltage, with the battery under load on a D-C voltmeter. A discharged wet cell will not heat the filaments of the set to operating temperature, and will not drive the vibrator. Hence the symptoms displayed will be the complete lack of any sound whatever, including the buzz of the vibrator. This buzz should be audible in a quiet room as soon as power is turned on. If the battery tests good and still the vibrator buzz is absent, look for vibrator troubles.

As in the case of all wet batteries, those found in radio receivers must be kept in a state of charge and must be filled with distilled water from time to time. Many wet battery failures are due to the negligence of the user, who may not know that a battery must be cared for.

In automobile radio receivers, which are supplied with 6-volt D-C power, battery faults are indicated in many ways other than the failure of the receiver to operate. The car may not start, which would point to a defective battery. Or the car lamps may not light. Car storage batteries may be tested by voltmeter readings, with the battery under load, or by the use of a battery hydrometer, a device which indicates the state of charge by measuring the specific gravity of the electrolyte.

A hydrometer, illustrated in Fig. 18, will measure 1300 for a full charge, 1200 for a half charge, or 1100 for a low charge. (These figures are specific gravity comparisons, with water used as a standard, and the decimal point omitted.)

If a car battery is strong enough to start the car, then it is strong enough to operate the car radio; therefore, a defective car battery can be instantly ruled out as the source of receiver failure if the car starts and runs normally. If the vibrator buzz is absent, and the battery is known to be good, look for trouble in the radio supply fuse, the power switch, the vibrator, the buffer condenser, or the tubes, as explained earlier.

Section 10. **SELENIUM RECTIFIERS**

The dry-disc selenium rectifier, Fig. 19, is employed in some AC-DC and 3-way portables to replace the rectifier tube, its advantages being simpler circuits, no rectifier tube heater current is required, less heat dissipation, and simpler operation.

Fig. 20 shows the circuit for an AC-DC power supply using the selenium rectifier, and omitting the rectifier tube. Line current passing into the circuit, due to the uni-directional quality of the selenium rectifier, flows only in the so called "forward" direction, through the load, toward the "plus" sign on the rectifier unit. The opposite half cycle is of course stopped by the rectifier, and half-wave rectification results. This rectifier produces its output almost as soon as power is supplied, a fact which is noticeable in a portable with 1.5 volt amplifier tubes (which also heat up quickly). However, in AC-DC receivers, signal at the speaker must wait for amplifier heaters to warm up, accounting for the lag between applying power and production of sound at the speaker.

A defective selenium rectifier will be indicated when no signal of any kind is heard at the speaker, and all the tubes check good. To verify this suspicion, read the voltage at the rectifier output; that

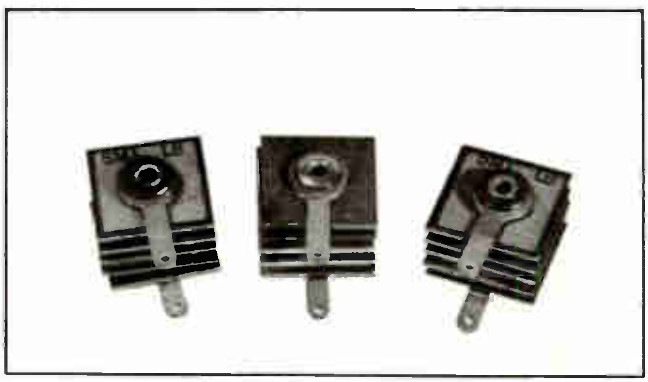

Fig. 19. Selenium Rectifiers.

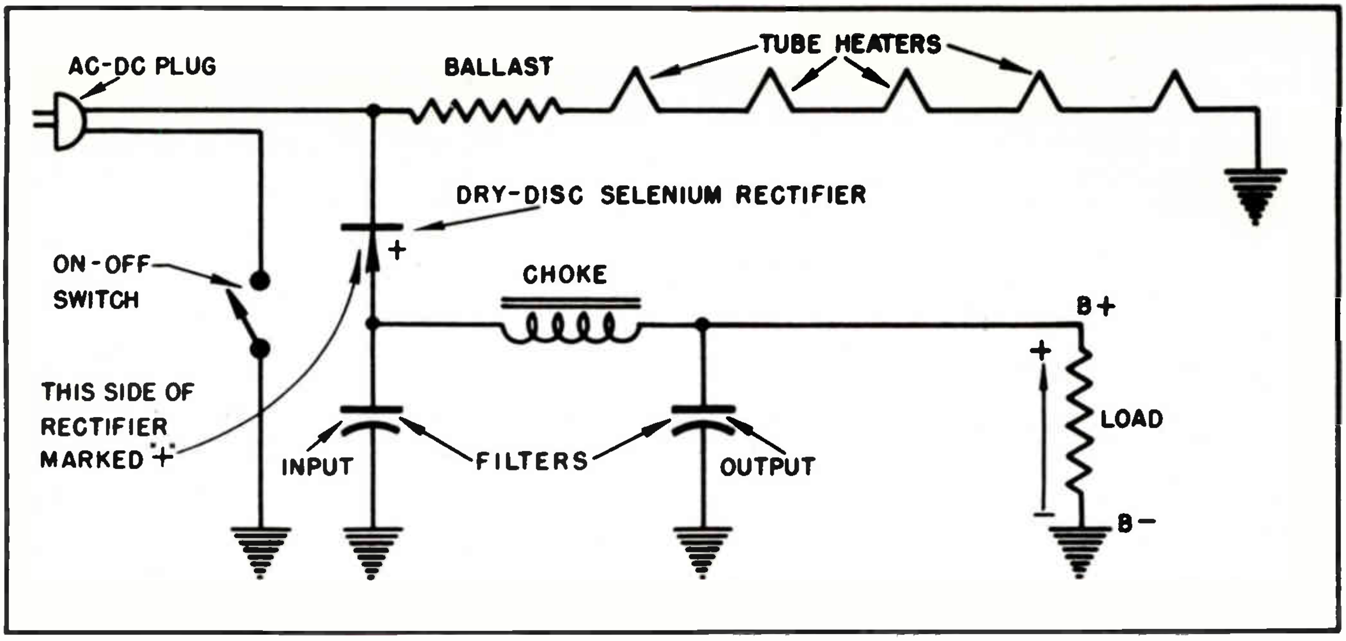

Fig. 20. A Selenium Rectifier Used in an AC-DC Power Supply.

is, between the terminal at the "plus" side of the rectifier and the negative side of the filter condensers. Voltage here should read 100 or so D-C volts, with a 20% tolerance. If this voltage is low or absent, (See Fig. 21) then we can suspect the rectifier for faults. Testing the rectifier can be done by measuring it with an ohmmeter in one direction, and then reversing the ohmmeter leads and measuring it in the opposite direction. A good selenium rectifier should read about 1500 ohms in the forward direction and no less than one megohm in the backward direction. Equally high ohmages in both directions indicate that resistance is too high in the forward direction. Equally low resistances in both directions indicate that the unit has lost its rectifying qualities. In either case, the rectifier unit should be replaced. In ordering this part, it is

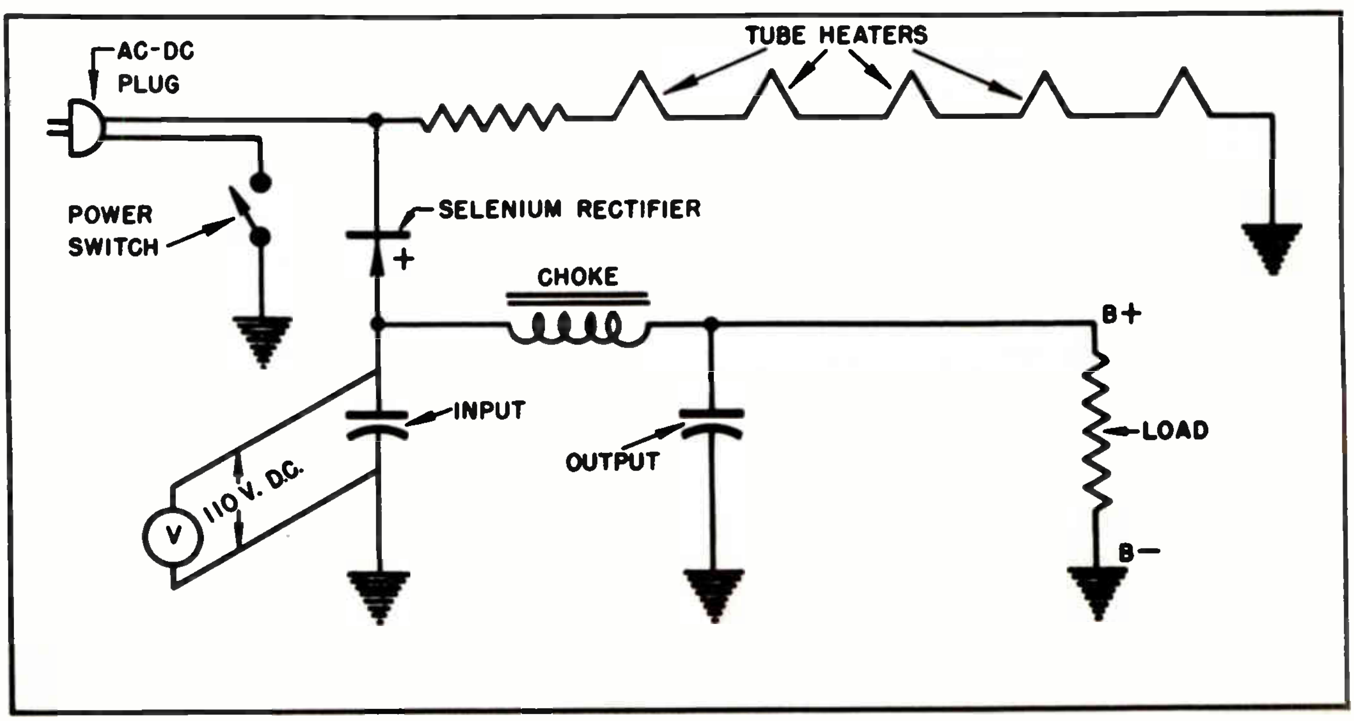

Fig. 21. Testing for Trouble in a Power Supply Using a Selenium Rectifier.

wise to send it to the supply house to make sure that physical and electrical characteristics will be exactly duplicated. When the rectifier unit is ordered from the receiver manufacturer, it is necessary only to state the make and model of the receiver in which it was found.

If 100 D-C volts are measured at the rectifier output, but low B-plus is present in the rest of the receiver, look for shorts across the "B" supply, as indicated earlier. If an excessively high B-plus is found at the rectifier output, test the tube filaments or heaters for open circuits.

NOTES FOR REFERENCE

All types of power supplies have the common property of producing heater (or filament) voltage, and plate supply voltage in the receiver of which they are a part. If either of these voltages is absent, the power supply is at fault.

Power supply troubles are most easily, and most accurately, discovered after first identifying the type, such as AC-DC, AC, portable, 3-way portable, re-chargeable portable, and automobile radio.

In checking rectifier tubes of AC-DC receivers, follow the tube-checker test with an ohmmeter check on all heater terminals of the tube. Consult the tube manual for the pin numbers, and make a careful 3-point check on those rectifier tubes which have a pilot-tapped heater. (Tube-checkers often check as good a tube in which that section of the heater is open which shunts the pilot lamp. This information may be erroneous and should be verified by an ohmmeter test.)

In an AC-DC receiver, if there is no sound of any kind in the speaker, and tubes do not light when power is applied, test all the tubes for heater continuity.

In an AC-DC receiver, if the rectifier tube shows no emission on the tube-checker, yet its heater lights when power is applied, look for short circuit in the "B" supply before replacing the rectifier tube. If this is not done, any replacement of the tube will be likewise damaged by the short circuit.

If the pilot lamp of an AC-DC receiver flickers on and off, look for an intermittent open in one of the tube heaters. If the pilot lamp has been burnt out, and replacements keep burning out when power is applied, replace the power rectifier. An open in the pilot lamp shunt within this tube can cause the symptoms described.

Hum interference in radio receivers are most often caused by open or deteriorated filter condensers. If signal is low, and hum is present, check the input filter. If signal is loud and hum is present, check the output filter. If neither of the filters is defective, a gassy output tube is indicated; replace and test to see if the hum disappears.

If all tubes check good in a receiver, and violent "motor-boating" is present, shunt the output filter with its equivalent and see if the motor-boating disappears.

In an A-C receiver, if the rectifier tube plates become red hot, look for a short circuit across one of the filter condensers, or some other point across the "B" supply. This would include shorts in any branch of B-plus and across screen by-pass condensers.

A burned, charred, or hot resistor in the "B" supply circuit generally indicates a shorted condenser closely associated with this resistor. Find the shorted condenser first, then replace the resistor it has damaged.

In checking automobile receiver power supply troubles, the faulty component can often be detected from external symptoms. These include the reading of the car ammeter when power is applied to the set, the presence or absence of the characteristic vibrator buzz, noting if the supply fuse has been blown, or if it blows replacements repeatedly, and whether or not the signal fades out when the car motor is turned off or is idling.

In those areas where commercial power is 110-volts *D-C*, do not plug in a purely *A-C* receiver. (This can be identified by the presence of a power transformer.) Also, in a D-C area, if an AC-DC receiver has no sound of any kind in the speaker, but the tubes and pilot lamp light up, *reverse* the polarity of the line plug in the wall receptacle. The AC-DC receiver will not work on the wrong polarity from a D-C source, although tube heaters and pilot lamp will light.

SPECIAL WARNING ON AC-DC RECEIVERS!

In this type of receiver, due to circuit connections, it is possible for the line voltage to be directly applied to the metal chassis. Reversing the wall plug will not eliminate the danger of rendering the chassis "hot". It can be seen from the circuit diagrams the chassis will be "hot" in either position of the wall-plug, depending upon whether the receiver power switch is on or off. Therefore, never use this type of receiver, or attempt to work on it, anywhere near water, water-pipes, concrete floors, gas pipes, radiators, or furnace registers. Under certain common conditions, fatal shocks can result from careless handling of an AC-DC receiver. It goes without saying that this type of receiver should not be used in the bathroom, and, if used in the kitchen or basement, should be far removed from any ground connection.

Manufacturers of AC-DC receivers specify that the chassis should never be connected to ground. It is well to heed this advice, and to pass it along to users when the opportunity arises.

In power supply trouble-shooting, various widely differing voltages are encountered. It is often necessary to make a voltmeter test, and then to follow it up with an ohmmeter test. Since the repairman will be using the multimeter frequently in power supply trouble-shooting, damage to this unit may result from neglecting to set the meter to the proper function or scale before each test. If the ohmmeter is inadvertently placed a high B-plus voltage, the chances are good that some degree of damage will occur to the meter. Ohmmeter measurements should always be made with the power turned off. The multimeter should be stored between readings with its scale set to a high voltage. This precaution will avoid damaging it or the receiver by applying its test leads to a circuit while on the wrong function or the wrong scale.

NOTES

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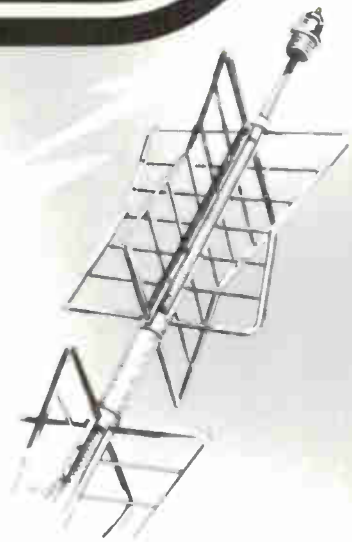

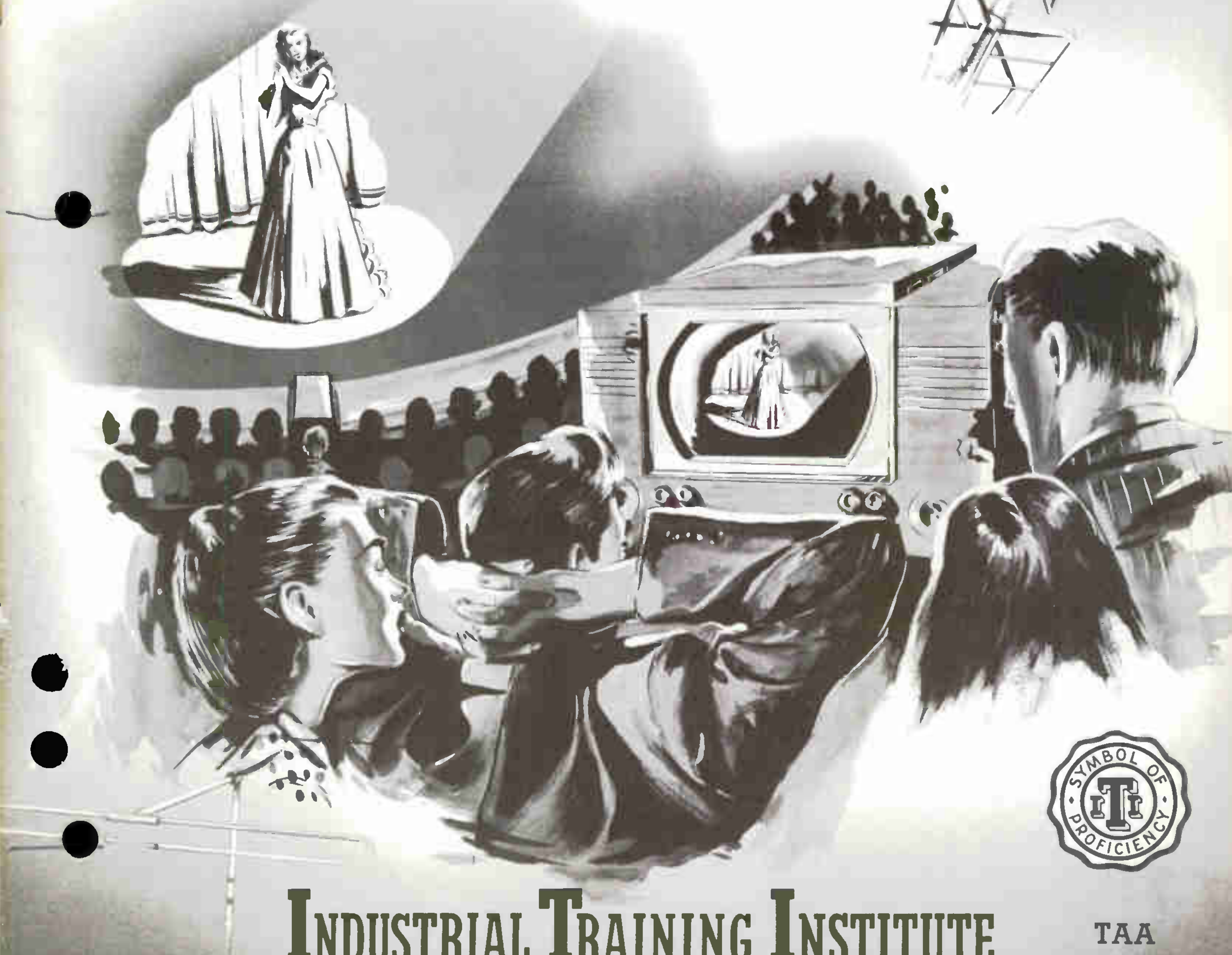

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RADIO TELEVISION

BASIC METER MOVEMENTS

Contents: Introduction - The D'Arsonval Meter - Meter Sensitivity - Ohms-Per-Volt - Meter Shunts - The Voltmeter - The Ohmmeter - The D'Arsonval Movement Applied to A-C Circuits - The Multimeter - The Vacuum Tube Voltmeter - The Dynamometer A-C Meter - The Hot-Wire Meter - Notes for Reference.

Section 1. INTRODUCTION

In radio and television repairing, the importance of meters and test equipment cannot be overestimated. The heart of almost every kind of test equipment used for taking measurements in radio and television work is a basic indicating device called a *current meter*. The variations and applications of this basic unit are wide and diversified, yet its fundamental operating principle is practically the same in every case.

Among the many test units used in radio and television work the current meter is the basic indicating unit in:

1. The ammeter, milliammeter, microammeter.
2. The voltmeter, on all its ranges.
3. The ohmmeter, on all its ranges.
4. The tube-checker.
5. Many types of frequency and wave meters.
6. The vacuum tube voltmeter.
7. Certain types of capacity analyzers and inductance computers.

In view of the many useful applications of the current meter to radio and television test equipment, the purpose of this lesson is to acquaint you with the various forms the current meter may take, and to show the special circuits involved in each of these forms. A clear knowledge of how and why his test equipment works gives the radio and television repairman the ability to interpret his findings with a sureness which he would not have without this knowledge.

Fig. 1. Multirange Milliammeter. (Courtesy Simpson Electric Co.)

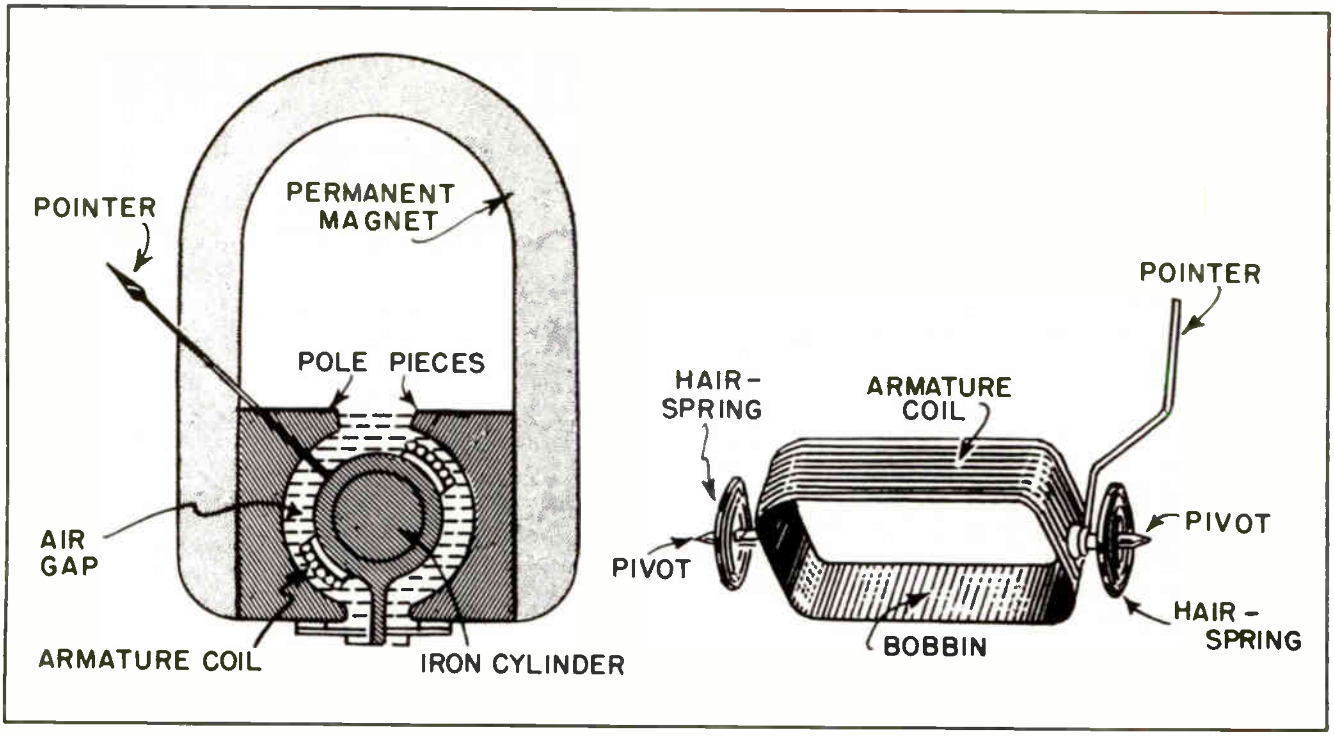

Fig.2. Construction of a Moving Coil Current Meter.

Section 2. **THE D'ARSONVAL METER**

Fig. 1 illustrates the outward appearance of a common current meter. In this case, the meter is quite sensitive and, for this reason can be described as a milliammeter. This meter, in its various forms, is the basis of the many types of test instruments mentioned above. Fig. 2 illustrates the construction of a milliammeter. This device was invented in 1881 by Arsene d'Arsonval and still bears the name d'Arsonval movement. More descriptive, however, is the name "moving-coil meter", which is also applied to this type current-measuring device.

The parts of the moving-coil, or d'Arsonval movement, are shown in Fig. 2. The permanent magnet is of the horseshoe type. Two soft iron pole pieces are fastened to its end with bolts, and the inner surfaces of these pole pieces are cut away to form arcs whose common center is midway between the two inner surfaces of the magnet ends. A soft iron cylinder is mounted between the two pole pieces, serving to minimize the reluctance of the magnetic circuit. The magnetic lines cross the air gap between the pole pieces and the soft iron core in a direction perpendicular to their surfaces.

Having thus an assembly with a uniform air gap between the core and the pole pieces, the magnetic field within the gap is constant in value but radial in direction.

The coil, which carries the current to be measured, is mounted so it can rotate around the iron cylinder. Supported on hard steel pivots which rest in jeweled bearings, this coil rotates against a minimum amount of friction, and carries with it during its rotation a light counterbalanced pointer. This pointer is so arranged that it moves over a suitable scale properly graduated which readily and clearly indicates the "reading".

Rotation of the coil results when current flows through it. Rotation is caused by the interplay of the magnetic lines of force of the permanent magnet and those created by coil current. Rotation is limited by the hair-springs, whose natural tension returns the pointer to zero reading when no current flows through the coil. The pointer swing is also limited by mechanical "stops" against which the pointer bears at both its zero and maximum positions. The spiral hair-springs are arranged to serve the triple function of supplying current to the coil, to return the pointer to zero reading, and to limit the swing of the meter pointer. One spiral spring winds up as the pointer moves, and the other unwinds. However, the mechanical stress represented by either the wound or the unwound position is the

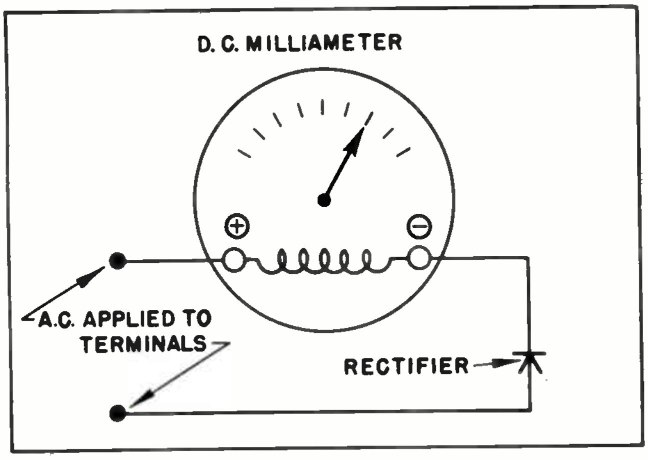

Fig.3. A Rectifier Makes the Meter Usable on A-C Circuits.

opposition against which the magnetic turning force acts. The meter pointer will therefore stop exactly at the point where the tension of the spiral springs equals the force of the magnetic field.

Thus, when coil current flows, the meter will stop at a point where these forces exactly counterbalance each other. The degree of deflection -- the distance through which the pointer swings -- will be *proportional* to the coil current. The scale can be calibrated in the proper current unit, such as amperes, milliamperes, or microamperes, and a direct reading of the current can be obtained.

The design and construction of the d'Arsonval movement as can be readily seen, limits its use to D-C measurements. If A-C were to be directly applied to this movement, the rotating coil would tend to follow the forces created by an alternating field. The inertia of the coil assembly, including the pointer carried with the coil, prevents its back-and-forth motion at A-C frequencies, and the result is that the coil assembly stands still. If, however, any applied A-C is *rectified* before being fed to the d'Arsonval movement, the resulting D-C, even though it is pulsating, will deflect the moving coil -- and the pointer it carries with it -- to an average D-C value. Fig. 3 illustrates the manner of inserting the meter rectifier into the circuit.

Now, to show the amplitude of A-C required for a given deflection, the meter scale can be calibrated in alternating current. Despite its calibration in A-C units, in reality the moving coil itself responds to the rectified direct current.

The insertion of a rectifier into a d'Arsonval type meter movement represents an important extension of this type of movement to radio and television uses. Various types of A-C measuring devices, will be discussed later in this lesson, but the many simple and useful applications of the d'Arsonval movement, plus its rectifier, make it of prime importance in radio and television servicing.

Section 3. **METER SENSITIVITY**

We have already learned that the strength of a magnetic field, or the flux density, surrounding a coil depends upon both the number of turns of wire in the coil and the amount of current flowing in it. When this principle is applied to the coil of a meter, it means that for any given amount of current the flux density will depend upon the number of coil turns. It is easy to see that the swing of a meter pointer, with a fixed amount of current, will depend upon the number of coil turns. In other words, the number of turns in a meter coil can determine how sensitive the meter is.

Let us now consider an example. If a meter coil is wound with enough turns to deflect the pointer to full scale when one milliampere of current flows through it, the meter is said to contain a "one mil-movement". (See Fig. 4.) The same meter, with half a milliampere of current flowing, will deflect the pointer to half-scale, and a quarter the current will deflect it to a quarter-scale.

The sensitivity of the meter, "one mil sensitivity", is a statement of the amount of current required for full-scale deflection of the pointer. As you can see, the sensi-

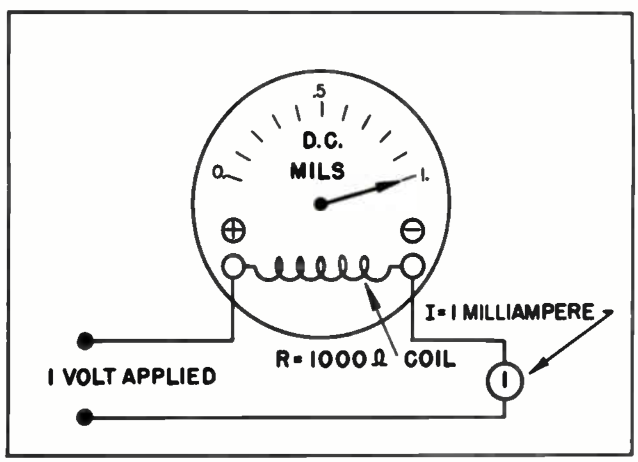

Fig.4.

tivity is actually independent of the amount of current flowing at any given time, but does express the necessary amount of current to achieve *full-scale deflection.* A "one-mil-movement" is a fairly sensitive meter and is commonly employed in many types of everyday test equipment.

Let us now consider another example. If the number of turns on a meter coil are such as to require five milliamperes of current for full-scale deflection, its sensitivity can be described as a "five-mil-movement". This meter would be one-fifth as sensitive as the "one-mil-movement".

A third example is a meter which requires ten milliamperes of current to achieve full-scale deflection of the pointer; the sensitivity here, of course, is described as a "ten-mil-movement". It is one-tenth as sensitive as the one-mil movement and one-half as sensitive as the five-mil-movement.

Because of their comparatively low sensitivity, the five-mil and ten-mil-movements are only used on less expensive test equipment, their chief applications being to laboratory and research procedures where the magnitude of the current measured is of a comparatively high value.

This provides us with a rule worth remembering: The lower the value of the "mil-movement", the higher the sensitivity of the instrument. Since the sensitivity of a meter is an indication of its quality, or figure of merit, a low "mil-movement" is a better meter than a high "mil-movement". We are now also provided with a means of identifying the sensitivity of a meter movement. If there is no internal or external resistance in parallel with a milliammeter, the number of mils of its maximum reading is the sensitivity of the movement. The most sensitive current meters are calibrated in microamperes and are called microammeters. (See Fig. 21.)

Section 4. OHMS-PER-VOLT

In the previous discussion of meter sensitivity we have assumed various values of current flowing in the meter coils. Let us now examine the nature of the source of this current, and show how the mil-movement sensitivity of an instrument is related to its ohms-per-volt sensitivity.

As the name implies, the ohms-per-volt sensitivity of a meter is its resistance divided by the voltage required to drive it to full-scale. When we recall that resistance, current, and voltage are related by Ohm's Law, where

$$R = \frac{E}{I}$$

it becomes obvious that if full-scale current is known, and if the applied voltage is known, the resistance of the meter can be determined.

Using a common example, let us now apply one volt to the terminals of a meter having a sensitivity of one milliampere. (See Fig. 4.) We know that one milliampere will drive this meter to full-scale deflection regardless of the source of D-C current flowing through the coil. If the pointer is deflected to its maximum reading, we know that one milliampere of current must be flowing through the coil. In accordance with Ohm's Law,

$$R = \frac{E}{I} = \frac{1}{.001} = 1{,}000 \text{ ohms.}$$

Since the applied voltage is only one volt it would be proper to say the meter had a sensitivity of 1000 ohms-per-volt. This is another common method of rating meter sensitivity.

In like manner, if one volt deflected a meter with a 5-mil-movement to full scale, its resistance would be,

$$R = \frac{1}{.005} = 200 \text{ ohms,}$$

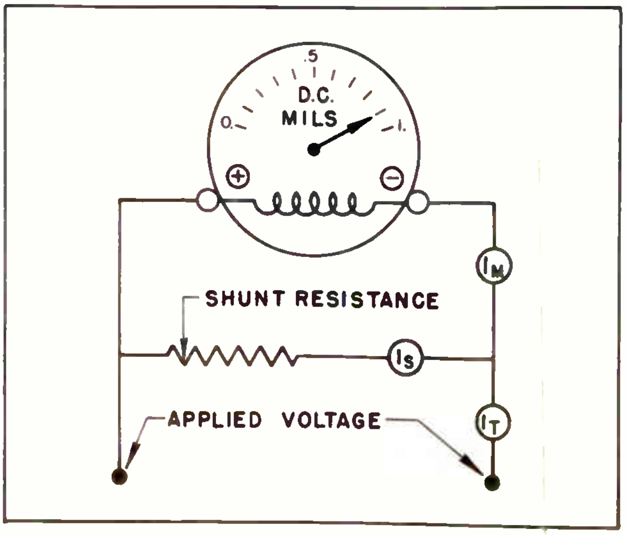

Fig.5. A Shunt can Increase the Range of a Current Meter.

and since here, too, the applied voltage is one volt, the meter's sensitivity is 200 ohms-per-volt.

It should be mentioned at this time that the ohms/volt sensitivity is generally used to describe the sensitivity of an instrument capable of indicating *voltages* -- that is, a voltmeter -- while mil-sensitivity is employed to indicate the quality of a *current measuring* instrument.

We can now see, however, that the basic movement employed to measure both voltages and currents is the same meter, the chief difference being in the manner of calibrating the dial of the indicating scale. The voltmeter scale is calibrated in volts while the current meter is marked off in suitable units of current. Another important difference between voltmeter and current meter applications is the use of the *multiplier* to extend the range of the voltmeter, and the use of the *shunt* to extend the range of the current meter. Multipliers and shunts will be discussed later in this lesson.

A third method for indicating the sensitivity of a meter is by assigning to its movement a millivolt drop figure. This is done in the following manner:

We know by Ohm's Law that the voltage drop across a resistance is equal to the product of current and ohms. If, in the case of a 0.1 mil-movement, we desire its millivolt drop sensitivity, we simply multiply the known meter resistance by the full-scale current, and their product will be the sensitivity in terms of the voltage drop across the meter. Suppose that the ohmic resistance of our 0.1 mil-movement is 100 ohms. Multiplying, we find that

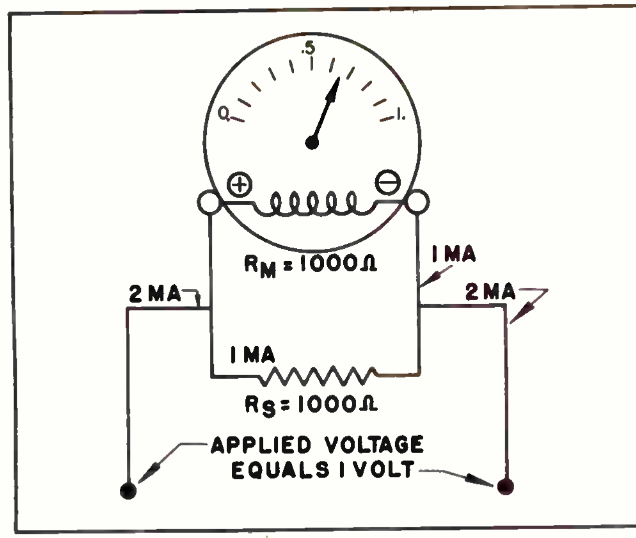

Fig.6.

The lower the millivolt drop rating, the more sensitive the meter.

Section 5. **METER SHUNTS**

There are several methods used to extend the range of a milliammeter, but the one most suitable to radio and television servicing is the use of the meter shunt resistance. This resistance, as illustrated in Fig. 5, is placed in parallel, or shunt, with the meter coil. Any current driven by a voltage applied to the meter terminals will now divide between the path through the meter and that through the shunting resistance. If the resistances of the meter and the shunt are known, the path through the meter itself will conduct a known fraction of the total current. This arrangement makes it possible to calibrate the meter dial in terms of total current (through both the meter and its shunt) while the meter move-

$$E = I \times R = .0001 \times 100 = .01 \text{ volts, or 10 millivolts.}$$

This value is the millivolt drop across the meter and is an indication of its basic sensitivity.

For emphasis, we repeat the following principles:

The lower the mil-movement, the more sensitive the meter.

The higher the ohms/volt rating, the more sensitive the meter.

ment itself, passes only a portion of the total current. Thus it is possible to use a milliammeter with a fairly high basic sensitivity in a variety of circuits where the currents may take a wide range of values.

Notice that in Fig. 6 the current flowing through the meter movement will be just half of the total current. The other half will flow through the shunt resistance. In Fig. 7, with the resistances of the meter and of the shunt bearing the ratio of 1:2

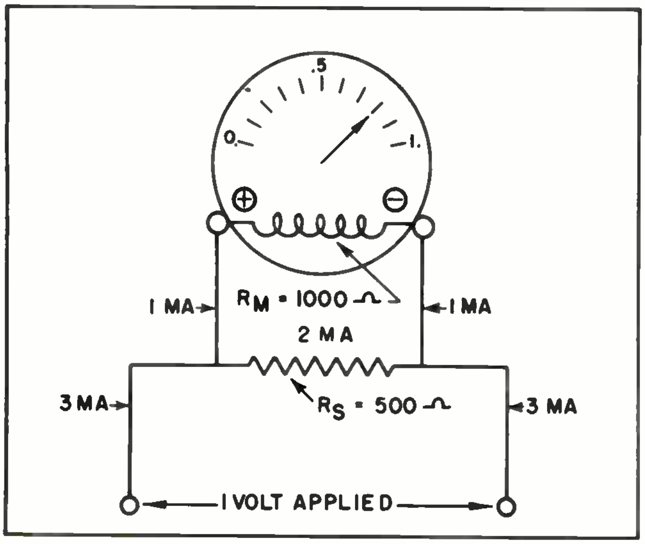

Fig. 7.

there will be twice as much current flowing in the shunt as there is in the meter alone. In the case of Fig. 6, where the meter and shunt resistances are equal, the meter will read full scale while the meter and its shunt *together* are conducting two milliamperes. Likewise, in the case of Fig. 7, the meter will read full scale while both paths *together* are conducting three milliamperes of current, one milliampere through the meter alone and two through the shunt.

Properly calibrated, and depending upon the value of the shunt resistance, the meter can be used in this manner to indicate

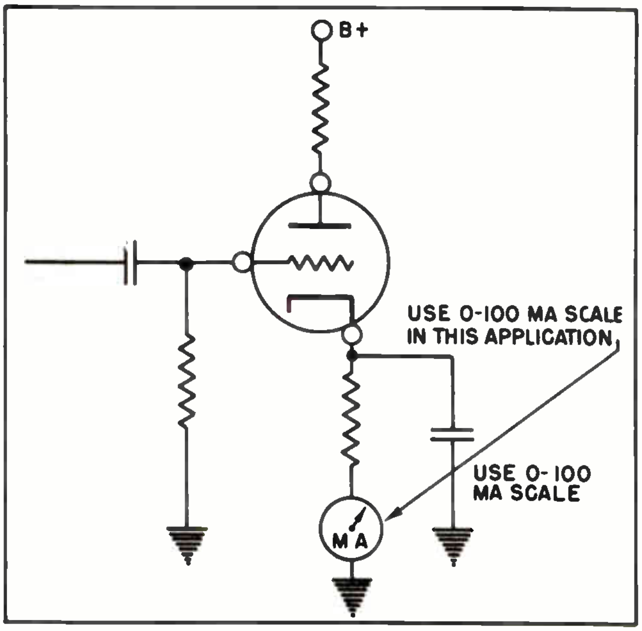

Fig. 9. How to Read the Current in a Cathode Circuit.

currents which would drive a sensitive movement far beyond maximum reading if the current were to be applied to the meter only. If current exceeding the rating of the meter is passed through the movement it will damage the movement, either by bending the pointer or burning out the meter coil.

A useful formula for determining the resistance value of the shunt required to extend the meter to any desired current range is:

$$R = \frac{R_m}{n - 1}$$

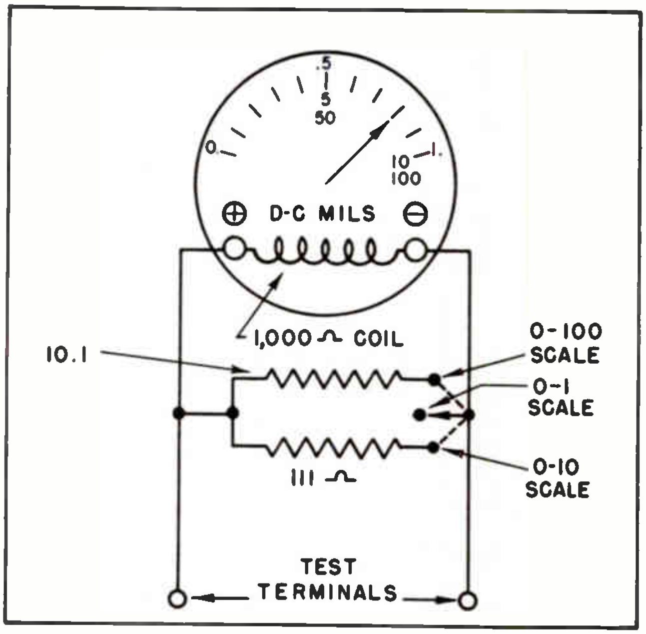

Fig. 8. Switching Arrangement for a Multi-range Current Meter.

where R is the meter shunt resistance, R_m the internal resistance of the meter, and (n) is the scale multiplication factor.

A practical problem using this formula is worth a few minutes study. Suppose we have a one mil-movement whose coil resistance is 1,000 ohms and we are required to use this meter to measure current approaching one hundred milliamperes in value. Substituting known values in the formula, and solving for R, we have

$$R = \frac{1,000}{100-1} = \frac{1,000}{99} = 10.1 \text{ ohms.}$$

This means the shunt resistance must have a resistance of 10.1 ohms to bring a one mil-movement to a range suitable for measuring current up to 100 milliamperes.

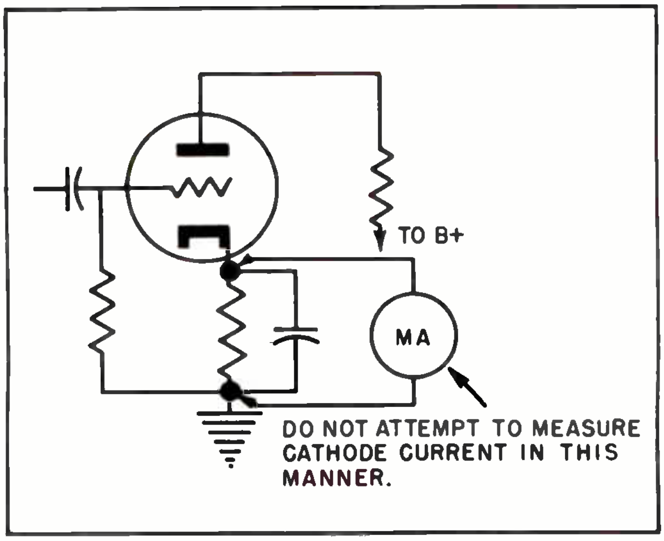

Fig.10. Wrong Way to Read Current.

Notice the term "n", in the formula. It is the range multiplication factor needed when we extend the range from one milliampere to 100 milliamperes, an increase of one hundred fold. If we were to increase the one mil-movement only to a 10 milliampere scale, the range factor would be 10. The basic sensitivity, however, does not matter in the use of this formula. The significant figure is the ratio of the desired current scale to the basic sensitivity of the meter. A meter having a basic sensitivity of 10 mils, when extending its range to 1,000 milliamperes, or one ampere, would have the same value for "n" and the same shunt resistance, as a one mil-movement when increased to read a 100 milliampere current.

Fig. 8 illustrates the switching and resistance values which make a basic one mil-movement into two additional ranges. It is wise for the radio and television repairman, when current measurements are required, to read an unknown current on the *highest* scale first, reducing the scale as convenient. This will minimize the possibility of damage to the instrument used.

Since the current meter is used to measure unknown values of current, it must be placed in a circuit in a manner which will permit it to do so. Fig. 9 illustrates the method of connecting a current meter in a typical radio receiver circuit. Notice that all the current which flows through the cathode circuit must make itself felt on the meter, which indicates its value. If the meter were to be placed across the cathode resistor, instead of in series with it, cathode current would divide in accordance with the conductance of each of the two paths. This would not only seriously alter the bias of this stage, but also would fail to indicate the value of the current through the cathode resistor. This wrong method is illustrated in Fig. 10.

Fig. 11 shows another wrong method of using the current meter. The comparatively low resistance of the meter across the plate supply circuit of a radio receiver would short this voltage to ground and would probably result in serious damage to the meter movement. Besides, as discussed in other lessons, connecting a current meter in this manner could destroy the rectifier

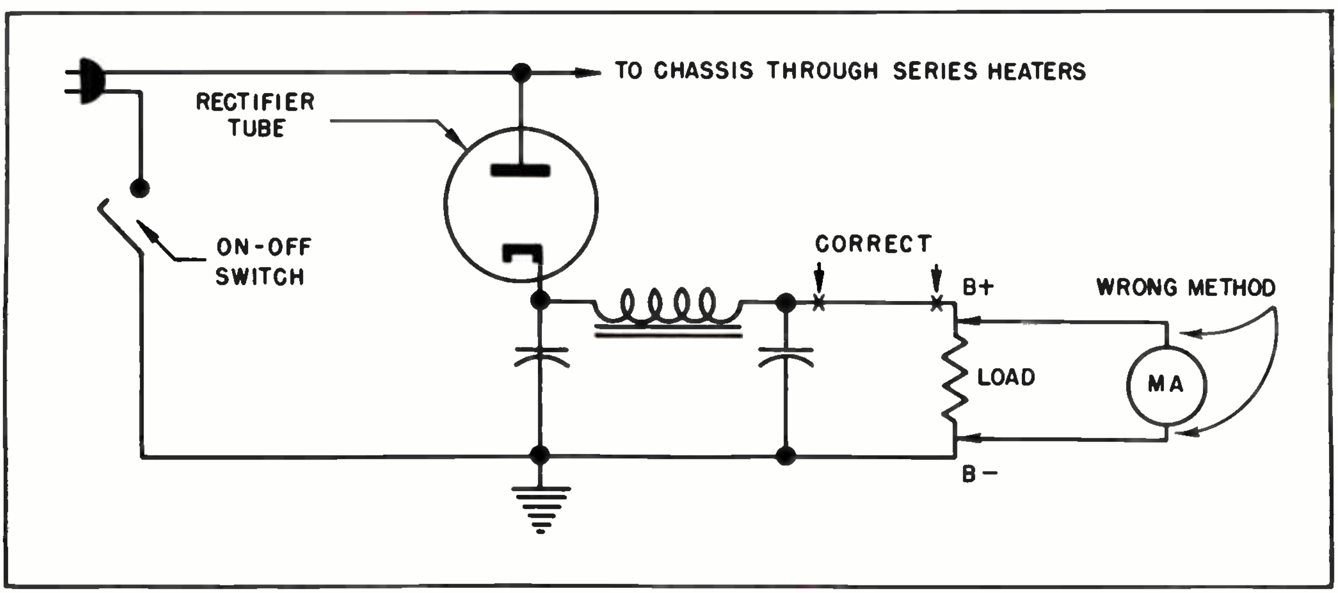

Fig.11. Wrong Way to Use Current Meter.

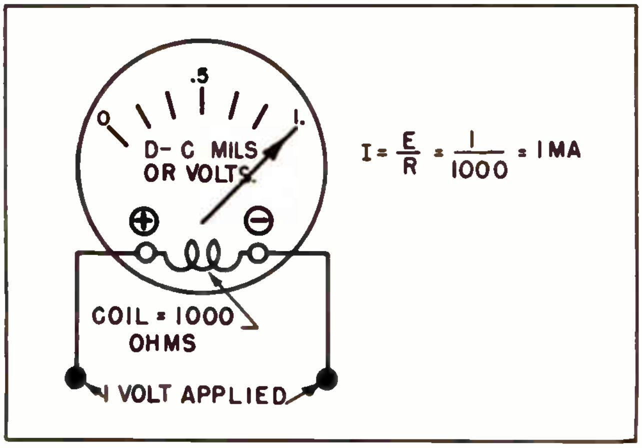

Fig.12. Using a Current Meter to Read Voltage.

tube of an AC-DC receiver. Keep in mind that a current meter should always be placed in series with the circuit whose current is to be measured.

Section 6. THE VOLTMETER

Converting the d'Arsonval meter movement to read various voltage scales is a comparatively easy matter when one understands the principles upon which this type of movement operates. Fig. 12 shows the manner in which a one mil meter may be used as 0-1 voltmeter. As described earlier in this lesson, the resistance of this meter would be 1,000 ohms, and its full-scale current would be one milliampere. And by the simple application of Ohm's Law it is obvious that one volt will drive the pointer to full-scale, or a reading of one milliampere.

If we mark this full-scale reading as one *volt* instead of (or in addition to) one *milliampere*, any fraction of a volt when applied to this meter will be indicated as a fraction of full-scale voltage on the meter. These fractional voltages, such as 1/2, 1/4, etc., can also be proportionally spaced on the meter dial. In practice, decimal representations are used, as .2, .4, .6, .8, and 1. Or, as in many instruments, the decimal fraction is indicated without the decimal point, which is understood as being present. (See Fig. 13.)

In radio and television repair work, such a low full-scale reading as one volt is seldom used. Ordinary voltages in radio receivers run from one to several hundred D-C volts, with A-C voltages running around 5-1,000 volts. It is therefore necessary to extend the range of a 0-1 voltmeter to read voltages, on successively higher scales, up to and including the highest voltage present in radio and television receivers. For this purpose, the voltmeter *multiplier* resistance is used, as illustrated in Fig. 14. This diagram shows how a 0-1 voltmeter, using a basic one mil-movement as a 1,000 ohms volt instrument, can be extended to read full-scale at ten volts. This, of course, makes it a 0-10 voltmeter. The basis underlying the value of the multiplier resistance is that if we desire the pointer to be deflected to full-scale only when ten volts are applied, we must limit the coil current to one milliampere (its mil-sensitivity) under a pressure of ten volts. Here again Ohm's Law comes to our help.

$$R_t = \frac{E}{I} = \frac{10}{.001} = 10{,}000 \text{ ohms.}$$

R_t, however, is the total resistance of the circuit, represented by the meter resistance in series with the multiplier. These combined resistances will limit the meter coil current to one milliampere when driven by ten volts. In order to find the value of the multiplier, we simply subtract the known meter resistance from the total resistance. In our example, the meter resistance is taken to be 1,000 ohms, and

$$10{,}000 - 1{,}000 = 9{,}000 \text{ ohms,}$$

which is the value of the multiplier resistance needed to extend a 0-1 volt scale to a 0-10 volt scale with a basic sensitivity of 1,000 ohms/volt.

In like manner, using the same meter movement, and applying the same principles, multipliers for other voltage scales can be computed, such as 0-100, 0-300, and 0-500 volts.

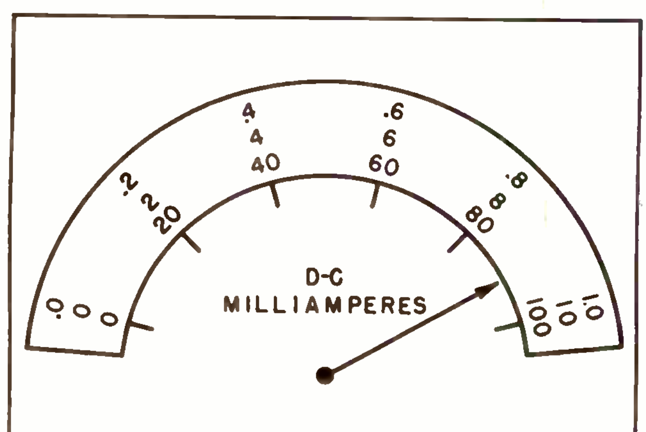

Fig.13. Scale on a Multirange Meter.

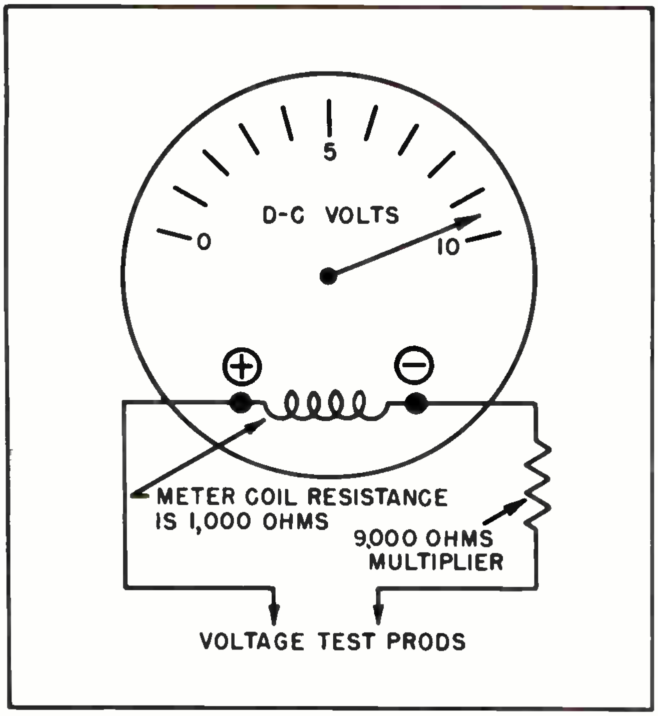

Fig. 14. A Series Resistor is Used as a Voltage Multiplier.

A simple and useful formula for finding the values of voltmeter multipliers to be used in series, with a milliammeter, is given for reference:

$$R = \frac{1,000\ E}{I} - R_m$$

where R is the series resistance, R_m the resistance of the meter, E is the desired full-scale voltage, and I the full-scale reading of the meter in milliamperes.

If it is required to extend the range of a voltmeter from one range to another range, the following will be of assistance:

$$R = R_m\ (n - 1),$$

where R is the value of the multiplier in ohms, R_m is the resistance of the voltmeter plus its low scale multiplier, and (n) is the scale increase factor.

Let us illustrate the application of the above formula by solving a sample problem. Suppose we have a 0-10 volt instrument which we desire to extend to read 0-100 volts. Substituting known values and solving for R,

$$R = R_m\ (n - 1) = (1,000 + 9,000)\ (10 - 1)$$

$$R = 10,000 \times 9 = 90,000 \text{ ohms}$$

This value, 90,000 ohms, when placed in series with both the meter and the previous multiplier will now limit the current through the meter coil to one milliampere when 100 volts are applied. This, of course, makes this instrument a 0-100 volt meter.

As illustrated at *A* in Fig. 15, scales commonly found on radio and television voltmeters include ranges of 0-5, 0-50, 0-100 and 0-500 volts. Most models have sensitivities which range between 1000 ohms-per-volt up to 20,000 ohms per volt.

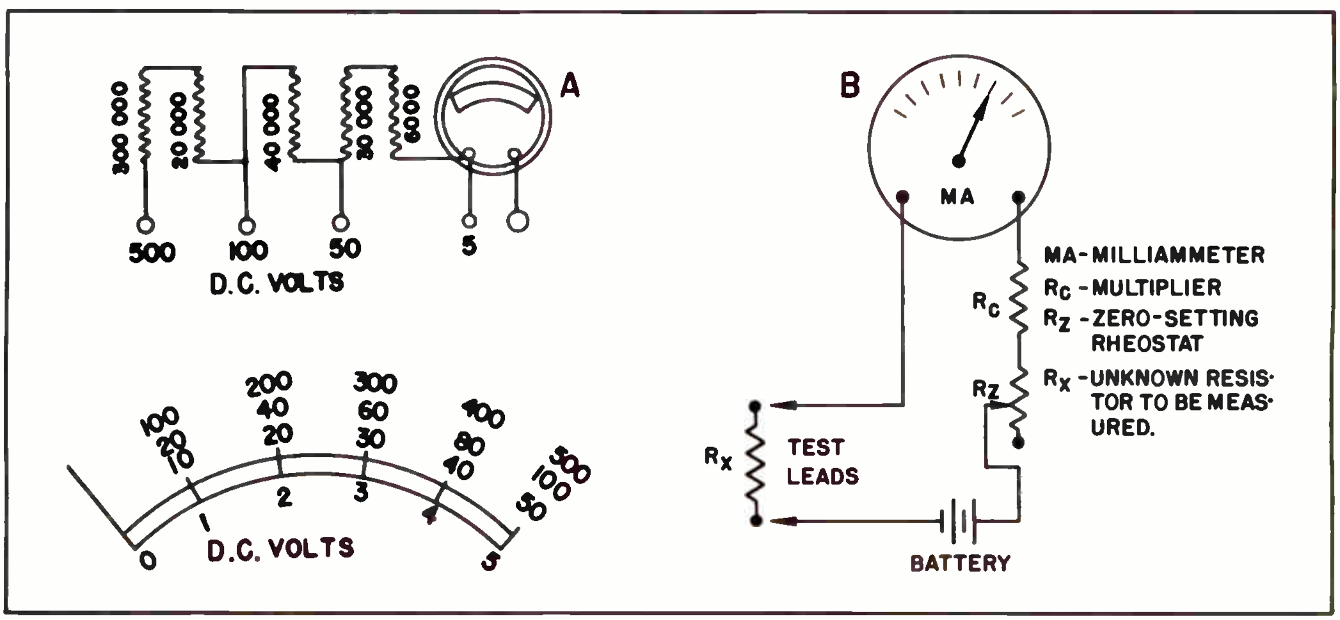

Fig. 15. A Multi-range Meter Scale and the Multiplying Resistors.

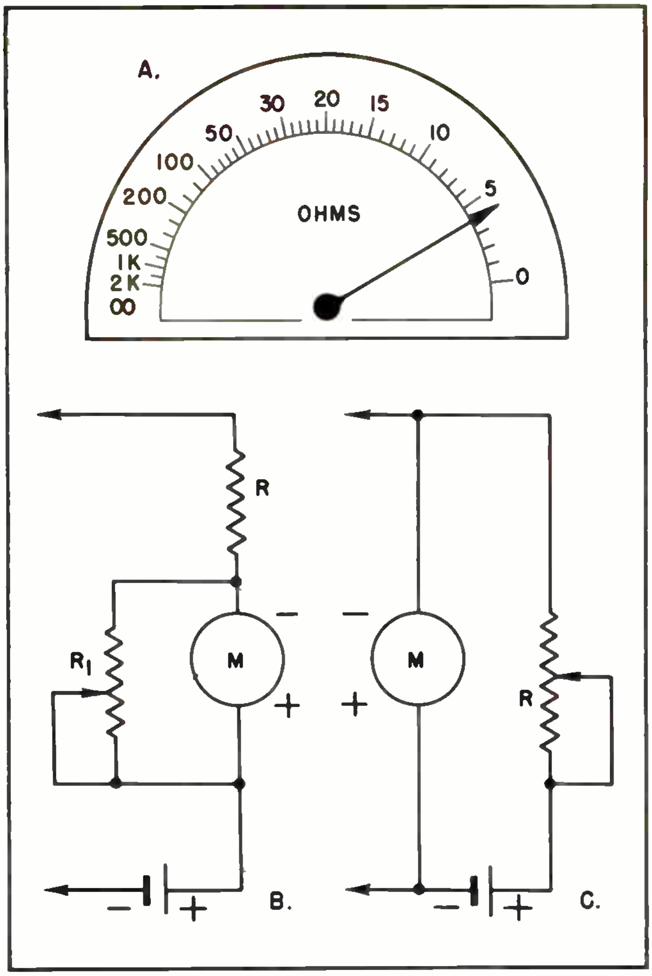

Fig. 16. Meter Scale Calibrated for Reading Ohms.

At B in Fig. 15 is shown the simplified circuit of an Ohmmeter.

Section 7. THE OHMMETER

Previous discussion has indicated that the milliammeter can be converted to a voltmeter by the proper use of multiplier resistances placed in series with the meter movement. This arrangement can be further extended to read an unknown series resistance when the applied voltage is held constant and the meter scale is calibrated in ohms.

With the test prods shorted together before testing the resistor the amount of current flowing in the meter coil will read approximately full-scale, depending upon the age and condition of the self-contained battery. It is highly important that the meter be "zero-ed", before a reading is made, by holding the test prods together and adjusting the compensator until the meter pointer reads exactly at full-scale. This control, on most ohmmeters, is marked "zero-adjust", or "zero ohms", and serves to precisely calibrate the meter for the condition of the battery at the time it is being used.

The principle underlying the operation of the ohmmeter is that if we know the applied voltage and the sensitivity of the instrument, any current reading obtained will depend upon the value of the unknown resistance placed into the circuit. This current reading can be converted to ohms of resistance required to limit the current to the measured value. Marking ohms on the meter scale can now be done accurately, with zero ohms at the extreme right of the scale (full-scale) and infinite ohms at the extreme left. (See A in Fig. 16.) A method of adjusting the meter deflection is shown at B in Fig. 16. Another method is shown at C. It is to be understood that any ohmmeter should be used only when the power is turned off in the equipment under test.

Fig. 17. A Multimeter Showing Ohms Scales and Zero Adjustments. (Courtesy Simpson Electric Co.)

This is due to the fact that radio receivers contain voltages far in excess of that required to operate the ohmmeter, and serious damage can be done to an ohmmeter by the application of even moderately high voltages to its sensitive movement.

Multirange meters, an example of which is shown in Fig. 17, contain all the requirements for all of their scales, with switching provisions to select any one of them at the will of the operator. Note the various "Ohms" scales on the lower right side of panel. Experience has shown that in learning how to use the ohmmeter, the student will find it extremely helpful to first estimate the value of the measurement expected in a given case, and then to set the proper scale on his meter and apply his test prods to the circuit.

Special precautions in the successful use of the ohmmeter are well worth learning:

1. Keep ohmmeter test prods away from a "live" circuit. Turn the power off in the equipment under test.

2. Make a precise adjustment of the "zero-ohms" control before reading an unknown resistance.

3. On a high ohmmeter scale, do not touch the metal parts of the test prods. You may be reading the ohmic resistance of your body instead of the component you want to measure.

4. Make sure, from the circuit you are measuring, that you are measuring the resistance of the component under suspicion, and not of another resistance in parallel with it. When in doubt, disconnect one end of the suspected part and thus be sure of your results.

Section 8. THE D'ARSONVAL MOVEMENT APPLIED TO A-C CIRCUITS

Reference was made earlier in this lesson to the use of the d'Arsonval, or moving-coil, movement in measuring the values of A-C current and voltages. Attention was called to the fact that a small meter rectifier was inserted into the coil circuit, enabling the meter to respond to the average value of currents when rectified from A-C to D-C, and permitting calibration of the meter dial in terms of effective A-C values. Fig. 18 shows a typical circuit of an instrument utilizing this principle and providing for current and voltage readings, on several scales, in A-C circuits.

The bridge-type rectifier, generally made of copper-oxide, permits current to flow in only one direction through the meter coil. This rectifier is made with extremely small

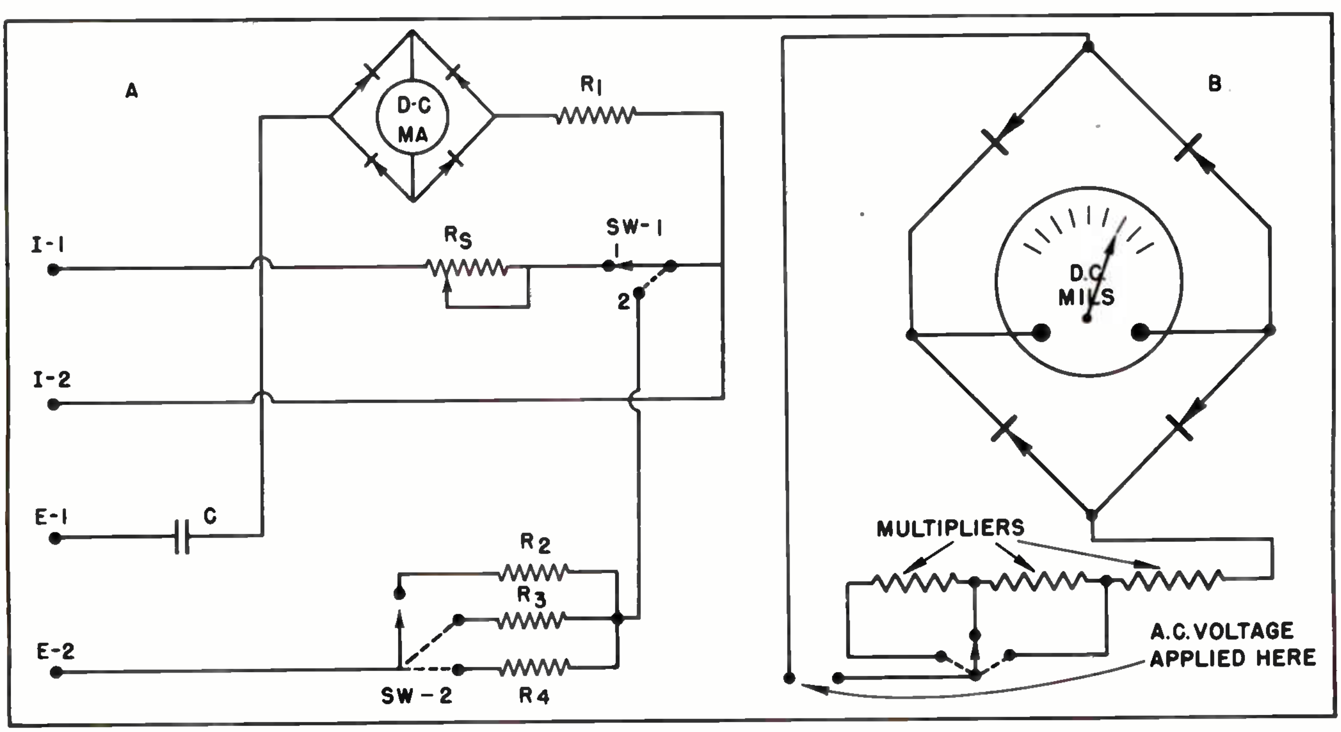

Fig. 18. Converting a D-C Current Meter Into a Multirange A-C Voltmeter.

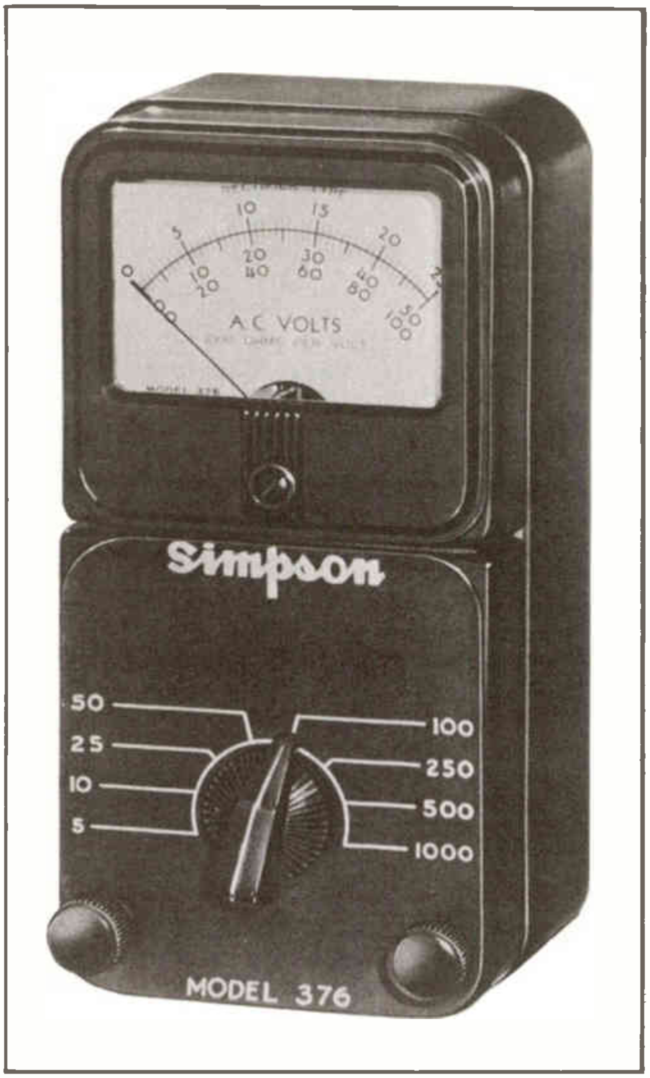

Fig.19. Multirange A-C Voltmeter. (Courtesy Simpson Electric Co.)

physical dimensions and its small size permits it to be included inside the case of even a small pocket-size multimeter. As can be seen from the diagram in Fig. 18, voltage multipliers are identical with those of a pure D-C d'Arsonval meter, and the method of computing their values is the same.

Fig. 19 is a multirange A-C voltmeter. The various ranges are selected by a range switch on the face of the meter.

Section 9. **THE MULTIMETER**

If we wish to have an all-purpose instrument, one which will measure current, voltage, and resistance, such as those found in radio circuits, we can combine all the functions of the d'Arsonval movement described into one compact unit. We can add a rectifier to extend its application to A-C currents and voltages, and the result will be as desired. At the heart of this versatile instrument will be a simple d'Arsonval meter movement whose pointer is calibrated in D-C voltages and currents, A-C voltages and currents, and ohms on both a low and a high scale. The circuit for this arrangement is shown in Fig. 20.

In Fig. 20 we can tabulate the switch positions and the functions as shown on top of following page.

Care should be taken in the use of a multimeter to avoid damage to its parts. To minimize this danger, it is wise to keep this instrument on a high voltage scale when not in use, and to return it to this position after using it for any other function. This prevents the possibility of accidentally applying the test prods to a circuit which may damage the instrument before the proper function is selected. The high value of the multiplier on a high voltage scale will, in most cases, limit the current through the meter to a safe value regardless of where the test prods may be placed.

Section 10. **THE VACUUM TUBE VOLTMETER**

While the conventional type of meter is satisfactory and suitable for most radio circuits, the vacuum tube voltmeter is superior in two respects: It does not *load* the circuit tested to an appreciable extent, which makes it more accurate; and it does not discriminate against high frequencies. The first advantage is accomplished by the extremely high input impedance it offers and the second by the non-inductive nature of its input circuit.

Where the conventional type of meter seldom exceeds a sensitivity of 25,000 ohms/volt, the VTVM (vacuum tube voltmeter) may have a sensitivity ten or more times as high on certain voltage ranges. This property renders it especially accurate and useful for measuring grid bias voltages, and detector and AVC voltages commonly checked in radio receiver repair work.

Its ability to measure voltages of almost any frequency permits the VTVM to ascertain the value of fast changing signal voltages, such as those encountered in radio frequency stages of a receiver. Since the frequencies encountered in television, FM, and radar are as a rule much higher than in communications radio, the VTVM is especially useful when working in these fields.

SELECTOR POSITION	TERMINALS USED	FUNCTION
1.	Com. D-C Volts/D-C MA	Low Milliamperes
2.	Com. D-C Volts/D-C MA	120 MA Scale Current
3.	Com. D-C Volts/D-C MA	300 MA Scale Current
4.	Com. D-C Volts/D-C MA	600 MA Scale Current
5.	Com. D-C Volts/D-C MA	Low D-C Volts
6.	Com. D-C Volts/D-C MA	High D-C Volts
7.	Com. - Ohms	Low Ohms
8.	Com. - Ohms	High Ohms
9.	Com. A-C Volts	Low A-C Volts
10.	Com. A-C Volts	High A-C Volts

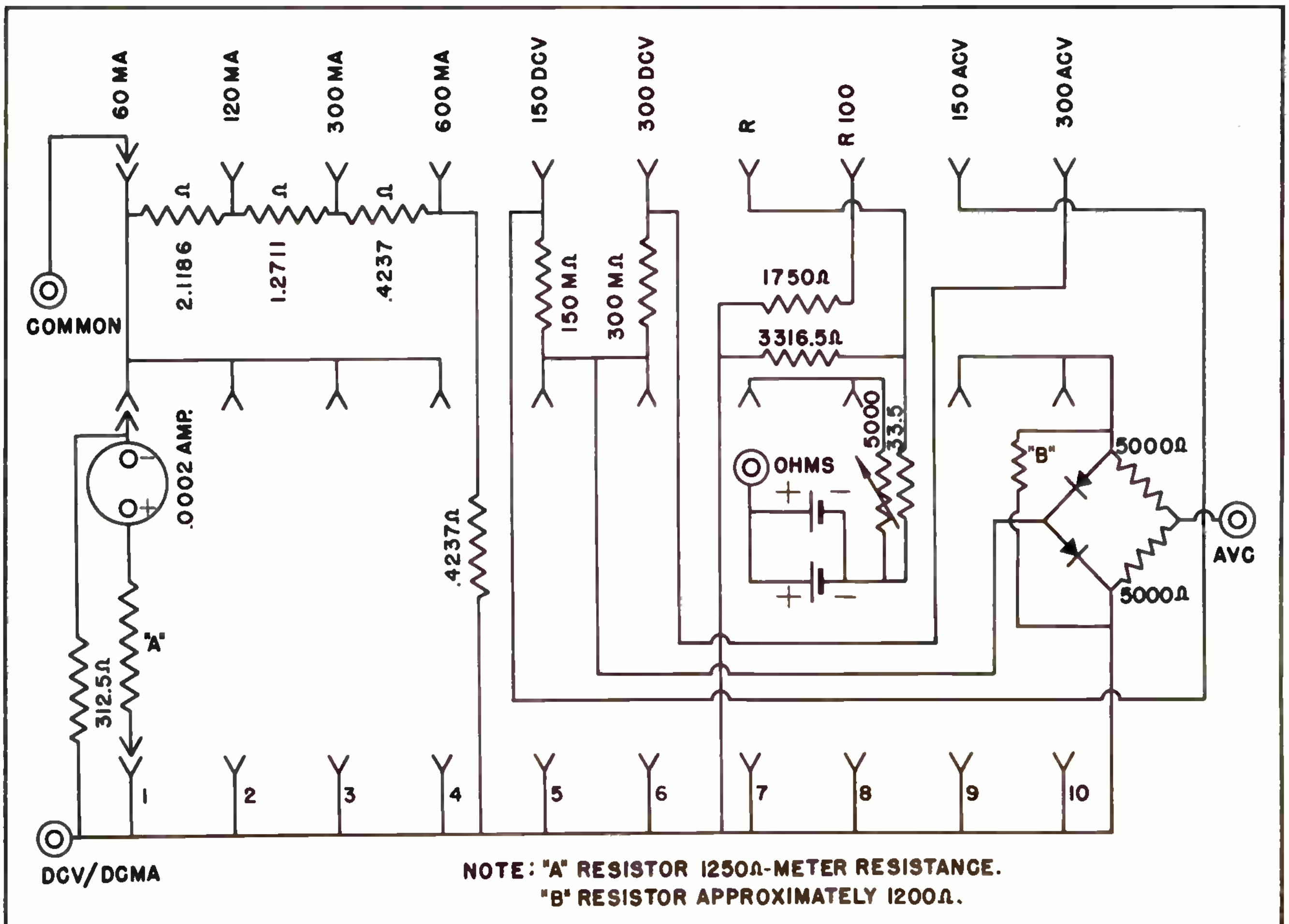

Fig.20. Schematic Diagram of a Multimeter Using D-C Current Meter as the Basic Indicating Device.

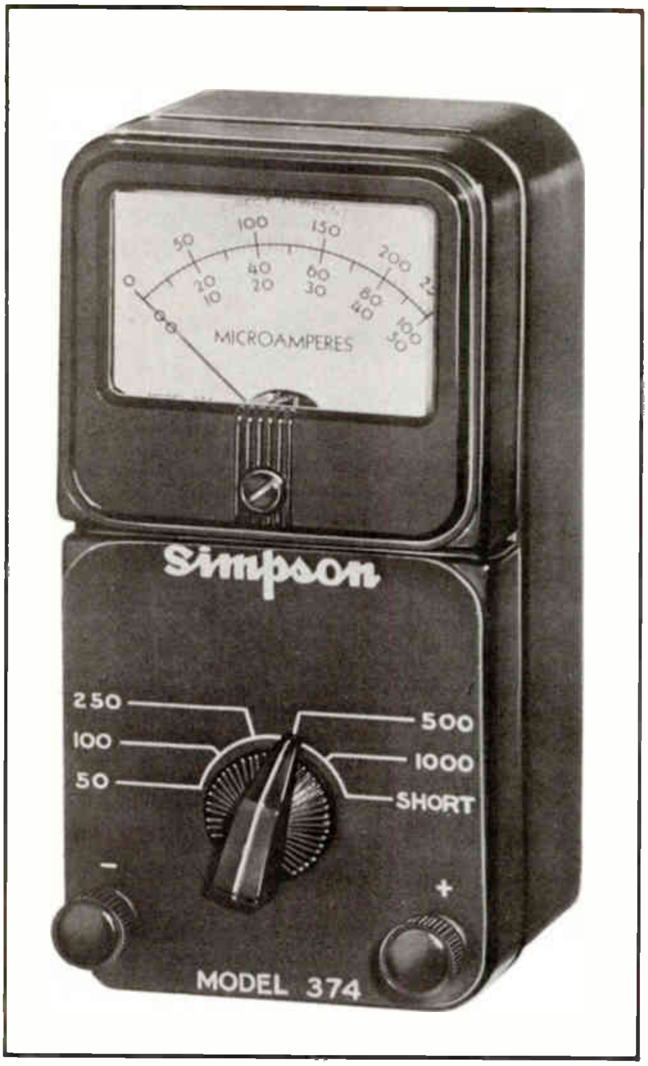

Fig.21. Multirange Microammeter. (Courtesy Simpson Electric Co.)

Fig. 22 shows a typical VTVM schematic circuit, consisting of a diode vacuum tube followed by a D-C amplifier. The indicating meter, placed in the cathode circuit of the D-C amplifier, may be an ordinary current meter such as is used in conventional type instruments, but whose sensitivity is enhanced by the nature of the circuits surrounding the d'Arsonval movement.

Reference to Fig. 22 will show that if an alternating voltage is applied to the input terminals the diode rectifier will cause pulsating current through both the diode tube and R_1. The grid of the triode, however, feels only the D-C component in the form of a filtered voltage drop accomplished by the action of C_2 and R_2.

The plate current change in the triode is indicated on the scale of the meter in its cathode circuit, and the variable resistor R_3 provides inverse feedback designed to keep the instrument calibration independent of possible tube differences. To permit expanded voltage ranges, R_3 is made adjustable. R_4 and R_5 provide proper bias for the triode amplifier, while R_6, also adjustable, is used to balance out the zero-signal component of the triode plate current.

D-C voltages can be measured on this instrument in essentially the same manner, except that the condenser at the upper input lead is short-circuited by the selector switch in the D-C position. This prevents the blocking effect of this condenser to D-C and permits the input voltage to be fed directly through R_2 to the triode grid.

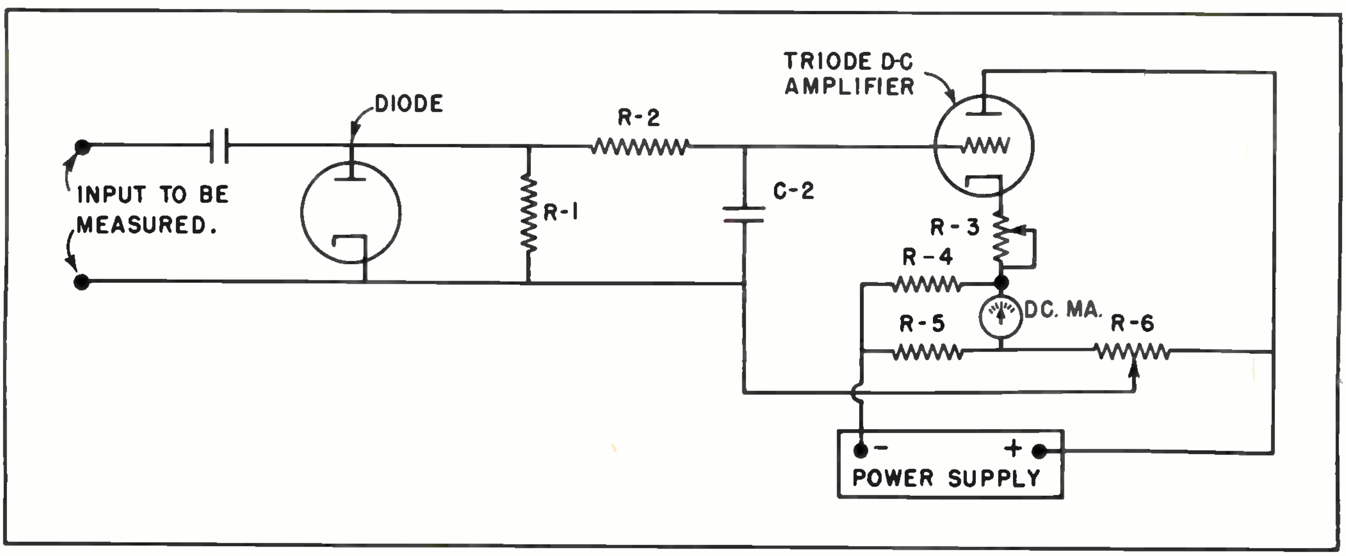

Fig.22. Circuit Diagram of a 2-tube VTVM.

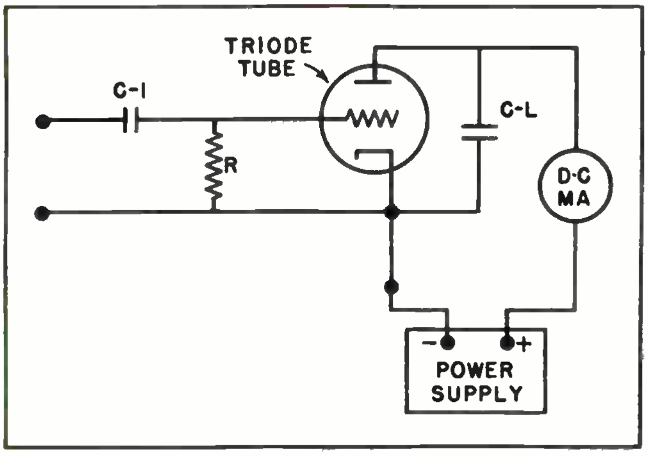

Fig.23. Circuit Diagram of Single Tube VTVM.

Another type of VTVM is schematically represented in Fig. 23. This type is known as a "grid rectifier" model and it dispenses with the input diode circuit shown in Fig. 22.

In Fig. 23 "no-voltage" applied to the grid of this circuit will cause no-plate-current-flow, due to the cut-off characteristic of the tube. When A-C is applied to the triode grid, plate current, proportional to the peak of the input amplitude, will flow through the tube and through the meter in its plate circuit. The same will hold true for D-C voltages when applied to the input terminals. By proper calibration of the meter dial, this arrangement can be a sensitive, high impedance device for accurately measuring both A-C and D-C voltages on several scales.

Mastery of the VTVM is an accomplishment in itself. The many types and models which are currently on the market make it impossible to outline a procedure which will acquaint you with all types. Each manufacturer, however, supplies a wealth of information regarding each of his models. These instructions should be followed to the letter, and practiced until you become familiar with the details of operation of the unit with which you are working.

Section 11. THE DYNAMOMETER A-C METER

In addition to converting a d'Arsonval type D-C meter to A-C operation by the use of a rectifier, other types of A-C measuring instruments are used. Two important examples are the dynamometer and the hot-wire types.

The Dynamometer, whose movement is shown in Fig. 24, depends upon the magnetic force exerted between two coils, both of which carry current. They are usually placed at right angles to each other, one of them being rigidly fastened to the frame of the instrument while the other is suspended or supported, and its position controlled by a spring. When current flows through both coils, the movable one tends to turn into such a position that its magnetic field is parallel to that produced by the current flowing in the stationary coil. The motion which results is opposed by a spring whose torsion tends to return the movable coil to its original position. The movable coil carries with it a pointer which moves over a scale in proportion to the amount of current flowing in the coils, which are connected in series.

When the instrument is used as an ammeter, the two coils consist of a few turns of large size wire, depending, of course, on the capacity of the instrument. Frequently, the stationary part is composed of two coils having a different number of turns. A full-scale deflection is caused by a smaller current when the stationary coil having the larger number of turns is used. In some cases, the stationary coils are arranged so that they can be connected in any manner desired to provide different ranges of values.

When used as a voltmeter, the dynamometer coils consist of a large number of turns of

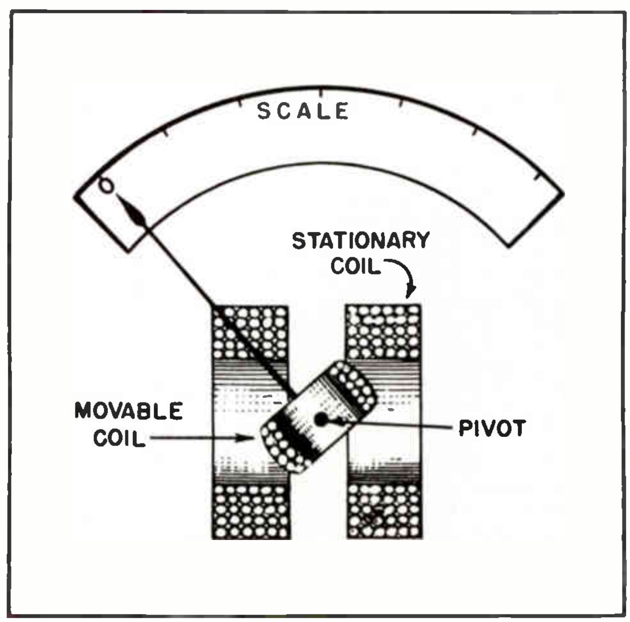

Fig.24. Dynamometer Movement.

thin wire. Often, a non-inductive resistance is placed in series with the instrument to multiply its range as a voltmeter. The inductance of a dynamometer type voltmeter should be as low as possible in order to minimize errors due to frequency differences in the applied voltage.

Section 12. **THE HOT-WIRE METER**

The hot-wire meter, unlike the dynamometer and the d'Arsonval movement, is independent of the frequency of the A-C measured. Fig. 25 shows the basic construction of this type of A-C measuring instrument. In Fig. 25 (h) represents a small wire which rapidly increases in temperature with an increase in current through it.

W_1 and W_2 are the instrument connections to this hot-wire. Both ends of the wire are permanently fixed, though insulated from the case. The middle of the wire is fastened through the insulating link (L) to the needle which is pivoted at (P). As in other indicating instruments, the needle has a spring attached to it. Unlike other instruments, however, when the temperature of the wire is above normal this spring tends to make it stand at full-scale reading. However, when the wire is at normal temperature, it will pull the needle to the zero position.

This action results from the fact that as current flows through the wire the temperature of the wire increases. The wire expands as a result of the increased temperature and the needle is permitted to indicate a reading to the right of zero. The scale is so calibrated as to indicate the effective value

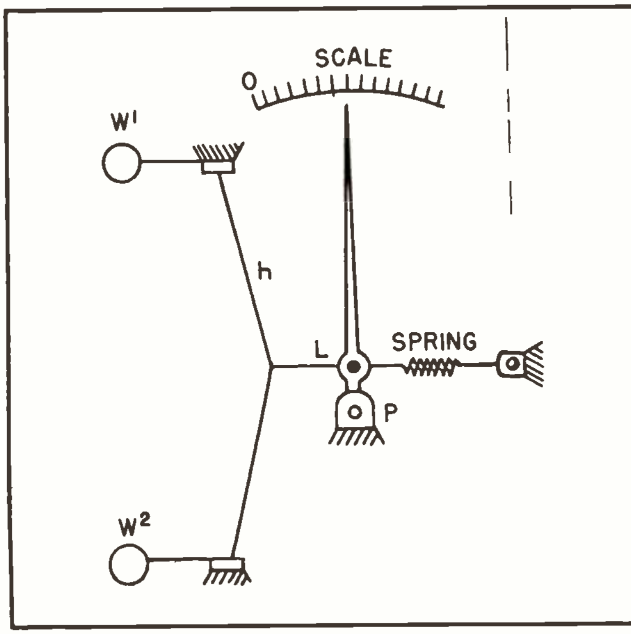

Fig.25. Theory of the Operation of a Hot-Wire A-C Meter.

of the current flowing through the wire. To take care of changes in atmospheric temperatures, the wire is mounted in the case in such a manner the coefficient of expansion between the mountings compensates for changes in air temperature.

Although the hot-wire type of instrument is independent of frequency, it has other important limitations. It is sluggish in action since time is required for heating the wire, and there is danger of burning out the instrument since any appreciable overload will produce a temperature great enough to melt the wire.

NOTES FOR REFERENCE

Associated with almost all models of test equipment is a milliammeter of the d'Arsonval, or moving coil, type.

Most test equipment will have this basic movement changed from one application to another by the use of switches.

Sensitivity of conventional type meters is sufficient for most purposes, but where extra sensitivity is required, the vacuum tube voltmeter is applied. The high input impedance of the VTVM permits it to be used without loading, and therefore without altering, the circuits to be measured.

Do not place an ammeter, a milliammeter, or a microammeter across a voltage. Place it in series with the circuit whose current is to be measured.

In measuring voltages across a circuit, first adjust your meter to the proper scale. If you are not certain which scale to use, try the highest one first, and then reduce the scale as convenient.

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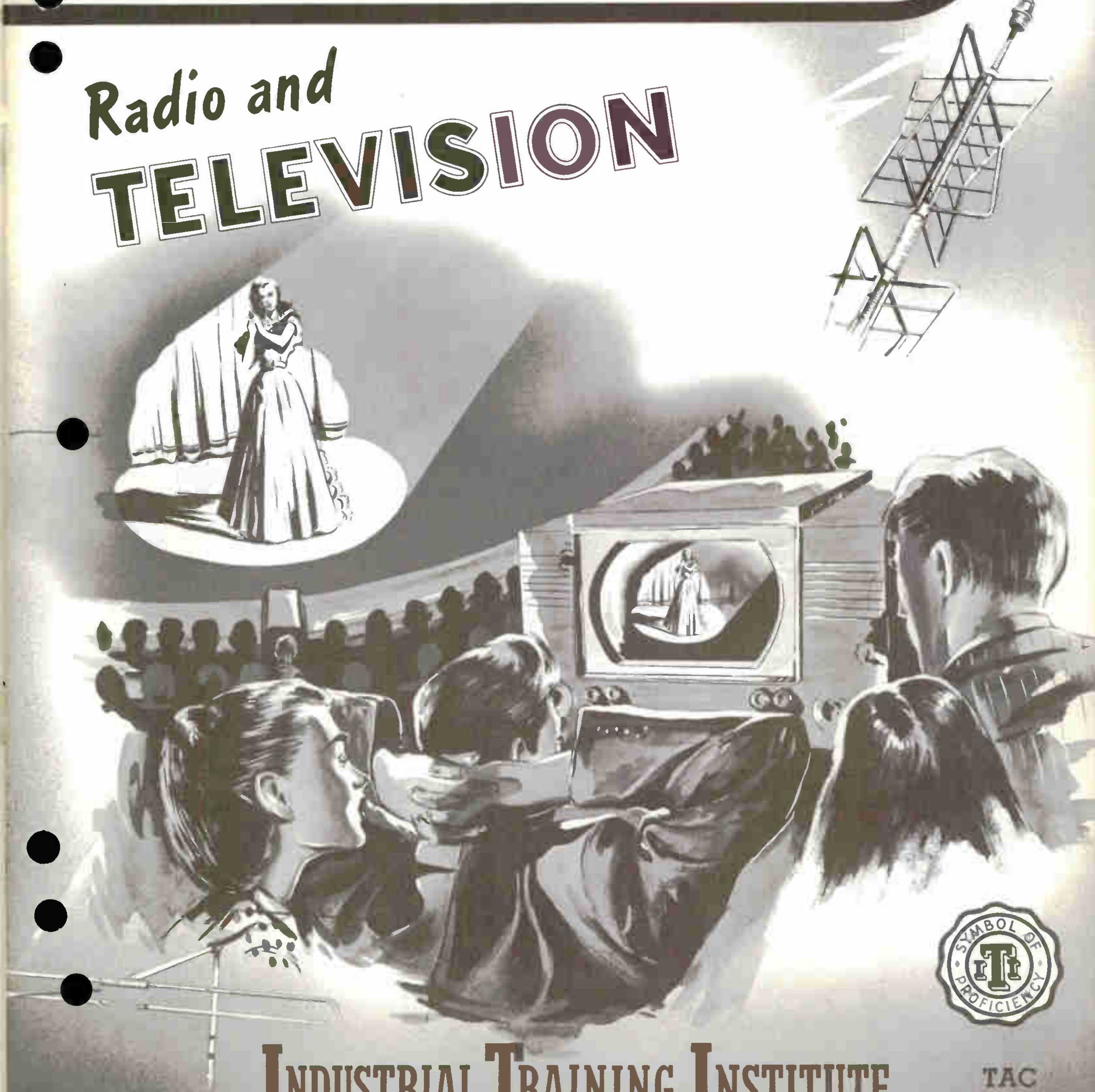

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LOUD SPEAKERS

Contents: Introduction - Types of Loudspeakers - Types of Dynamic Speakers - Low Resistance Fields - High Resistance Fields - Automobile Speaker Fields - Identifying a Loudspeaker - When to Look for Trouble in the Speaker - Specific Checks for Speaker Troubles - Open Voice Coil - Field Coil Troubles - Dragging Voice Coil - Speaker Cones - Automobile Radio Speakers - Frozen Voice Coil - Hum-Bucking Coil - Extension Speakers - Universal Matching Transformer - Inverse Feedback from Voice Coil - Procedure for Re-placing or Re-centering a Speaker Cone - Notes for Reference.

Section 1. INTRODUCTION

The purpose of the loudspeaker in any form of communication equipment is to convert electrical impulses into sound energy that can be heard by the human ear. In FM and AM receivers, in television receivers, in public address systems, and in inter-communication equipment, the loudspeaker is the final component, toward which all music and speech signals are directed.

At the beginning of an electrical path of communication, sound energy is converted into electrical impulses by a microphone. At the end of the electrical path, these electrical impulses are re-converted back into sound energy by a loudspeaker.

It is worthy of note that the listener does not hear the original sound -- he hears only a faithful reproduction of it. Such faithfulness -- or fidelity -- in repro-ducing a sound whose source may be many miles away, is no accident. It is made possible by years of research and pains-taking engineering.

The result is that we can turn on our radio and television receivers today and hear reproductions of the speech of orators, voices of great singers, and the full, rich tones of a 100-piece symphony orchestra -- all of them with such fidelity that we find it hard to distinguish between the original and the reproduction.

Section 2. TYPES OF LOUDSPEAKERS

Loudspeakers may be divided into two general groups; the magnetic type, and the dynamic type. A modern dynamic type loud-speaker is shown in Fig. 2.

While extensively used in the earlier days of radio, the magnetic speaker has today become practically obsolete, and discussion

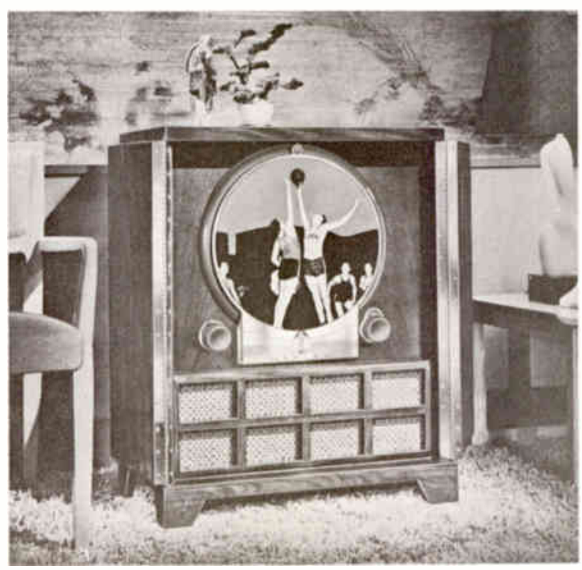

Fig.1. The Larger Television Receivers Often Use More than One Loudspeaker. (Courtesy Zenith Radio Corporation)

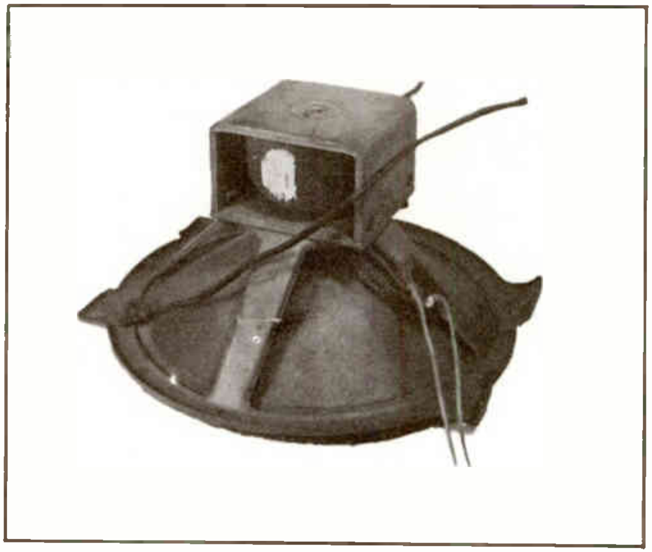

Fig. 2. Dynamic Loudspeaker.

of this type is designed to study its historical significance rather than provide a guide for trouble-shooting this almost extinct type of speaker.

Today we are chiefly concerned with the *dynamic* speaker, which is found almost universally in modern communications equipment.

A dynamic speaker is one in which a low-impedance voice coil moves in a strong, fixed magnetic field. Fig. 3 shows the component parts and structure of a dynamic speaker.

While dynamic speakers may, in accordance with their special applications, take a variety of forms and sizes, as pictured in Fig. 4, they all contain low-impedance voice-coils moving in strong, fixed magnetic fields. This entitles them to membership in the *dynamic* family. The nature of these stationary fields, however, provide us with a convenient way of distinguishing between one family member and another.

Section 3. TYPES OF DYNAMIC SPEAKERS

Dynamic speakers can be grouped in the following general classifications:

1. Those containing permanent magnet ("PM") fields.

2. Those containing low resistance electromagnetic fields.

3. Those containing high resistance electromagnetic fields.

4. Those containing 6-volt electromagnetic fields.

Let it be stressed that all the above speakers are of the *dynamic* type, the classification being only on the basis of how the magnetic field is produced.

Fig. 5 is a photograph of a PM dynamic speaker, which requires no electromagnetic field because a stationary field is always present surrounding the permanent magnet block. Fig. 6 illustrates the associated circuit which feeds the signal to this PM dynamic speaker. Plate current, flowing from the output tube under the control of the signal voltage on its grid, must pass through the transformer primary on its way toward B-plus.

Changes in the plate current induce secondary voltages which drive a higher current through the speaker voice coil, creating a changing magnetic field, one which changes in accordance with signal current. These changes in the voice-coil magnetic field act to push and pull the voice coil, with its paper cone, through the fixed magnetic field. The wide expanse of the cone distributes this vibration through the air surrounding the speaker and enables a listener to hear the sound energy thus produced. Since the speaker cone moves in response to changes in the signal frequency, the listener hears a reproduction of sound which originally was converted to

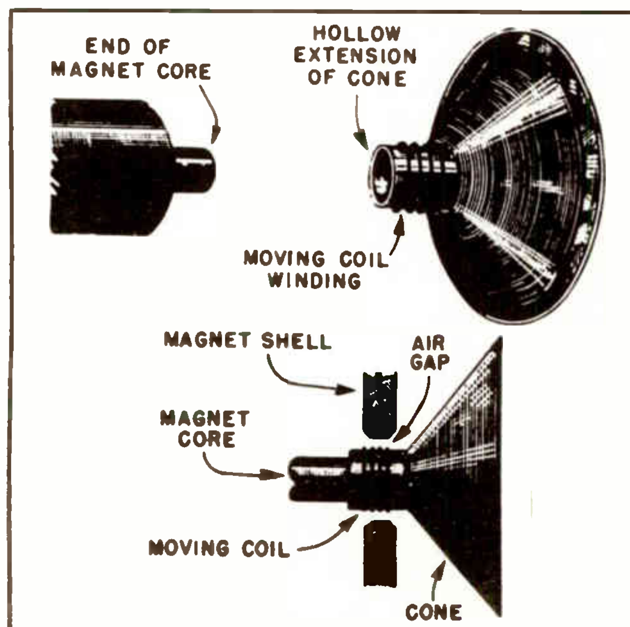

Fig. 3. The Parts which are Used in a Loudspeaker.

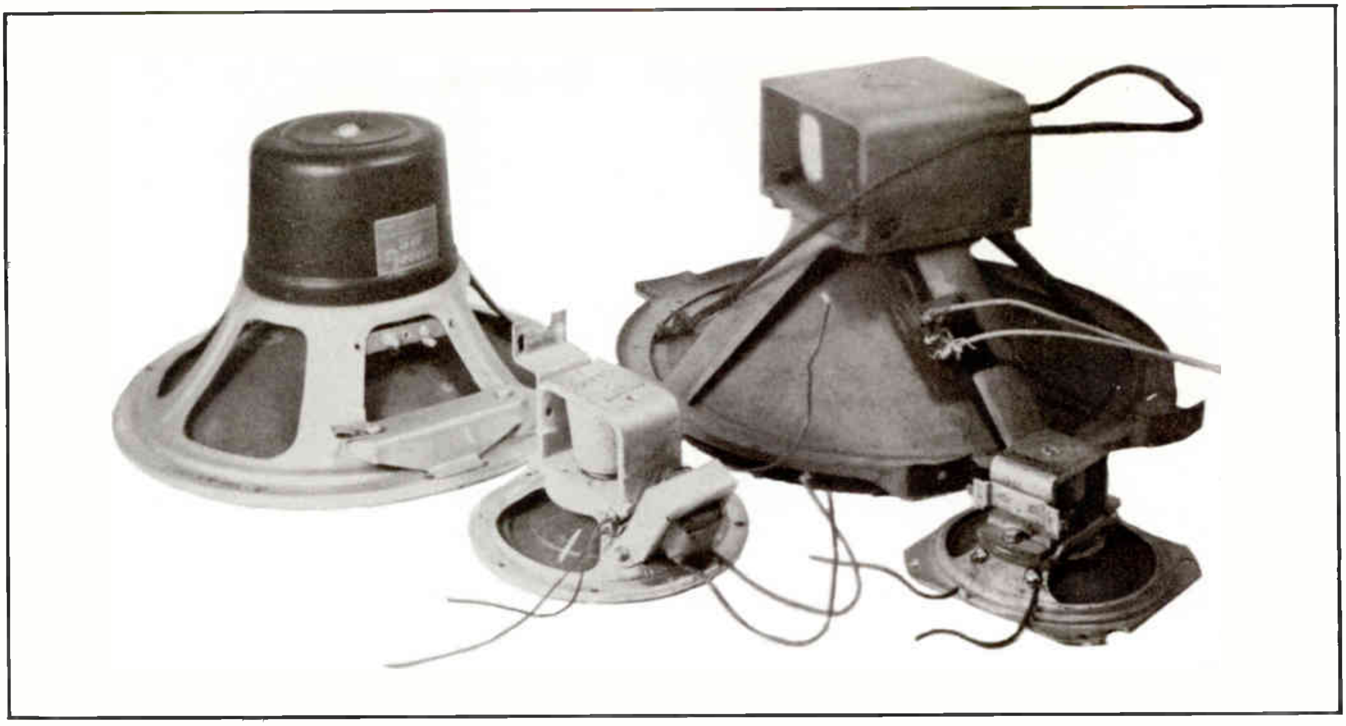

Fig.4. Several Kinds of Dynamic Loudspeakers.

electrical impulses. The physical location of the output transformer is shown in Fig. 7.

Section 4. LOW RESISTANCE FIELDS

An example of a dynamic speaker with a low resistance field is shown in Fig. 8. Notice that it has a pair leading to the voice-coil. With its associated transformer and output stage circuits, this type of speaker is shown schematically in Fig. 9. Here we do not have a permanent-magnet field, but a fixed field is created by current flowing through the winding especially designed for such purpose.

The low resistance speaker field is also known as the choke type, the reason being that magnetizing current for the speaker field is provided by the power supply filter system. (See Fig. 9.) Since the speaker requires current in D-C form for field magnetization, and since the filter system requires inductance in the form of a filter choke, the two requirements are built into a single unit by letting the field coil act as a filter choke. Economy of space, weight, and cost have made this type of dynamic speaker extremely popular in medium and large receivers. In smaller receivers the field is almost always of the PM type, and filtering is provided by a filter resistor in place of the more bulky filter choke.

Certain specifications must be met by the low-resistance speaker field however -- specifications which are determined by the requirement of both the filter choke and speaker field. It must have enough turns to create a sufficiently strong fixed magnetic field, and it must have enough inductance to oppose changes of current in the power supply load. These requirements are well met when the ohmic resistance and inductance of the winding are approximately those of the filter choke whose place it takes, and when the resulting fixed field

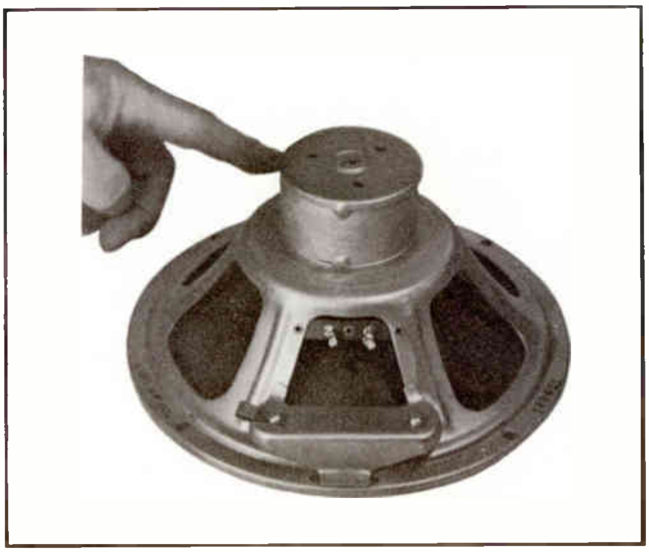

Fig.5. PM Speaker.

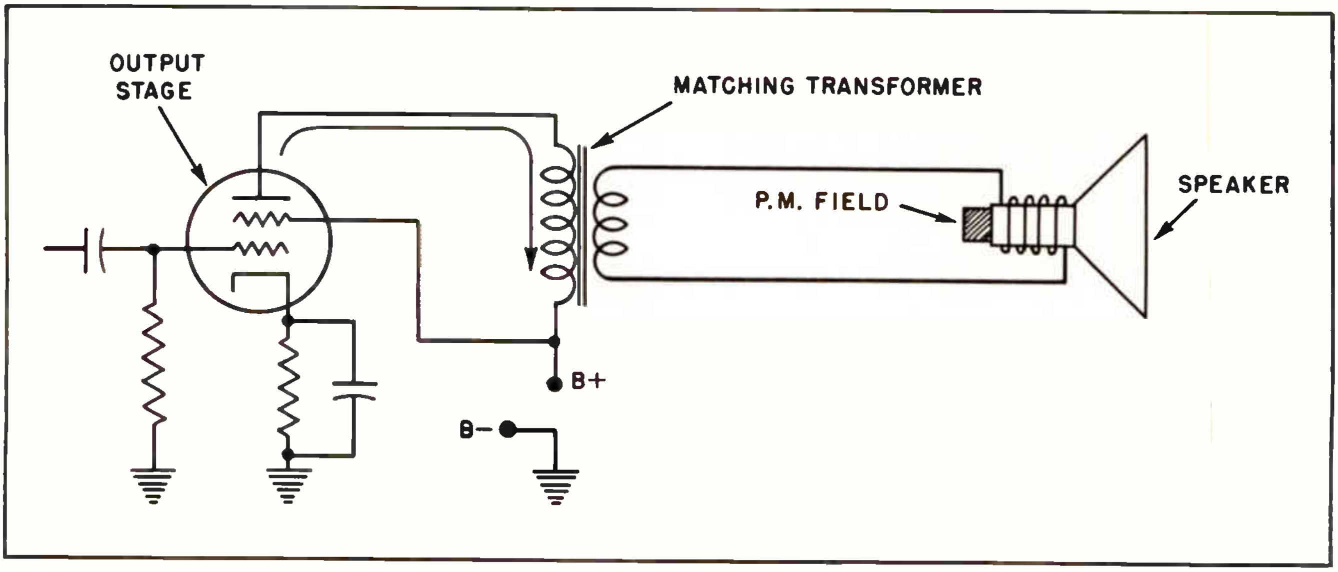

Fig.6. Circuit Connecting the Output Tube with the Speaker.

flux strength is about as intense as a PM field. In medium-size receivers the ohmic resistance of this type of field coil is between 200-800 ohms. In larger sets this resistance may be as high as 1500 ohms.

The action of the voice-coil of this type dynamic speaker is the same as in the case of the PM dynamic speaker. The stationary field windings provide the magnetic flux through which the voice-coil field may be made to move by the interaction of the two magnetic fields. As we already know, the motion of the voice-coil, and the cone to which it is attached, imparts vibrations in the form of sound to the air which carries the sound to the ears of the listener.

Section 5. **HIGH RESISTANCE FIELDS**

The high resistance field coil is an early type which is becoming less popular. However, since many receivers with this type of speaker field are still in use, it deserves a place in our discussion. Fig. 10 pictures an example of a dynamic speaker employing a high resistance field. Note the similarity between this type of speaker, with its four

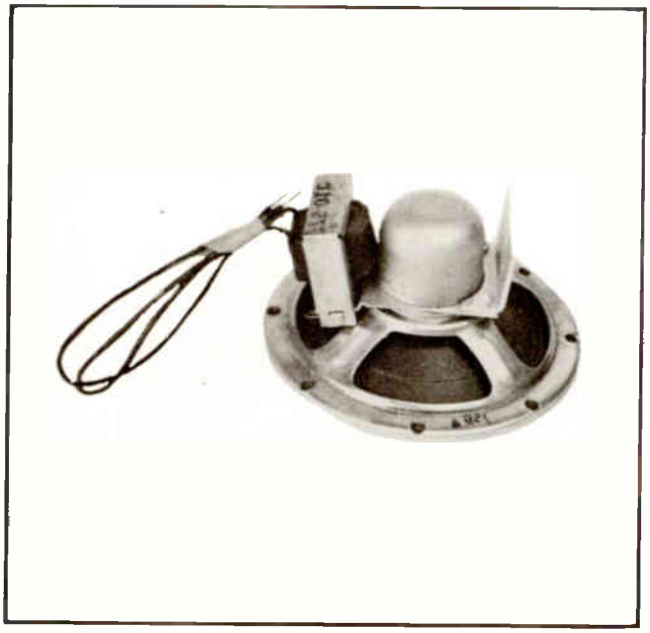

Fig.7. Output Transformer Mounted on the Speaker.

Fig.8. Low Resistance Field Speaker.

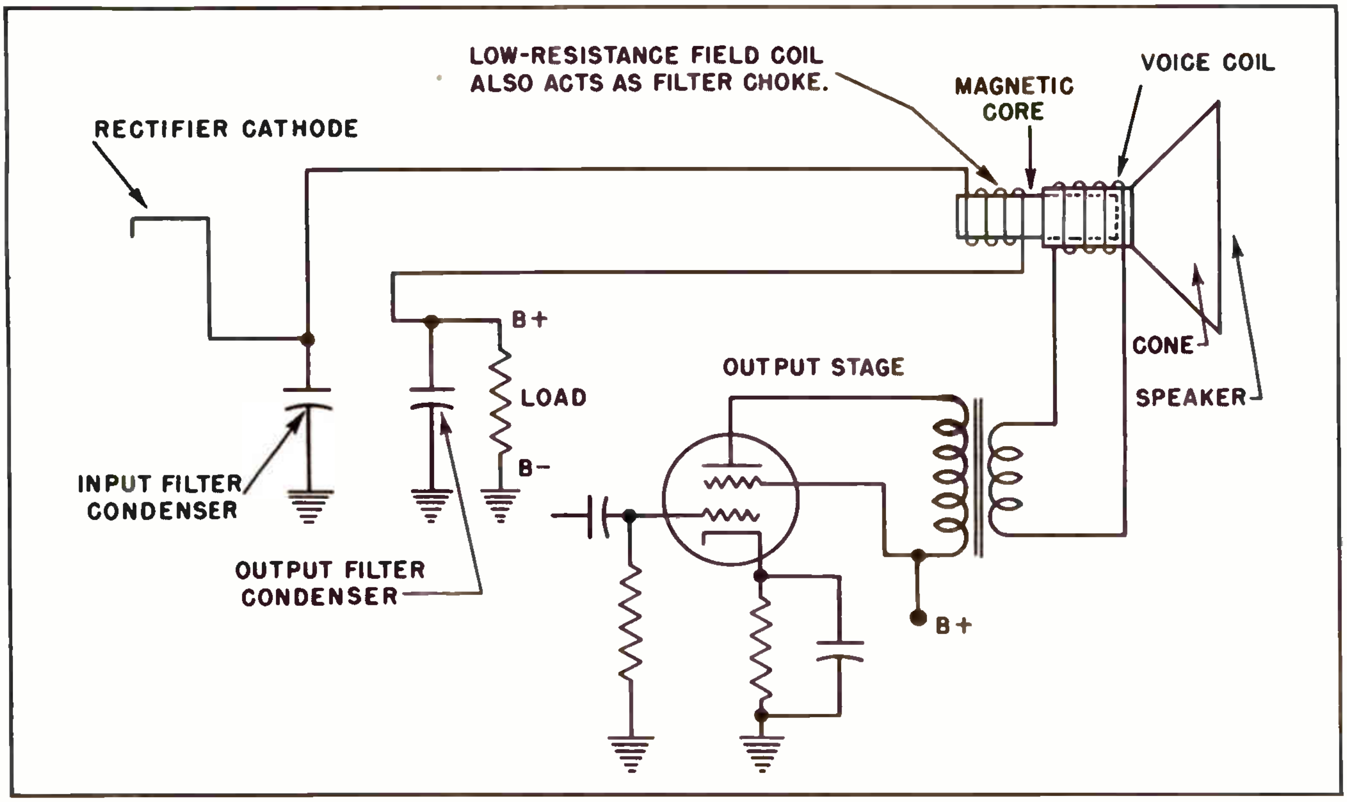

Fig.9. Schematic Diagram of a Low Resistance Field Speaker.

leads and the low resistance type, which also has four leads. Fig. 11 schematically represents the high resistance field and its associated circuit. The power supply choke is a separate unit, while here the speaker field serves the additional function of acting as the power supply bleeder. Here again certain specifications must be met; there must be enough ampere-turns to create a strong magnetic field, and the ohmic resistance of the winding must be high enough to leave the value of B-plus relatively unaffected when this type of field is connected across the "B" supply as shown in Fig. 11.

As in the case of the PM dynamic and the low resistance dynamic speakers, the action of the voice-coil field, changing at signal frequency, against the fixed field of the high resistance dynamic speaker is such as to cause vibration of the voice-coil and cone, which reproduces the signal in the form of sound.

The ohmic resistance of a high resistance dynamic speaker field winding is usually in excess of 2500 ohms. This represents the value which properly limits the voltage drop through the filter choke or resistor. If the voltage drop became too small it would tend to lower the value of the B-plus voltage to a point where the operation of the receiver would be seriously impaired.

Section 6. AUTOMOBILE SPEAKER FIELDS

The fourth member of the dynamic speaker family is generally found only in automobile

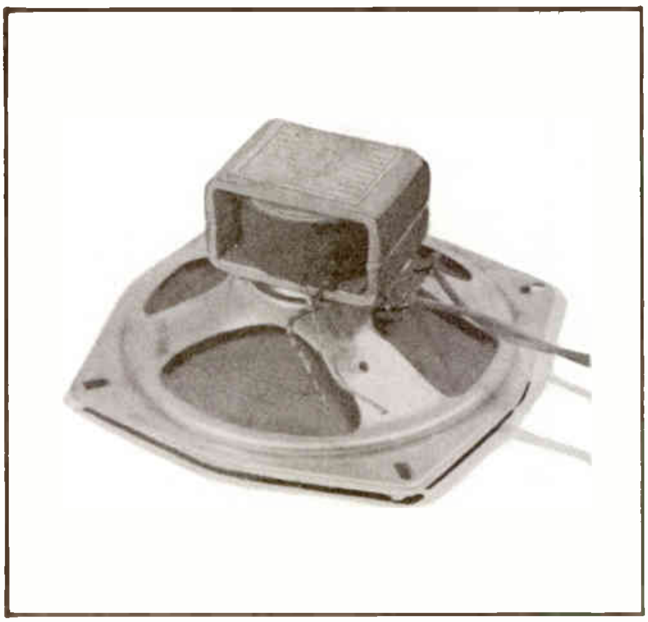

Fig.10. High Resistance Field Speaker.

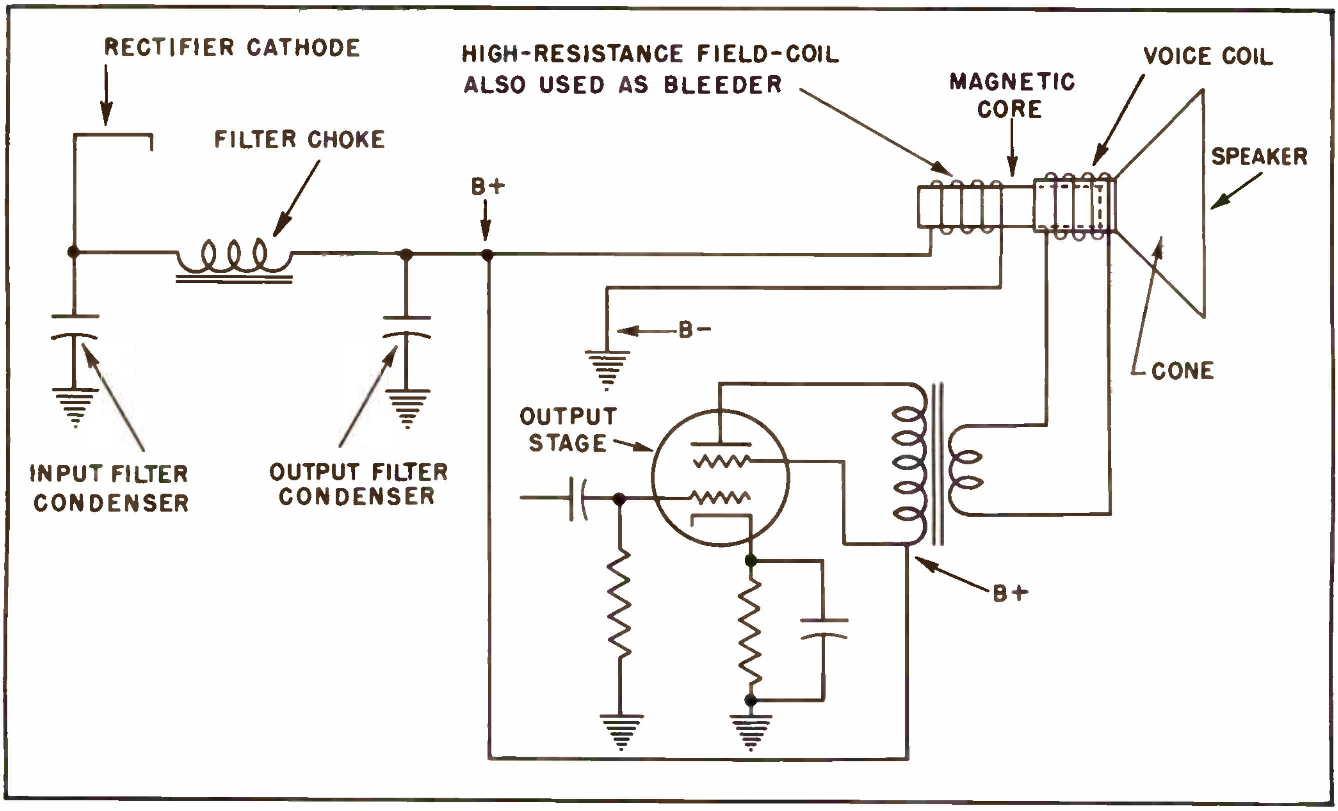

Fig.11. Schematic of High Resistance Field Speaker.

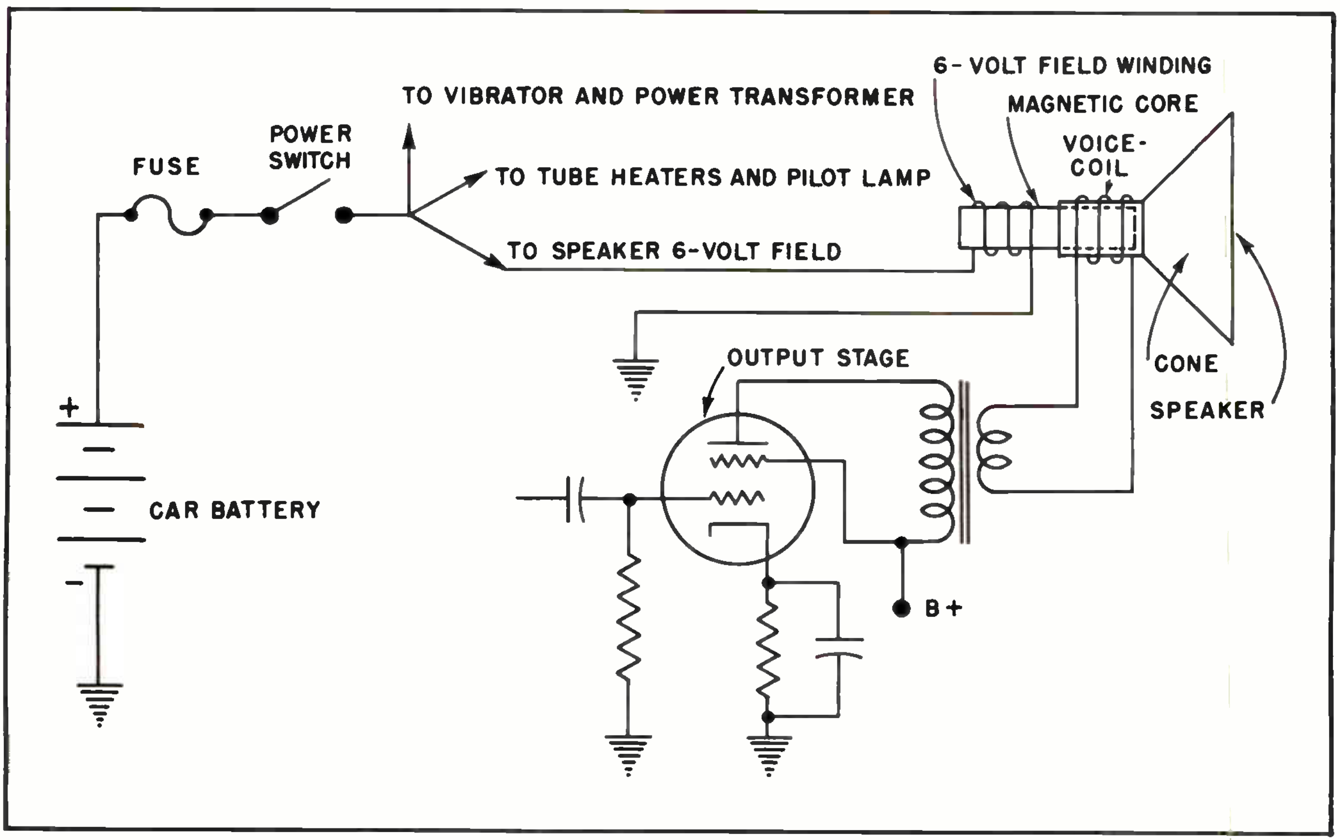

Fig.12. Schematic of Automobile Receiver.

receivers, and is known as the 6-volt field type. Fig. 12 represents the manner of supplying field current from the car storage battery, in contrast to the previously mentioned methods of taking field current from the high-voltage power supply. Ohmic resistance of the 6-volt field winding is somewhat less than ten ohms, on the average, a value which limits its current to less than one ampere drain from the car battery.

The modern tendency in automobile receiver production has been in the direction of replacing the 6-volt field type of speaker with the PM model. This eliminates the need

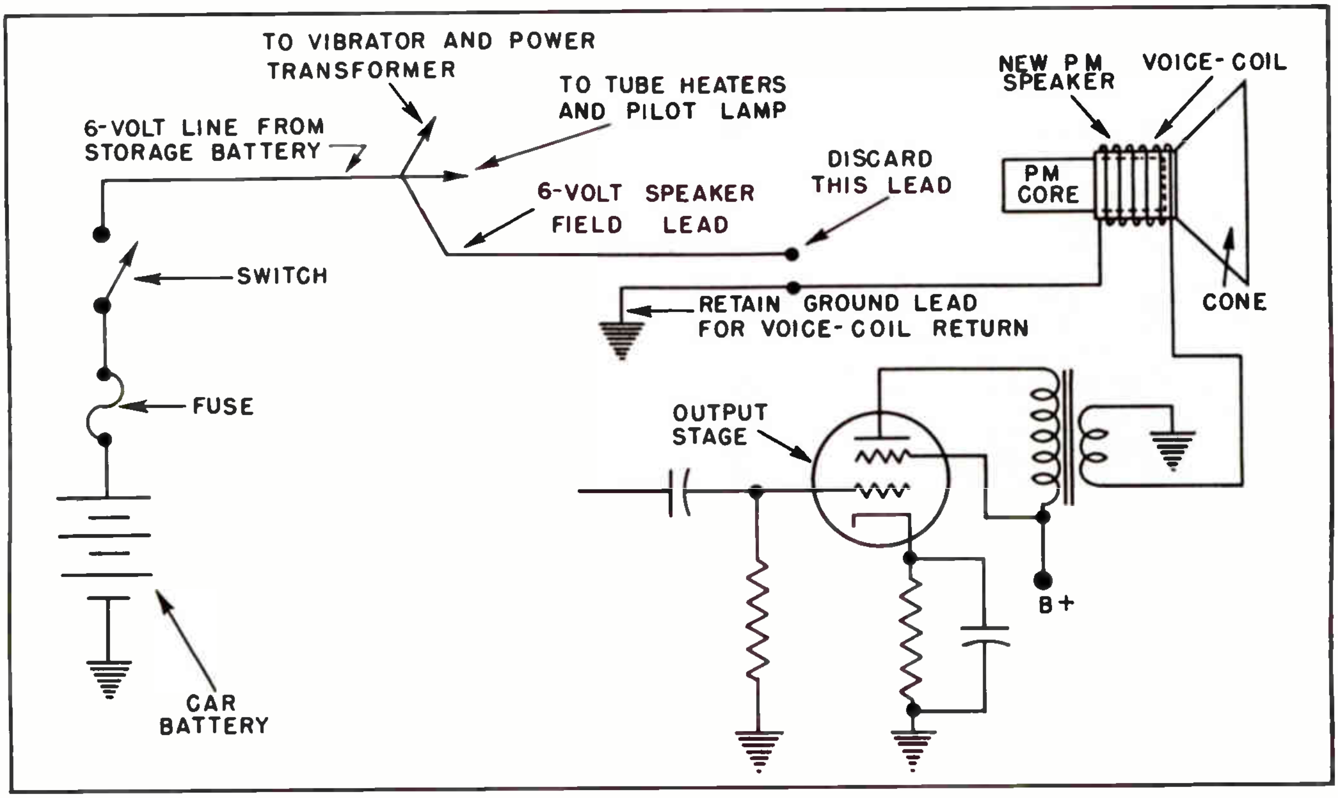

Fig.13. How to Convert an Automobile Loudspeaker to One with PM Field.

for taking any battery current for the speaker field, an improvement which lightens the load on the battery.

Modern radio repairmen in keeping with this tendency, often replace a defective speaker which used the 6-volt field with a PM speaker of the same size and shape. This makes for economy in the power used by the automobile receiver, and at the same time simplifies the work involved in making the replacement.

The manner of accomplishing such a change-over is clearly shown in Fig. 13. From a practical point of view, it should be remembered that such a change from a 6-volt field speaker to a PM speaker should be done only when the 6-volt field speaker is defective beyond reasonable repair, and actually needs to be replaced. The change should not be made merely for the sake of making a change.

Section 7. IDENTIFYING A LOUDSPEAKER

Successful trouble-shooting and repair of loudspeakers depend to a great extent upon the repairman's ability to identify the speaker and to expect only those troubles to which such particular type is subject. This recognition will automatically rule out an entire group of troubles (possible only in other types of speakers) and will eliminate the need for confusing, and time-consuming tests.

Loudspeakers lend themselves well to identification in accordance with the following plan:

The PM dynamic speaker. Identified by the absence of a field coil and the presence of a magnetic block or cylinder, as shown in Fig. 14 and by the finger in Fig. 5.

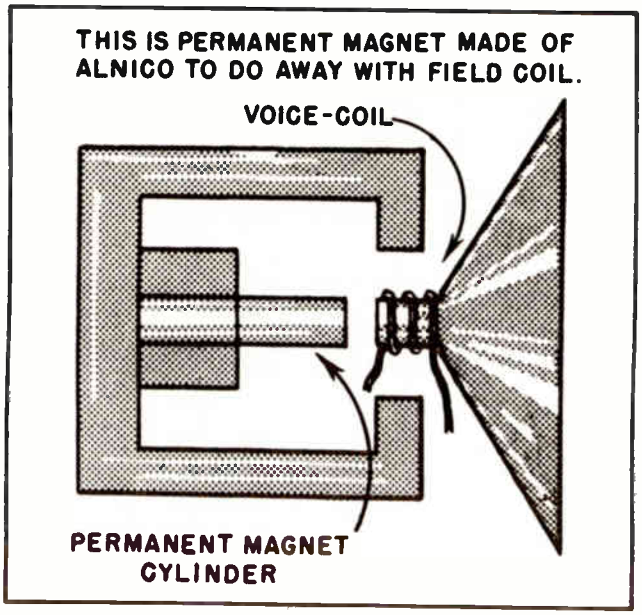

Fig.14. PM Field Speaker.

The low-resistance-field dynamic speaker. This type is characterized by connections from the speaker field directly to the positive terminals of the two filter condensers. This is illustrated in Fig. 15. Notice that one side of the field winding goes to the positive side of the *input* filter condenser, with the other end of the field winding going to the positive side of the *output* filter condenser.

The high-resistance-field dynamic speaker. If one of the field winding leads is connected to B-plus, and the other to B-minus (or chassis), the speaker field is of the high resistance type.

The 6-volt field type dynamic speaker. This type is found in all automobile receivers where there is a *field coil* speaker. (Exceptions are only in the case of a PM speaker, identified by the method described above.) Therefore, if an automobile radio has a field-coil speaker, it must be of the 6-volt field type.

The identification procedures outlined in the previous paragraphs, if applied carefully, will immeasurably assist in speaker trouble-shooting and repair. These methods, as is evident, are independent of the condition of the speaker. While it is important to know the ohmic resistance of a defective speaker field, this reading may not be available in a speaker whose field is open. Circuit connections, on the other hand, will at once indicate whether we are working on a low- or high-resistance field and will tell us -- if the trouble is an open field winding -- what kind of a replacement to make.

In those rare cases where a receiver may be equipped with a *magnetic*, or *high impedance*, speaker, we will notice the absence of the matching transformer, an example of which is shown in Fig. 16. Do not confuse the *magnetic* with the *PM* speaker, nor the *high-impedance voice-coil* with the *high resistance field coil*. To further clarify this point, we may add that the high impedance speaker *is* a *magnetic* speaker, and therefore does not claim membership in the dynamic speaker family.

A picture of a magnetic speaker with its coil, horse-shoe magnet, and cone is shown in Fig. 17. Since a magnetic speaker requires no matching transformer, the presence of a matching transformer immediately typifies a speaker as dynamic. It can then be further examined to determine which of the dynamic types it is. Speaker matching transformers, also called

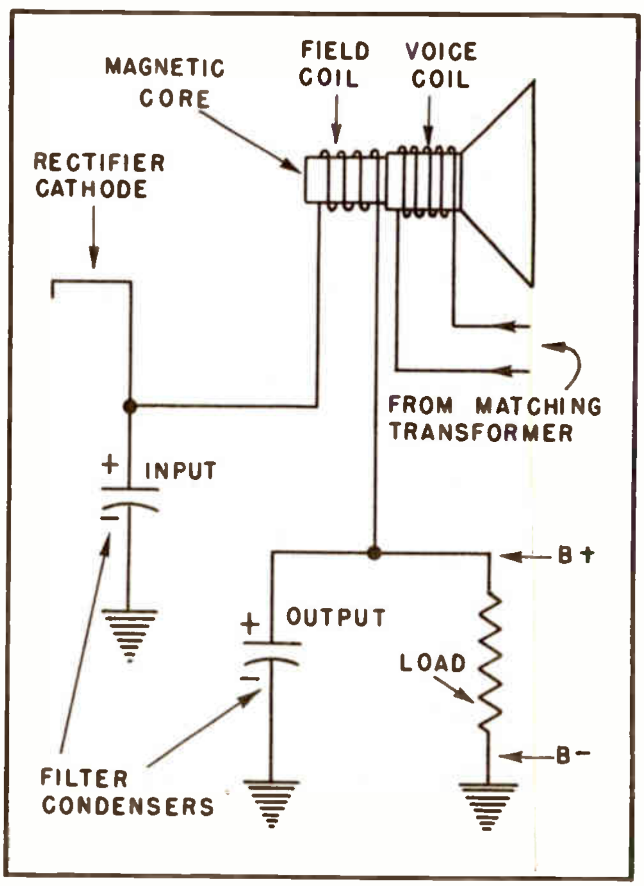

Fig.15. How Speaker Field is Connected to the Filter Condensers.

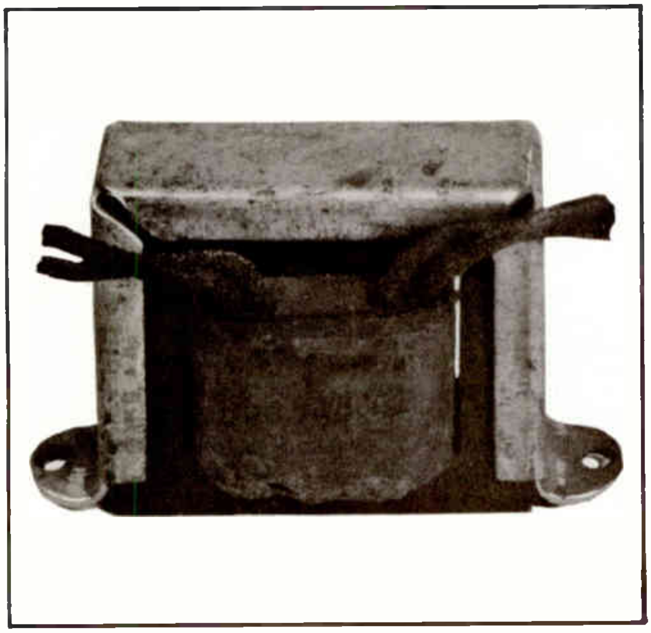

Fig.16. Output, or Matching Transformer.

impedance matching transformers, are usually mounted on the speaker frame itself, as illustrated in Fig. 7. Occasionally the matching transformer is mounted in the radio chassis, with leads extended to the voice-coil of the speaker. Whether the speaker is chassis-mounted or installed on the structure of the cabinet often determines the location of the transformer. This brings up a point which is important from the practical viewpoint.

In a modern receiver, even if the matching transformer is not immediately conspicuous, do not assume the speaker is of the high-impedance magnetic type. The chances are it will be a dynamic type and, on examination, the matching transformer will probably be found mounted on, or under, the chassis of the receiver. Tracing the leads from the speaker back to the chassis will soon provide the desired identification.

Section 8. WHEN TO LOOK FOR TROUBLE IN THE SPEAKER

If we were to examine the records of professional radio repairmen we would find that speaker troubles are among the most common of all found in radio and television receivers. In spite of the excellent workmanship and engineering put into loudspeakers, they are subject to certain inherent troubles due to the very nature of their construction.

Not only do speakers involve electrical and magnetic principles, but their operation includes the mechanical action necessary to convert electrical impulses into sound energy. This makes them vulnerable to many troubles. Their faults may spring from electrical conditions, magnetic failures, mechanical friction, and temperature changes.

More than this, the speaker is the final component in the receiver, towards which all audio signals are directed; it is the last "gate" through which the signal passes before reaching the ears of the listener. In view of these conditions, it is a wise policy to check the loudspeaker first when trouble-shooting a receiver, unless the trouble is obviously in some other part of the unit.

Specifically, the speaker should be checked when the receiver displays any of the following symptoms:

1. When there is *no sound of any kind* in the speaker and tubes have been checked and are known to be good. Check for open primary or secondary of the output transformer, or for open voice-coil of the speaker. Check for open low-resistance field coil.

2. When the signal is extremely weak, all tubes known to be good, and the speaker is one of the two field-coil types. Check for open high-resistance field coil, or for end-to-end short across a low-resistance field coil.

3. When the signal is distorted. Distortion in a loudspeaker may be traced to

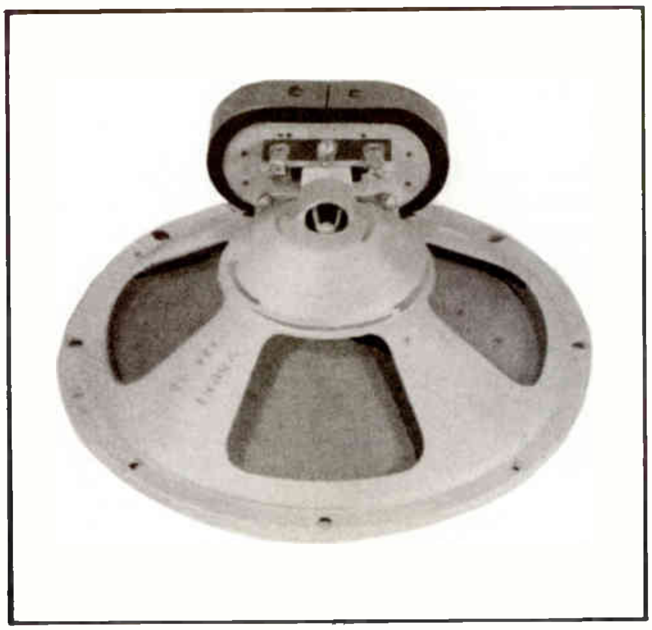

Fig.17. Magnetic Speaker.

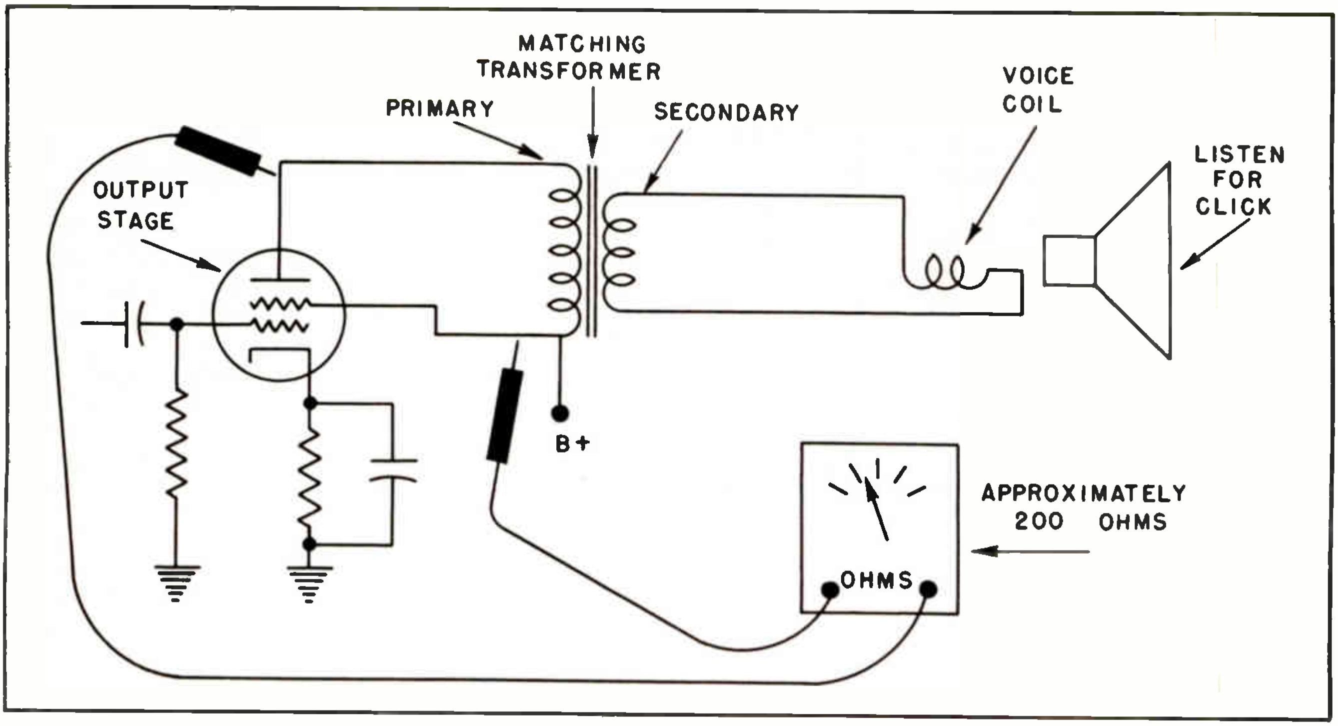

Fig.18. Using an Ohmmeter to Check a Speaker Circuit.

friction occurring between the voice-coil and the pole-pieces, due to the voice-coil form being out-of-round or warped, or to the de-centering of the speaker cone in the speaker frame. This type of distortion may occur at any time the signal is heard; it may occur only after the set has been warmed-up for a period of time; or it may occur while the set is comparatively cool and then disappear when the set has become warmed up. Speaker distortion of a rattling nature, especially on the lower audio notes, may be due to either a torn speaker cone or to one whose outside or inside edge has become totally or partially loose from the speaker frame.

4. When a normally loud and clear signal comes through intermittently, interrupted by one or more sharp clicks followed by periods of complete silence: Check for a loose connecting lead from transformer secondary to the voice-coil, with special emphasis on the soldered connections on the speaker cone itself, or on the terminal-strip mounted on the speaker frame.

Section 9. SPECIFIC CHECKS FOR SPEAKER TROUBLES

Checking the output transformer and the voice-coil. Fig. 18 shows the method for making a simultaneous triple check on the transformer windings and the voice-coil by a simple procedure. Turn the power off in the receiver and connect the ohmmeter leads across the output transformer primary. It is best to use a low-scale on the ohmmeter, for primary resistance will be about 200 ohms.

If the primary is open, of course, the meter will indicate this fact by a reading of infinity. Listen for a click in the speaker during this test. If a click is heard at the time the ohmmeter leads are applied or removed, the transformer secondary and the voice-coil of the speaker are proved to be good. If no click is heard at this time, and the ohmmeter reads infinity, the trouble is obviously an open primary winding.

If, however, no click is heard and the ohmmeter reads the expected value of about 200 ohms we have two remaining possibilities: Either the transformer secondary or the voice-coil itself is open. Fig. 19 shows how to distinguish between these two possibilities. Keep in mind the important precaution that an ohmmeter placed across either of these circuits without disconnecting the other will give an unreliable reading. If either of these two windings are good, the meter will read a few ohms (not over five) even if one of them is open. Isolate the two windings from each other by breaking at point "X" as shown in Fig. 19.

If either of the two transformer windings are open, examine the connections before replacing the transformer. An open winding is usually, but not always, due to a break in the solder joint at the junction point between the thin, enameled wire of the winding and the fabric-covered stranded wire of the lead. Remove carefully the upper layers of the protective sheeting around the windings, trace the leads to their connections on the winding, and examine the joints for cold or broken solder.

If, on the other hand, it is reasonably certain that the joints are intact, then an internal open in the winding is indicated. While it may be possible to unravel several hundred feet of thin wire and locate the fault, it is more advisable to replace the transformer completely. In ordering a speaker transformer for replacement, it is necessary only to specify the type of output tube used to feed the transformer.

Transformers of this type are usually mounted upon the speaker frame by means of a pair of rivets. Replacing the transformer means removing the rivets. A precaution is in order at this time. In removing the rivets, which is usually done by filing or drilling, iron filings are apt to fall toward the field pole-pieces, especially in the case of a PM speaker. If these filings, or any other foreign particles, become lodged between the pole pieces and the voice-coil, bad distortion will occur after the new transformer is installed. To avoid this possibility, file or drill the rivets in such a position as to allow the filings and burrs to fall well out of the magnetic reach of the field. In most cases, this will involve turning the speaker upside down during this filing or drilling job. But, in spite of the awkwardness of this position the results will be well worth the additional trouble.

Section 10. OPEN VOICE COIL

If the voice-coil is found to be open, you have the choice of either replacing the cone and the voice-coil it carries, or replacing the entire speaker. The latter choice is the more sensible, since speaker cones are difficult to duplicate, even from the same manufacturer, and more difficult to install properly. Speakers, on the other hand, are relatively inexpensive and are readily available at radio supply houses. In those cases where a duplicate speaker is unavailable it is possible to replace the speaker cone. A procedure for replacing speaker cones is given at the end of this lesson. There are several firms which specialize in speaker cone replacement, and their work is dependable. If there is no hurry to put the receiver back in operation, you may take advantage of this cone-replacement service. Such firms are generally listed in the trade papers and magazines on Radio and Television.

Section 11. FIELD COIL TROUBLES

To *check the low resistance field coil* as shown in Fig. 20, place an ohmmeter across the terminal leads of the field coil (with power turned off in the receiver) and look for an ohmage reading of 200-800 ohms. A verifying check is to turn the power on in the receiver and measure the voltage between B-minus and *both* positive sides of the

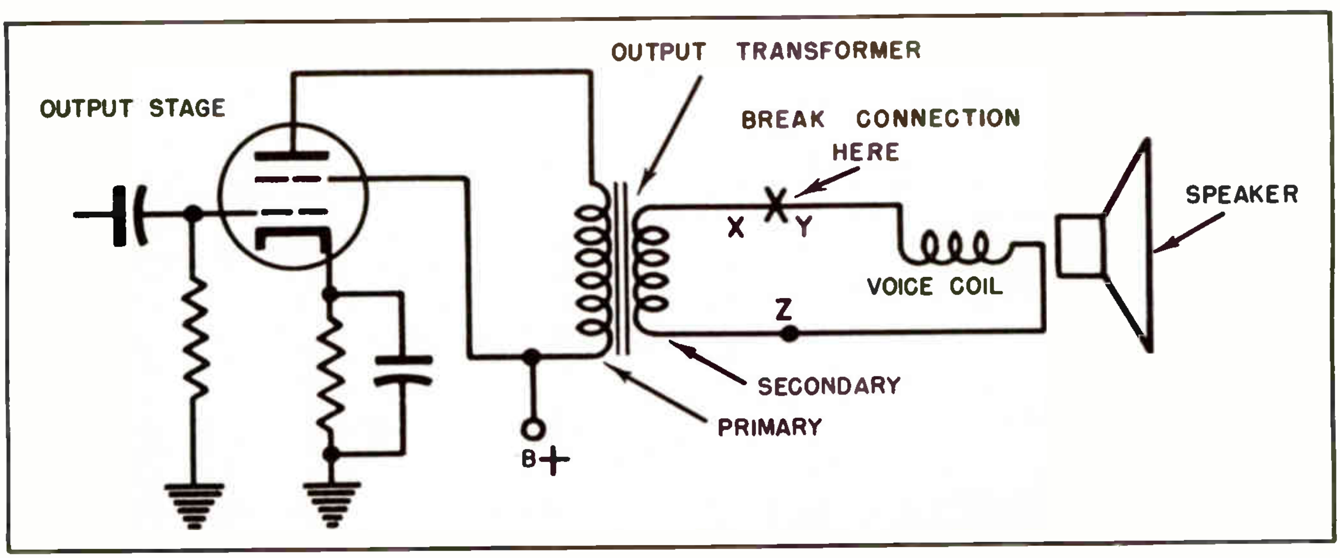

Fig.19. How to Check for Open Secondary and Open Voice Coil.

filter condensers. If B-plus is present at the input filter (which is connected directly to the rectifier cathode), but *absent* at the output filter, and if there is no short across the "B" supply, then the suspicion of an open circuit in the low resistance field coil is justified.

As in the case of transformer opens, breaks in the circuit are most likely to occur where the solder junction of the thin enameled wire joins with the fabric-covered lead wire. Examine such joints carefully before replacing the field coil. These solder joints are accessible after removal of the protective layers covering the field coil.

this field coil will result in the absence of magnetic strength at the speaker core, or will show only the very weak magnetism due to residual effects. Measuring with an ohmmeter across the B-supply must be done carefully if accurate results are to be expected.

To avoid the possibility of unreliable readings due to voltage dividers, filter-condenser leakage, and other circuits across the "B" voltage supply, one (or both) speaker field leads should be unsoldered, and disconnected from the rest of the set. This will permit an isolated ohmmeter reading across the field coil only, and results will be accurate.

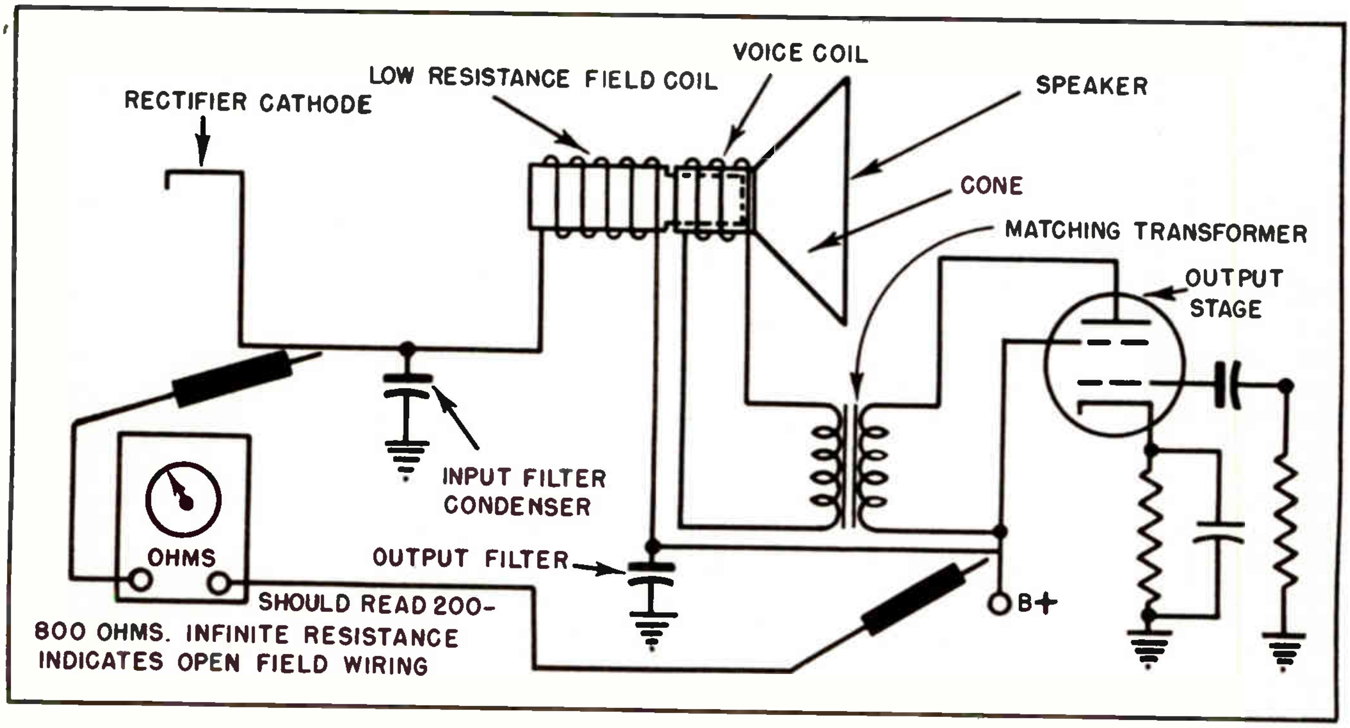

Fig. 20. Checking the Low Resistance Field Coil.

If the solder joints are intact, an internal open is indicated, and it is best not to attempt repairs on this winding. Replace the complete speaker, instead, and the job will be more reliable. In ordering low resistance field coil speakers for replacement, specify the make and model number of the receiver, so that both the physical and electrical characteristics of the speaker will be duplicated.

In *checking the high resistance field coil*, where the speaker field has been definitely identified as of the high resistance type, its continuity can be checked as in Fig. 21. First of all, an open in

An ohmic reading taken in this way will read a value somewhere between 2500 and 3000 ohms, but in some rare cases may indicate 4,000 or even 5,000 ohms for this winding. Anything over 10,000 ohms should be viewed with suspicion, especially if the field strength is absent or very weak.

As in the case of the low resistance field coil, repairs on this winding are not recommended unless the open in the circuit is at the junction between the enameled wire of the winding and the fabric-covered wire of the leads. Replace the speaker for best results. In the average receiver, any ohmic value approximating that specified for the

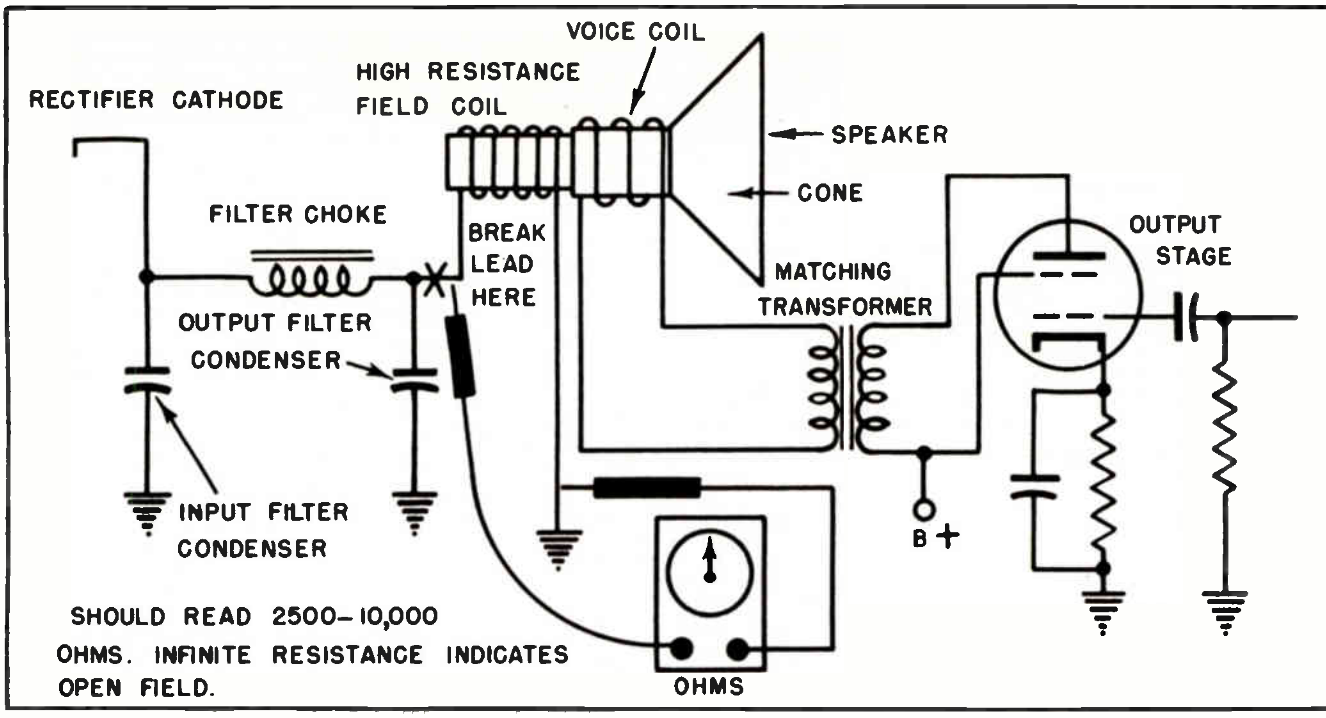

Fig.21. Checking the High Resistance Field Coil.

field coil by the manufacturer will be satisfactory, so long as physical dimensions are duplicated. If possible, it is best to take or send the speaker to the supply house when ordering a replacement for it.

A shorted winding in the high resistance field coil is unlikely, yet deserves some discussion. If the ohmic resistance across the field shows zero resistance while the speaker field connections to the receiver are intact, we can suspect *not* a short in the speaker field, but in an associated circuit in parallel with it within the set. The most likely probability in this case would be a short-circuited filter condenser or some other short across the "B" supply. This is technically not a speaker trouble, although its effects, like those of so many other troubles, are evident in the action and operation of the speaker. To verify this possibility, loosen one or both of the field leads from their connections in the receiver, and repeat the ohmmeter test. If the ohmmeter still reads zero ohms, look for crossed leads in the speaker

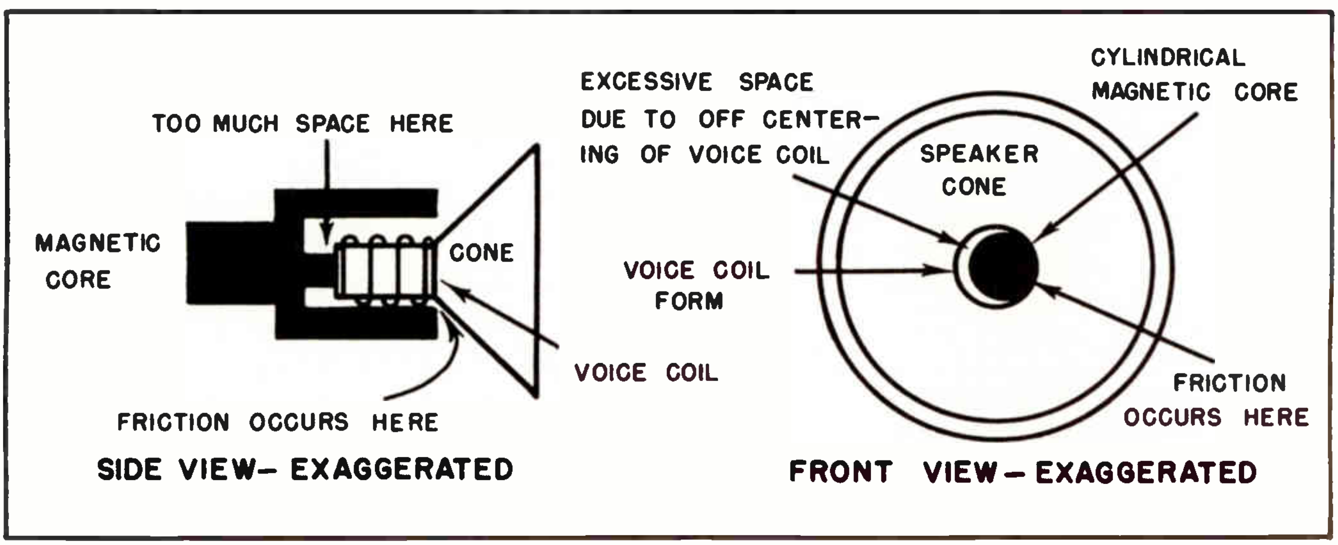

Fig.22. Dragging Speaker Cone.

field; if the ohmmeter reads a normal value (2500-3000 ohms) we can be sure the trouble lies outside the speaker, probably in the power supply.

Section 12. DRAGGING VOICE COIL

At the first sign of signal distortion, friction should be suspected between the voice-coil and field pole-pieces. Fig. 22 shows an exaggerated drawing of a speaker where such friction would occur. While it must be borne in mind that signal distortion may spring from causes other than speaker faults, a simple test can be made to ascertain that the distortion is either the result of speaker trouble, or that the speaker can be ruled out as the source of trouble.

Remove the chassis of the receiver from the cabinet and set it on the bench in a position which gives easy access to both the front and back surfaces of the speaker cone. Turn on the power and set the volume up so the distortion can be heard unmistakably. While this distortion is present, bear *gently* with the finger successively against the bottom, sides, and top of the speaker cone, Test both front and back, noting any changes in the character of the distortion. If distortion is due to the speaker cone, such finger pressure applied at one or more of the points mentioned, will either remove the distortion or reduce it appreciably.

If at any one of the pressure points the distortion is found to disappear, a temporary expedient can be used to correct the trouble. Press a sponge-rubber or cotton "shim" between the speaker frame and the cone at the point where finger pressure removed the distortion. Note well that this is merely a temporary repair job, and distortion may still be evident when the receiver volume control is turned higher.

The most reliable procedure is to replace the speaker or the cone. The general rule for speaker replacement holds in this case. When ordering a speaker replacement from the manufacturer, state the make and model of the receiver. In ordering from a radio supply house, if possible take or send the speaker to their salesroom. This will insure exact duplication of both electrical and physical characteristics.

Section 13. SPEAKER CONES

A speaker cone that has been torn or punctured will often -- but not always -- cause distortion. In this case, the distortion will cause a "rattling" sound, which may be more evident at the low frequencies than at the higher frequencies. A visual inspection, under good light, will reveal such tears in the speaker cone. If not too wide open, these tears and punctures can be successfully repaired by spreading a

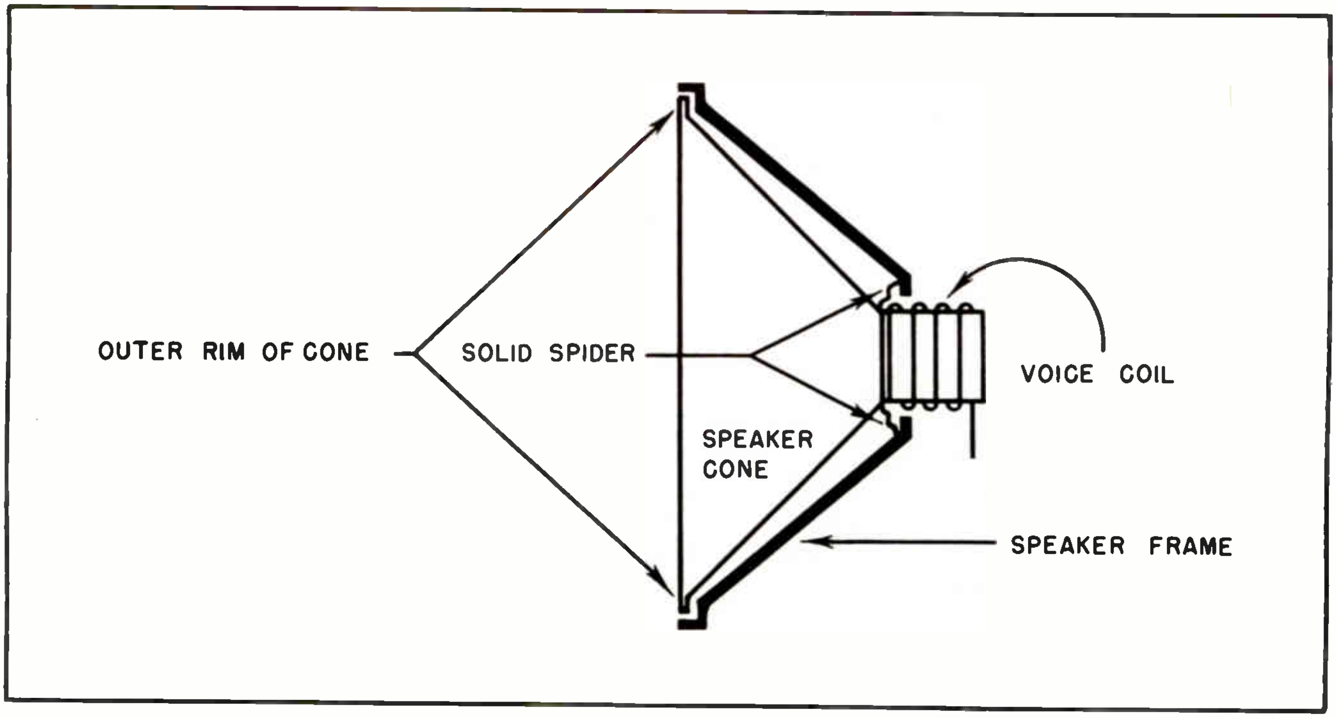

Fig. 23.

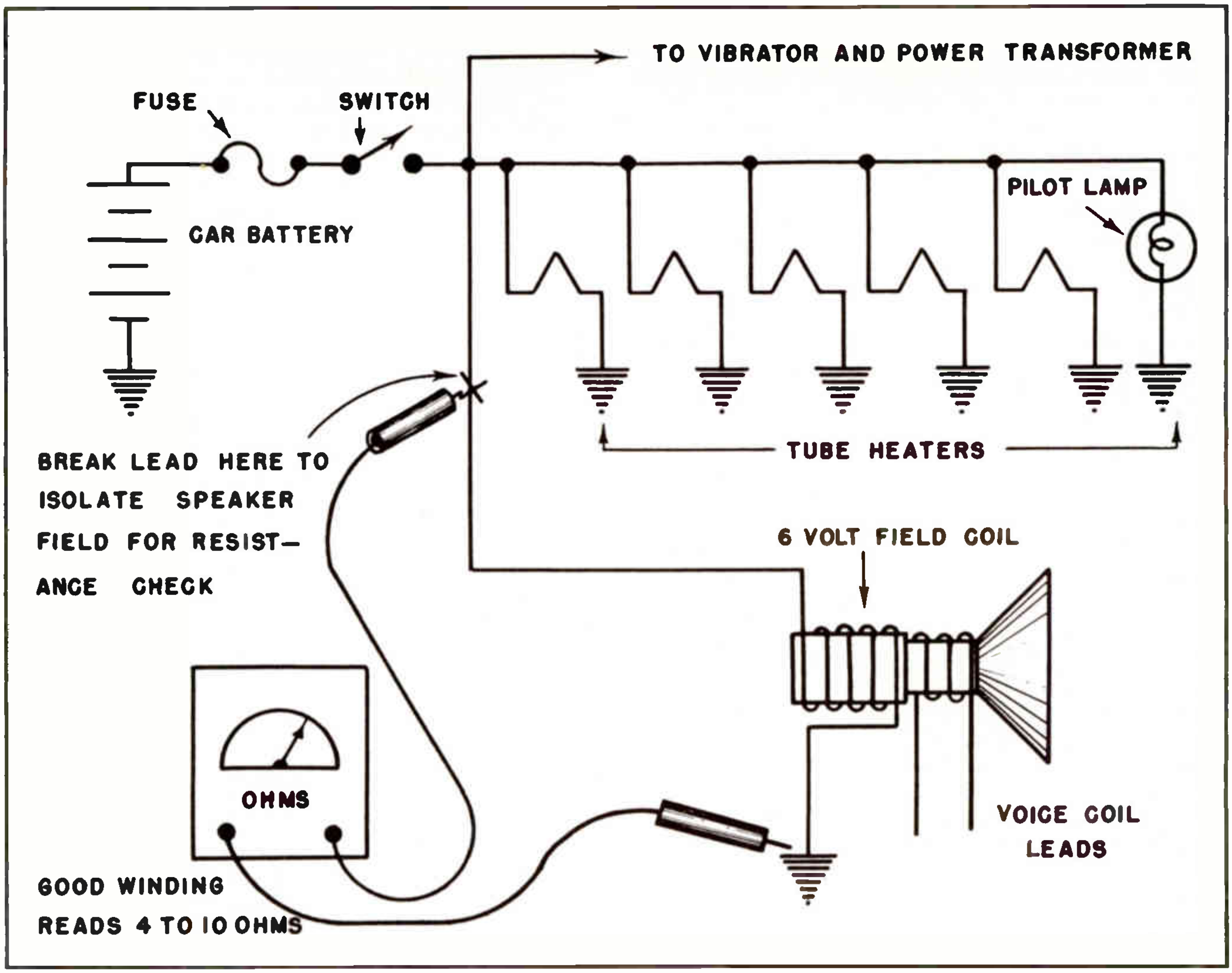

Fig.24. Checking an Automobile Radio Receiver.

suitable quantity of speaker cement (made especially for such repairs) over both the front and back of the tear. A drying period of five minutes is usually satisfactory before operating the receiver again. Lacking the special speaker cement, airplane glue, or any other thick cement can be used.

A speaker cone that has become loose from its glued moorings at the outer edge or the inner "spider" (see Fig. 23), will also cause rattling and distortion, especially at the lower frequencies. This is a common trouble often found in automobile radio speakers. If the outer edge is either partially or totally loose from the speaker frame, but the spider is still solid, the outer edge can be re-glued to the frame without any special precautions. If, however, the spider is loose, the speaker cone must be re-centered carefully during the gluing process. This procedure follows that of replacing the speaker cone, and is presented in detail at the end of this lesson.

Section 14. AUTOMOBILE RADIO SPEAKER

When completely disconnected from all other circuits, an ohmmeter can be used to check the field of an automobile receiver speaker. It will indicate a good winding by a reading of 4-10 ohms. A verifying test can be made by holding a screw-driver or similar piece of metal at the speaker core to estimate the magnetic strength of its field. An open 6-volt field, when all other connections are removed, will read infinite resistance on an ohmmeter, while its magnetic strength will be either absent or extremely weak.

The importance of disconnecting the speaker field from all other connections cannot be overstressed. As shown in Fig. 24, the 6-volt field is paralleled by the tube heaters and vibrator, and if these are not separated from the field, the ohmmeter will read their net resistance at approximately one ohm or less regardless of whether the 6-volt field is open or not.

Due to the limited space available in automobile receivers, it is especially important that physical as well as electrical characteristics of a replacement speaker are exactly duplicated. When there is a choice of replacing a field-coil speaker in an automobile receiver with either another field coil type or a PM, replace it with a PM, providing its physical dimensions are suitable. This will make it unnecessary to reconnect the field leads, will draw less battery current, and will avoid similar winding troubles in the future. The unused 6-volt leads can be clipped out of the way, or taped and folded to avoid short-circuiting the 6-volt power supply to ground by accidental contact.

On some automobile receivers where the speaker is mounted as a part of a single unit receiver, the ground return for both the voice coil leads and the speaker field is made through the frame of the metal case. Where this is true we should not expect any field magnetism to be present with the top cover, upon which the speaker is mounted, removed. If the top cover must be removed for analysis, as it usually must be, then complete the ground return for the speaker by a heavy jumper fastened solidly to both the top cover and the receiver case. It may even be necessary to scrape a small amount of paint off to secure the necessary electrical contact. The reward for this extra effort is that tests made under these conditions are reliable. Otherwise, tests are incomplete and doubtful. *It is a wise axiom that any test worth making at all is worth making right.*

Section 15. FROZEN VOICE COIL

A voice-coil which is immovable in the space between the pole-pieces will give forth no sound of any kind. Not even signal nor hum. Such rigidity of the voice-coil can be classified as a freak trouble, although it may occur in a receiver which has been stored in dampness or dust for a prolonged period of time.

Any receiver which is in use, and which tends toward voice-coil friction for any reason, will gradually deliver a more and more distorted signal until the user can no longer listen to it with comfort. Repairs will usually be made long before a condition of complete binding is reached. To test for a frozen voice-coil, press the speaker cone with the finger placed at the center of the

Fig.25. Testing for a "Frozen" Voice Coil.

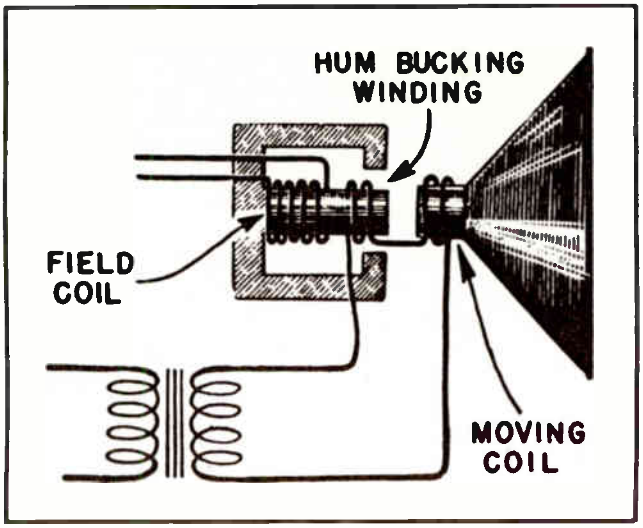

Fig. 26. Hum-Bucking Coil.

cone. (See Fig. 25.) A good speaker should "give" about a quarter of an inch *without any audible scratch.* If the center of the speaker cone is found to be rigid, especially if the receiver and speaker are very dusty or rusty, then a frozen voice-coil is certain. If the speaker cone "gives" but such pressure causes an audible scratch, friction is present.

In either case, the speaker should be replaced. Attempts to clear the very narrow space between the pole-pieces of a speaker of rust, dust, or any foreign matter are usually unsuccessful. Time can be saved by installing a speaker replacement.

Section 16. **HUM-BUCKING COIL**

A refinement of the field-coil dynamic speaker is sometimes encountered in receivers in the form of a *hum-bucking coil*, schematically illustrated in Fig. 26. As indicated by its name, the hum-bucking coil is designed to minimize the 60- or 120-cycle hum component of the field current as it affects the voice-coil.

The hum-bucking coil consists of a few turns of wire wound around the field core 180 electrical degrees out of phase with the ripple component in the plate circuit of the output stage. This permits the ripple component of the output plate current to cancel out its counterpart in the field current, the result being that residual hum is reduced to a negligible value.

Notice that the hum-bucking coil and the voice-coil are in series. While this describes their electrical connections satisfactorily, we might better understand the function of the hum-bucking coil if we consider that the voice-coil is being fed from two power sources; the secondary of the matching transformer, and the hum-bucking coil. Since the ripple components of these two sources are 180 degrees out of phase with each other, their effects on the voice-coil are cancelled and the voice-coil therefore responds to neither one. This leaves the *signal* itself completely unaffected, which is the desired result.

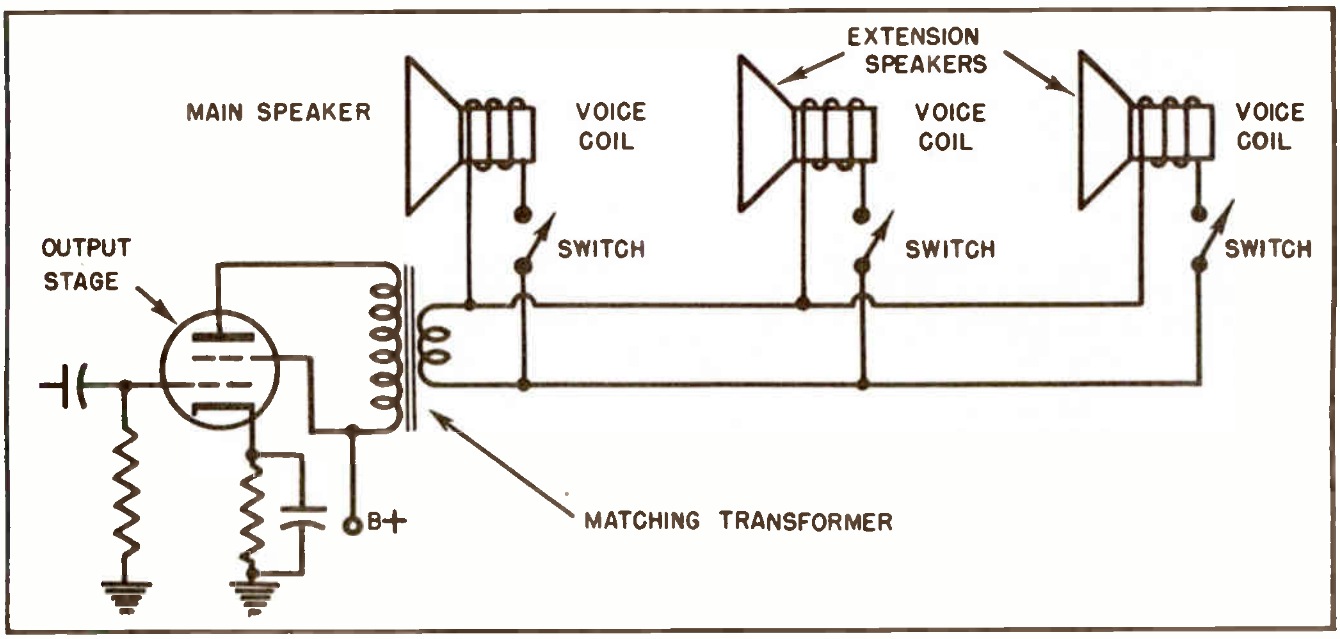

Fig. 27. Extension Speakers.

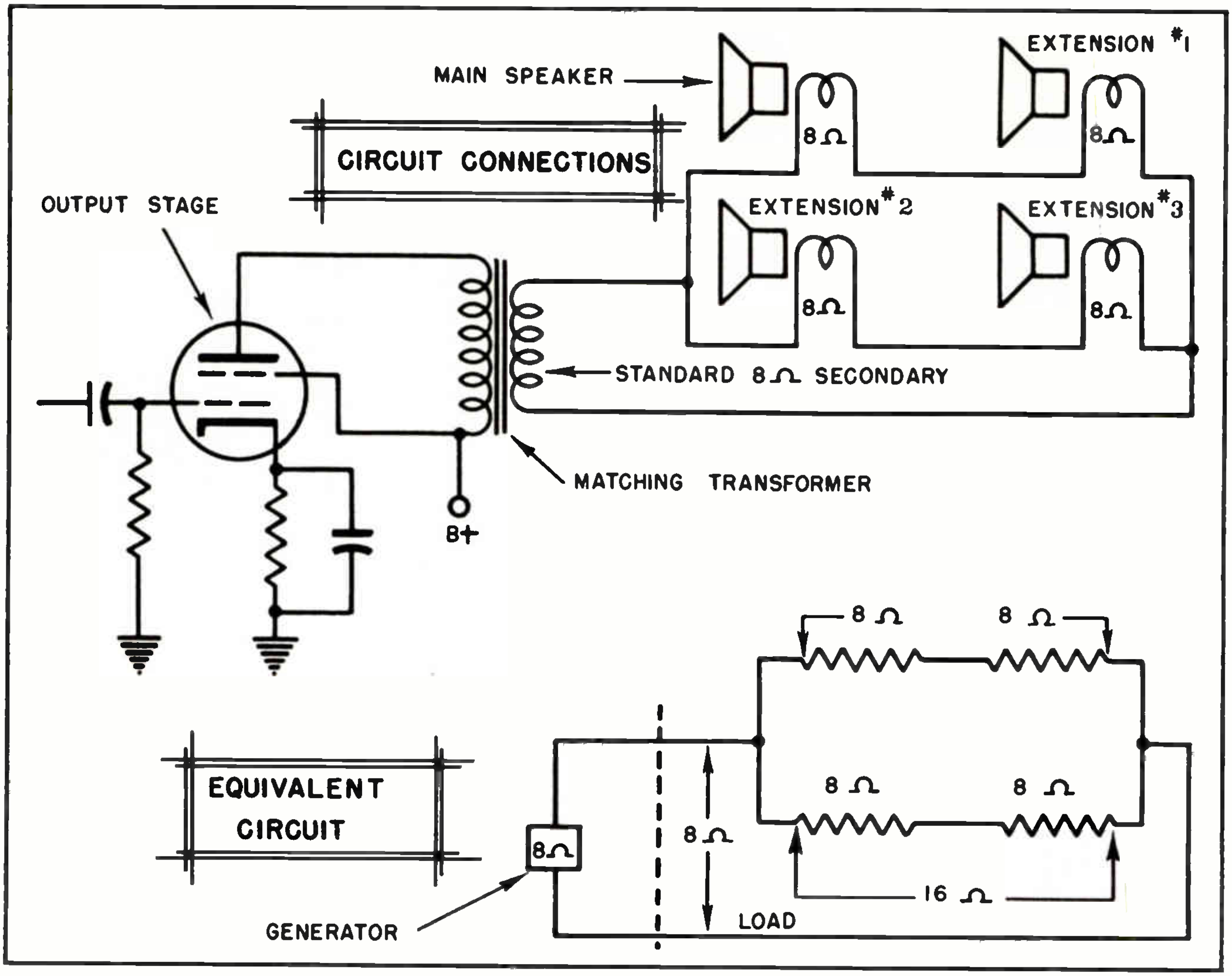

Fig.28. Impedance Matching with Four Speakers.

Hum-bucking coils should not be ignored when replacing a defective speaker. The replacement should be an exact duplicate.

Section 17. EXTENSION SPEAKERS

Additional speakers may be added to the transformer output circuit for the purpose of delivering a signal to extended locations, such as kitchens, bedrooms, and basements. Usually one or two speakers can thus be connected without seriously disturbing the impedance matching arrangement meant for only one speaker. However, where three or more extensions are required, the question of properly matching impedances becomes important and must be considered. Fig. 27 is a schematic diagram of the circuit involved in adding one or two additional speakers to a receiver. Where only one speaker is added, the connections to the other additional speaker, shown in Fig. 27 may be ignored. Notice that the voice-coils are in parallel, with each of them controllable by its own on-off switch. Using fairly heavy conducting wires, No. 16, signals may be carried up to as much as 500 feet with excellent results.

In the average radio installation it is seldom necessary to add more than three speakers for extension purposes. Here, with a total of *four* speakers to be driven by a transformer secondary, a simple method of connecting them can be followed. This is illustrated in Fig. 28, and shows that no changes in the already existing impedance matching need be made.

The main speaker and extension #1 are in series with each other. This gives them a net impedance of their sum, or 16 ohms. Extensions #2 and #3 are also in series with each other, giving them a net impedance of

16 ohms. The two *pairs* of series-connected speakers are now connected in parallel with each other, and their net impedance thus becomes 8 ohms. Since the speaker transformer secondary, with its 8 ohms impedance was originally used to match a single 8-ohm voice-coil, it also matches the four speakers connected in the manner described. Since the impedance matching in this system would be disturbed by on-off switches at each speaker, such switches are omitted from the circuit.

Section 18. UNIVERSAL MATCHING TRANSFORMER

Where a special problem of impedance matching is introduced by the addition of many speakers to a receiver output, or to a public address system, the universal transformer can be used as a replacement. Fig. 29 shows the appearance of such a transformer.

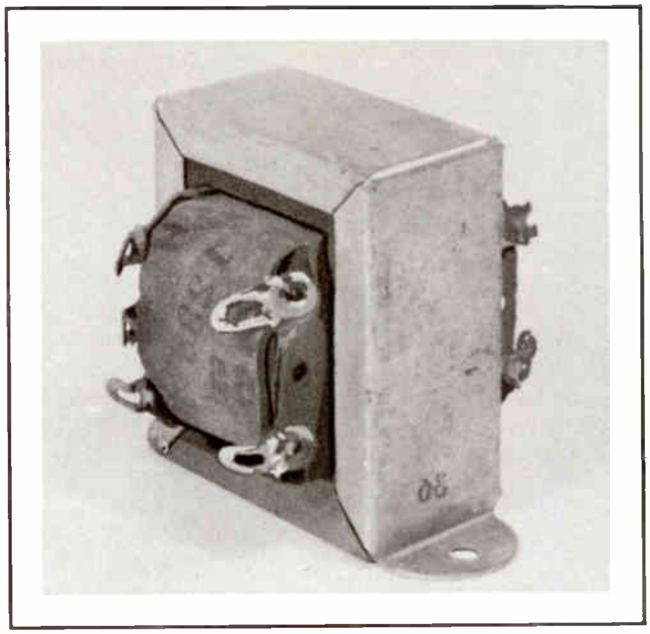

Fig.29. Universal Matching Transformer.

The universal matching transformer has a primary with a wide tolerance of impedance to match almost any output tube. Furthermore its secondary is tapped at various impedances, such as 2, 4, 6, 8, 15, 250, and 500 ohms. This makes it possible to use whatever taps most closely match the required load. It also permits the load connections to be adjusted to match an available transformer tap.

The high impedance taps of the transformer are used to carry a signal along a very extended path. The use of high impedance circuits uses high voltage at low current to minimize power losses without using heavy conductors. In using a universal transformer, consult the data sheet supplied with the unit for specific instructions and tap into the connections fitting the requirements of the problem at hand.

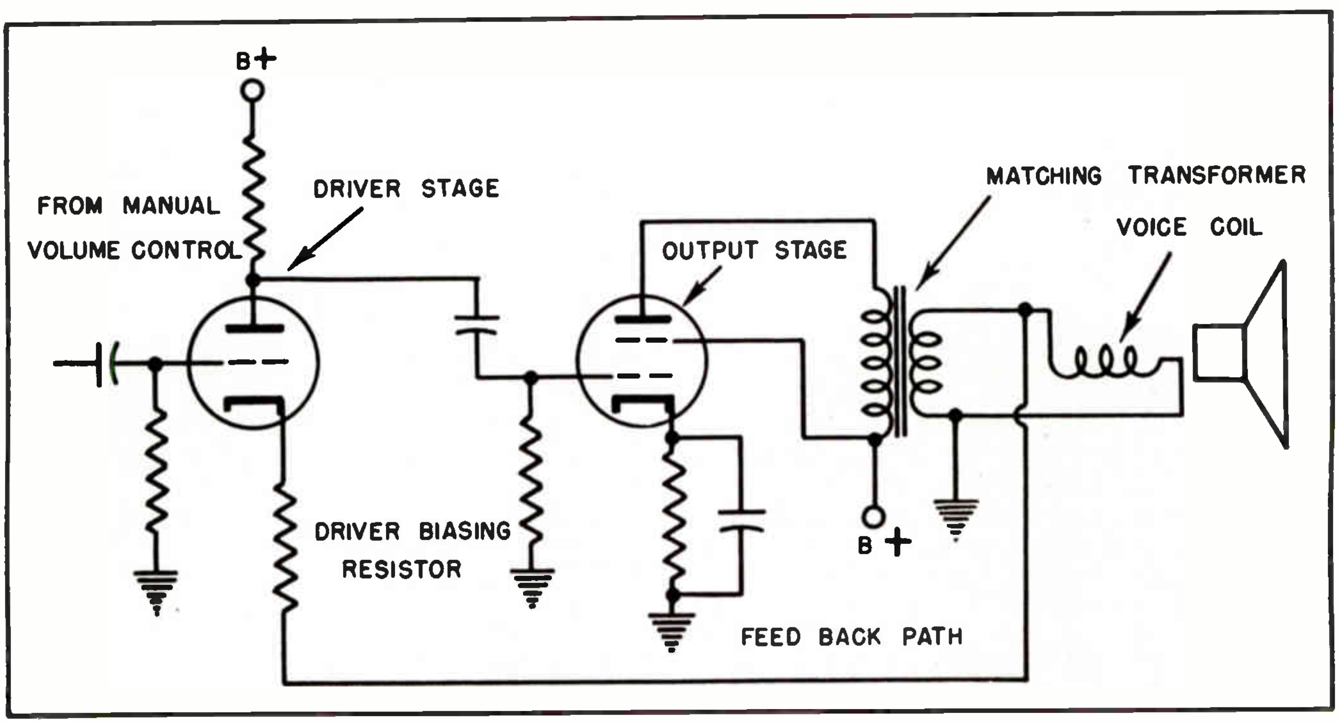

Fig.30. Inverse Feedback.

Section 19. INVERSE FEEDBACK FROM VOICE COIL

Closely associated with the speaker in some receivers is the inverse feedback circuit illustrated in Fig. 30. While not a popular practice, it nevertheless deserves mention from the trouble-shooting point of view.

The comparatively low voltage developed across the voice-coil is, as shown by Fig. 30, delivered back to the cathode of the driver stage in series with the tube biasing resistor. To aid this degenerating process, which is used to reduce undesirable harmonics, the cathode by-pass condenser is omitted from the driver stage.

Our interest in this type of circuit is not so much from the functional standpoint, it arises from the fact that if a speaker transformer is replaced which uses this circuit, and if the *wrong side* of the secondary winding is grounded during replacement, then an oscillatory howl will result. When this occurs, after a speaker has been replaced, reverse either the primary or secondary connections of the matching transformer. This will put the feed-back signal properly out of phase with the driver cathode voltage and again accomplish the desired degenerative action.

It should be mentioned that this type of degenerative circuit cannot be used in most of the modern receivers. This is because the driver cathode is most often directly connected to chassis. This is true of receivers employing duo-diode detector and triode driver in the same envelope and using a common cathode which must be connected to chassis for best operation of the diodes.

Section 20. PROCEDURE FOR REPLACING OR RECENTERING A SPEAKER CONE

To replace a speaker cone (and voice-coil) proceed as follows:

Step 1. Unsolder the voice-coil leads from the terminal strip on the back of the speaker frame. (See Fig. 31-A.)

Step 2. Remove the old speaker cone and voice-coil by pulling it forward. (Damage to the old cone or voice-coil is unimportant, since replacement is about to be made.) Where the outer rim of the cone or inner "spider" are glued to the frame, they can be scraped off with a blade. Scraping them off may be made easier by soaking them with carbon tetrachloride for a few minutes. Clean these points on the frame thoroughly. (See Fig. 31-B.)

Step 3. This step must be done carefully and quickly, and therefore should be planned in detail before it is started. Place a moderate amount of speaker cement around the area on the frame upon which the spider is to be set, place the new cone in position within the frame, and the voice-coil within the pole-pieces. Place three

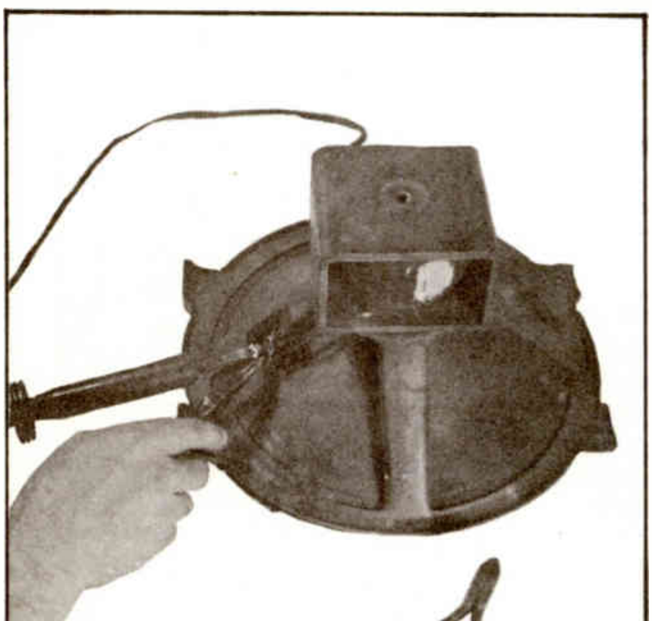

Fig. 31-A.

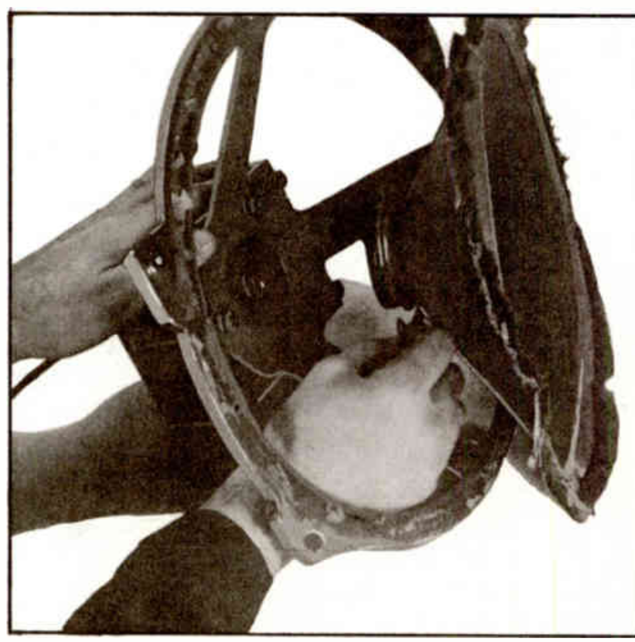

Fig. 31-B.

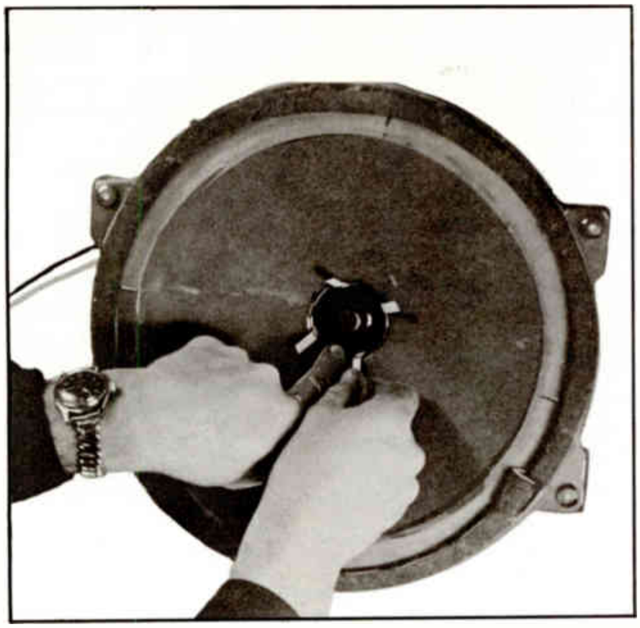

Fig.31-C.

Fig.31-D.

or four "speaker shims" between the rounded core and the *inner* surface of the voice coil form, standing the shims upright. With the fingers, press the spider against the glued surface of the frame and hold in position *until the glue is dry*. (See Fig. 31-C.)

Step 4. Cement the outer rim of the speaker cone against the area of the frame against which it lies, being careful to avoid both vertical and sideways strain. Press and hold until the glue is dry. (See Fig. 31-D.)

Step 5. Solder the new voice-coil leads to their corresponding connections to the terminal strip on the back of the speaker frame. (See Fig. 31-E.)

Step 6. Remove the shims from the center of the speaker cone and test the speaker for friction. If none is present, the speaker is now ready to be mounted on the receiver chassis or in the cabinet for operation.

As indicated earlier, this procedure must be executed with a great deal of care and advance planning, since accurate positioning of the voice-coil form within the pole pieces must be accomplished before the glue becomes too hard for adhesion. The speaker cone must be on hand, the glue within easy access, and the spacing shims must be set in carefully, and pre-selected for the right clearance. Spacing shims can be procured at radio supply firms, each packet containing three or four sets of various shim thicknesses.

The recentering procedure follows the replacement procedure, with the exception that the cone is not removed, since such removal would damage it beyond repair. Since speaker cones seldom can be recentered from the outer edge, it is obvious that recentering can be done only on the inner spider, and then only if the spider is almost completely released from its moorings. In the closed type of spider, prevalent in-

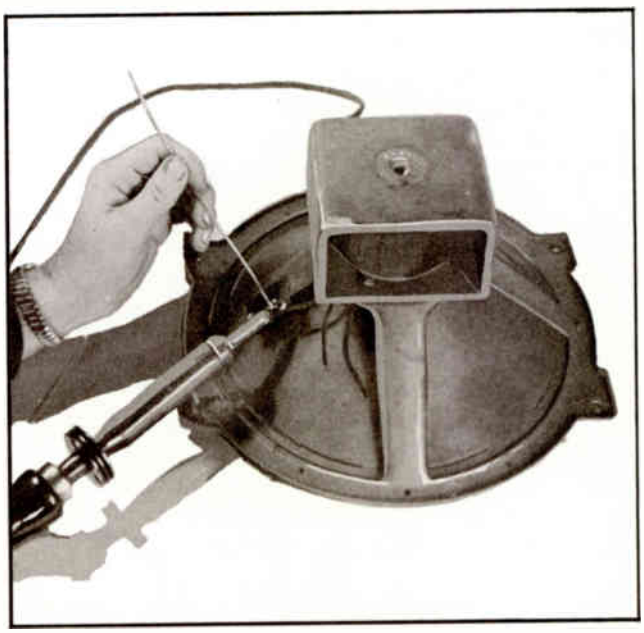

Fig.31-E.

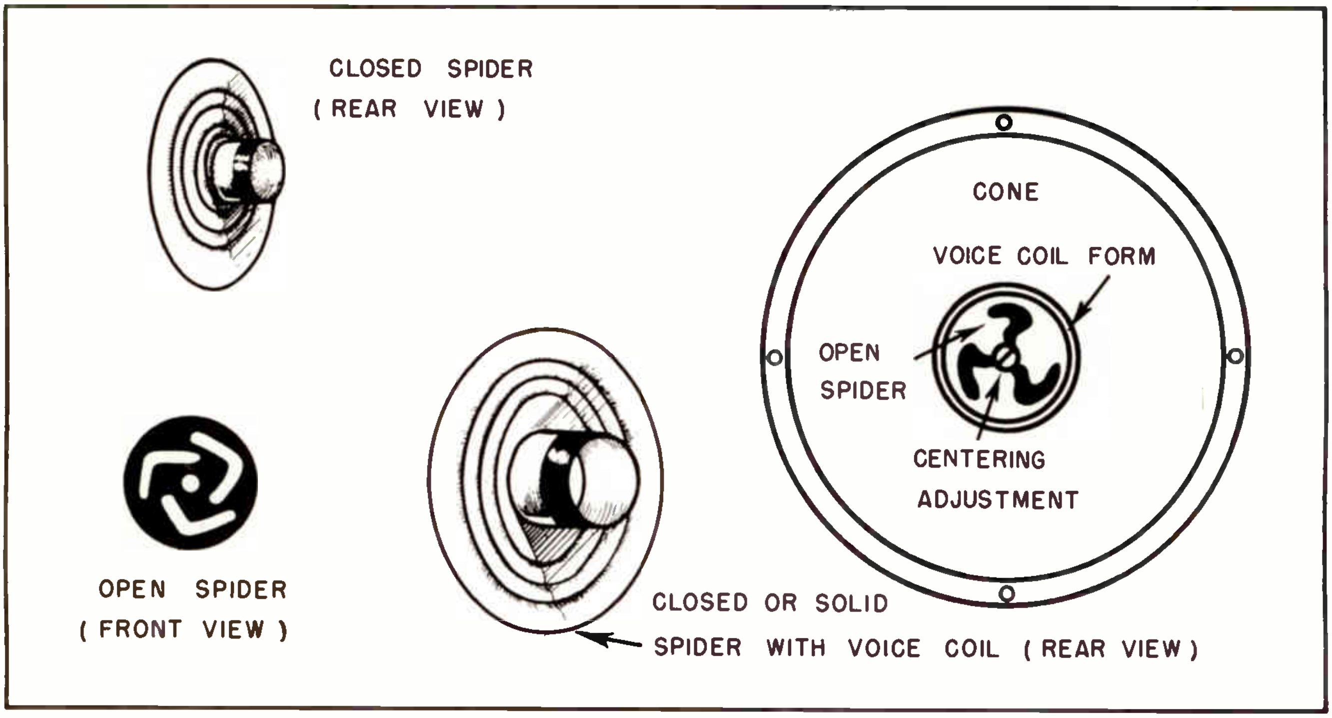

Fig.32. Speaker Cone Spiders.

the most modern speakers, the glue must be placed *under* the spider upon the surface of the frame and, with the shims properly positioned, pressed until dry.

In the older type of speaker, with an open spider, glue is not used at all. Instead the bolts which hold this spider in position are loosened, the spacing shims inserted, the holding bolts tightened, and finally the shims are removed. Examples of open and closed spiders are shown in Fig. 32.

It should be emphasized that re-centering will not help the condition of a *warped* or out-of-round voice coil form, since here it is not a matter of centering, but of alignment of the coil form within the limited space where it should freely move.

The service man should, in the case of speaker defects, ask himself this pointed question: "Is it wise, in this case, to replace or re-center the cone; or would it be better to install a completely new speaker?" The answer to this question will, of course, be determined by the nature of damage, and to other local circumstances for which no general rule can be set. Yet in most cases it is usually more satisfactory to replace the speaker than to attempt the repair of a cone.

NOTES FOR REFERENCE

Modern speakers may be classified as follows:

1. PM dynamic type.
2. Electrodynamic type.
   a. The low resistance field, or "choke" type.
   b. The high resistance field, or "bleeder" type.
   c. The 6-volt type.

Each type can be identified by its appearance or the nature of its field connections. Identifying the speaker type is the first step in trouble-shooting this component.

NO SOUND OF ANY KIND IN SPEAKER. Look for open voice-coil, or open circuit in primary or secondary of the matching transformer. If B-plus is absent and speaker is perfectly silent, look for open in low resistance field coil, or for shorted filter condenser in the power supply, and check the rectifier tube carefully.

SIGNAL DISTORTION. Look for friction in the voice-coil, a torn speaker cone, looseness of the cone. In an automobile receiver check the ground return of the speaker field coil, and the speaker core for magnetic pull. In high resistance field speakers, check for open field coil and test magnetic pull.

WEAK SIGNAL. Look for open field winding.

HOWLING, after replacing the output transformer. Reverse the leads to either the primary or the secondary of this transformer.

HOT FIELD WINDING. In a low resistance field speaker, look for a shorted output filter condenser or a short anywhere across the "B" voltage. Both the signal and the hum will be absent under this condition. An overheated *high resistance* field winding cannot occur, under ordinary circumstances.

Where a speaker trouble is intermittent, look for its cause in a *temperature change*. This applies especially to intermittent distortion, and cutting out of the speaker sound at random intervals. A change in temperature may expand or contract the close fitting parts and cause them to bind. The correction is to provide a little additional tolerance. This is not a frequent cause of trouble but a good service man will keep the possibility in mind.

Speaker circuits may involve voltages as high as 300 volts, and damage to personnel and equipment should be avoided. Use the proper voltage scale of the multimeter, and turn receiver power off when making ohmmeter tests.

As a final precaution if a low-resistance field is open, and receiver power applied, the input filter condenser *will charge up and have no discharge path*. Don't let that discharge path be *your* body! Use a screw-driver or insulated jumper to discharge all high-voltage condenser circuits before handling them.

NOTES

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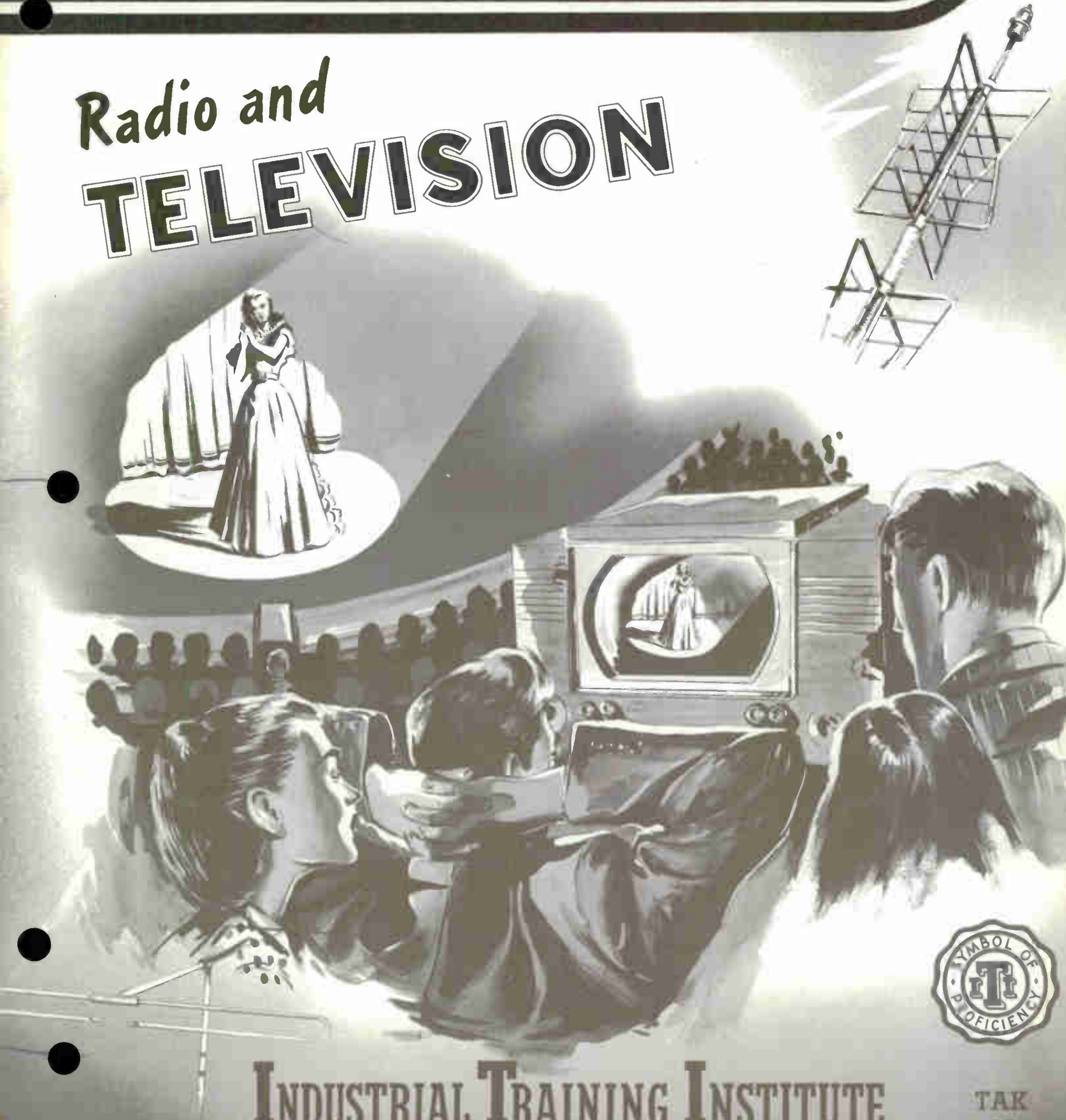

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TECHNICAL TRAINING SERVICE

RADIO TELEVISION

THE AUDIO SECTION

Contents: Introduction - Essentials of the Audio Section - First Procedure - The Output Stage - Output Transformer - R-F By-Pass - Grid Leak Resistor - Cathode Bias - Coupling Capacitor - Operational Test for the Output Stage - Testing with Signal Generator - Common Troubles in Output Stage - Motor Boating - Other Troubles and their Symptoms - The Driver Stage - Volume Control - Notes for Reference.

Section 1. INTRODUCTION

The audio section of a radio or television receiver is that portion designed to accept the amplified signals which are audible to the human ear. A glance at the block diagram in Fig. 1 will show the functional location of the audio section and its relation to the rest of the receiver.

The block diagram does not detail the signal circuit of the receiver, which means that it does not indicate whether it is a TRF or a superheterodyne circuit. Neither does it show whether it is an A.M., F.M., or television receiver. The essential elements for all types are indicated. The signal must be "captured" from space by the antenna, selected from all other signals by the tuning section, its audio component must be extracted by the detecting section, and the audio signal must be faithfully amplified in the audio section, then fed to the loudspeaker or picture tube for conversation into audible or visual energy.

Section 2. ESSENTIALS OF THE AUDIO SECTION

Fig. 2 enables us to compare the functional block diagram of the superheterodyne receiver with that of the TRF receiver. Note that while the tuning sections differ, and the detecting sections are somewhat

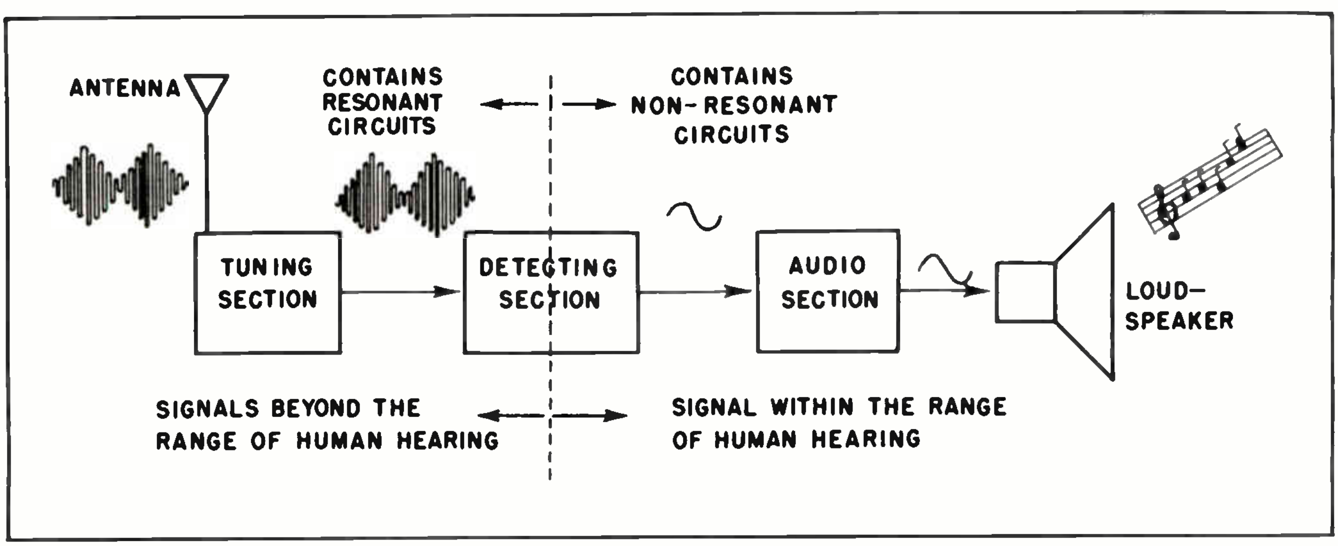

Fig.1. Block Diagram of Sound Channel.

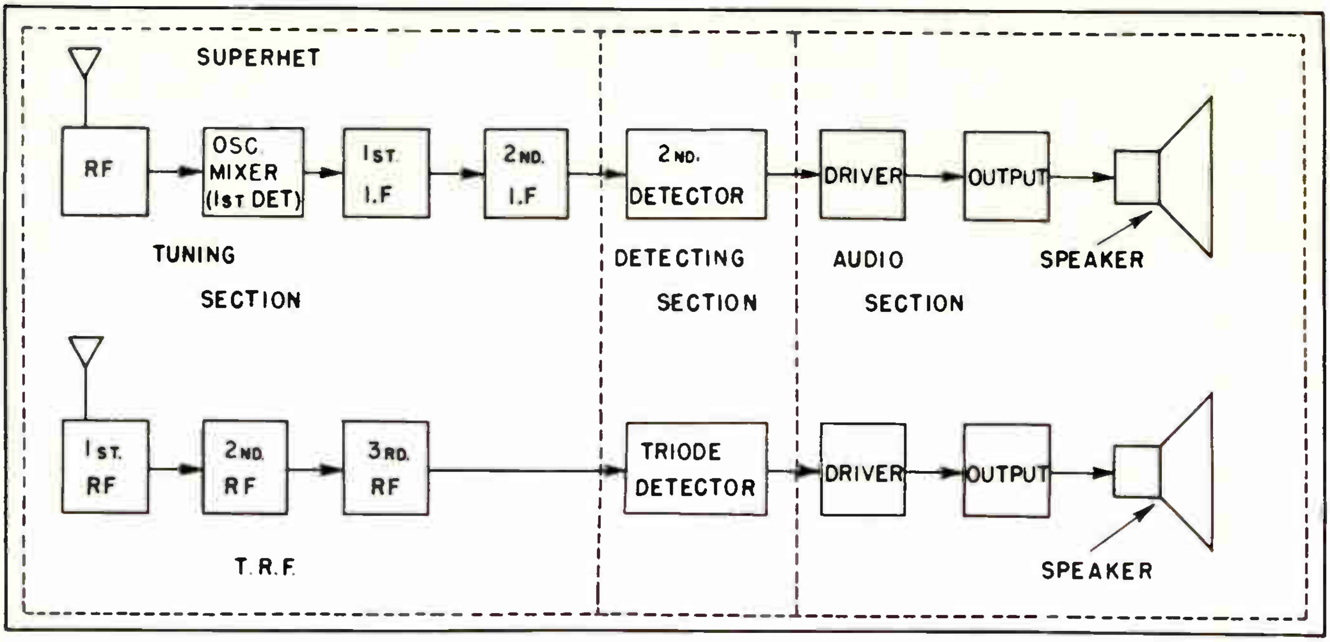

Fig.2. Block Diagram of Two Main Types of Receivers.

different, the audio sections are the same. It is important to note that while the signal may be tuned by either a TRF or superheterodyne in A.M., F.M. or television tuning circuit, the sound signal from each after demodulation in the detector, is audio and must be handled like audio frequencies.

This places certain requirements upon the audio section design. These requirements may be stated briefly as:

1. The signal must be acceptable to the grid circuit of the first audio stage -- the driver.

2. The signal must be amplified sufficiently to be heard.

3. The signal must be faithfully reproduced in each stage of amplification of the audio section. None of the original content of the signal should be lost, and no new, undesirable content should be introduced.

4. The signal from the output stage must be acceptable to the speaker.

5. The speaker must change the signal to its final form -- sound energy whose variations are patterned after the electrical impulses causing them.

It is our purpose here to show how these four basic requirements are built into the audio section of a radio or television receiver. We also show how trouble-shooting the audio section is a matter of correcting the cause of any variation from the four named requirements. While tuning, detector, and speaker-section trouble-shooting are discussed in detail elsewhere, frequent reference will be made to other parts of a receiver where they affect the operation of the audio section. For while it is true that the audio section is a separate and distinct portion of the receiver, it does not exist alone -- it is related to every other portion of the receiver. Trouble-shooting the audio section will depend to a great extent upon your understanding of how all the sections of a receiver are related to each other, and to their common power supply.

Several stages comprise the audio section of most receivers. This is illustrated in Fig. 3. They are:

1. The driver, or voltage amplifier stage.

2. The output, or power amplifier stage.

3. In push-pull amplifiers only, a phase inverter stage may be inserted between the driver and the push-pull output stages.

Section 3. **FIRST PROCEDURE**

It should be evident by this time that the process of radio and television trouble-shooting must have some specific starting point. If some definite starting point is not used, trouble-shooting will become a haphazard array of wild guesses. While some of these wild guesses, in rare cases, may point to the real trouble, the method is not reliable, and is not recommended. On the contrary, such a method of electronic trouble-shooting is wasteful of time and energy, and will lead you into an endless maze of useless and meaningless tests.

On the other hand, if you fix a starting point for your analysis, you are well on the way toward a rapid solution of the trouble at hand. The audible and visible symptoms -- which are merely the outward signs of more deep-seated trouble -- combined with a few well-directed voltage and resistance readings, will give you an array of facts from which you can readily deduce the cause of the trouble. With a definite starting point, each new fact will bring the trouble (as yet unknown) within a continually narrowing range. Finally, when the possibilities are narrowed down to only a few, you can make specific checks on the suspected component parts to determine which of them is responsible for the operational failure of the receiver.

Reference to the block diagrams of Fig. 2 will show that in a radio receiver there is a chain of links between the signal at the antenna and the listener's ear. If any one of these links is broken or disturbed, the receiver will not operate properly. Moreover, each link depends for its signal upon the link before it, and it -- in turn -- provides the signal for the link following it. If we examine any link in the chain (that is, any stage of a receiver), we can by appropriate tests determine if the trouble lies in the stage tested, in a following stage, or in a preceding stage.

When any stage accepts a normal signal but does not deliver a normal signal, that stage is at fault. If a stage accepts no signal, but delivers one when introduced in the stage artificially, the trouble lies in one of the previous stages. If a stage accepts a normal signal and delivers a normal signal, but the receiver does not operate properly, the trouble must lie in one of the following stages.

From this point of view, then, we shall find it wise to use as our starting point the very last component of the receiver, the last link between the receiver and the listener's ear. The last link in a radio or in the sound portion of a television receiver is the loud-speaker. Regardless

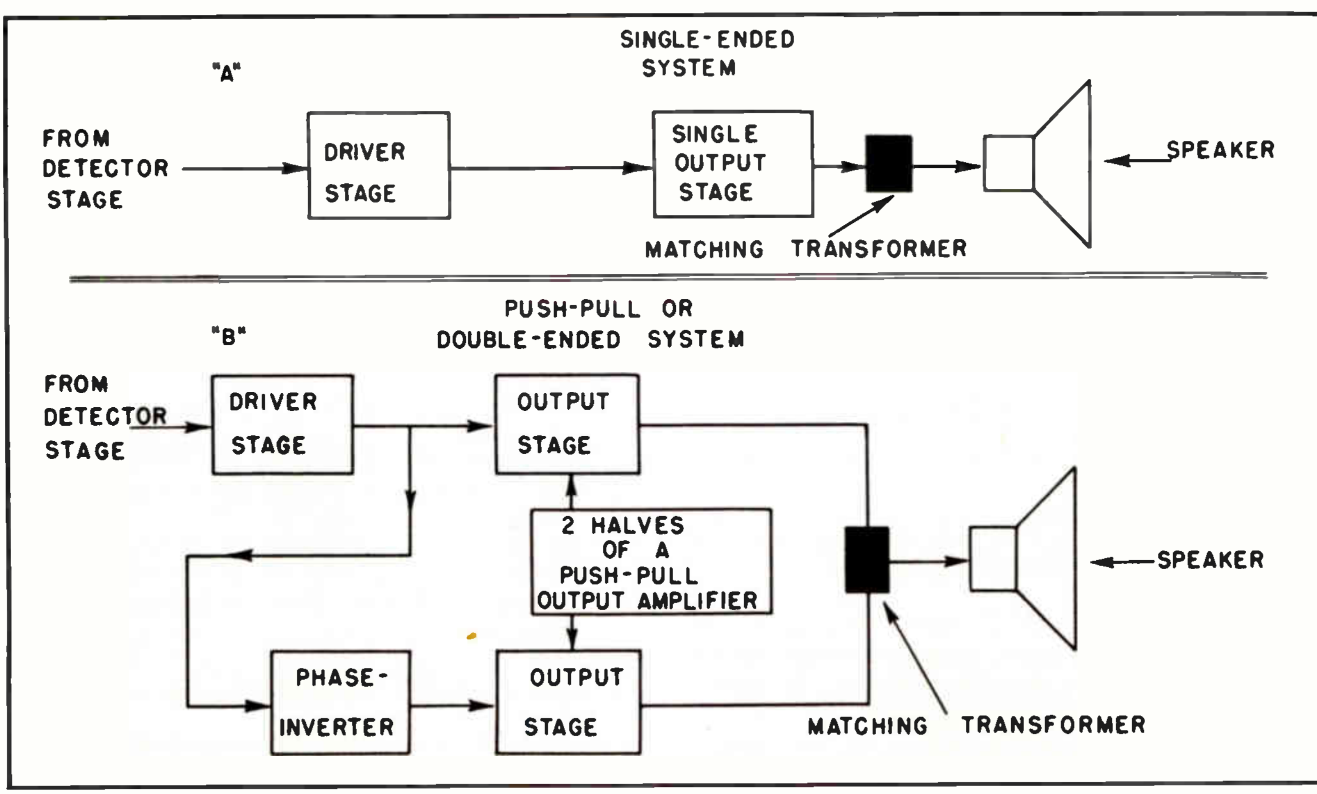

Fig.3. Block Diagram of Audio Section.

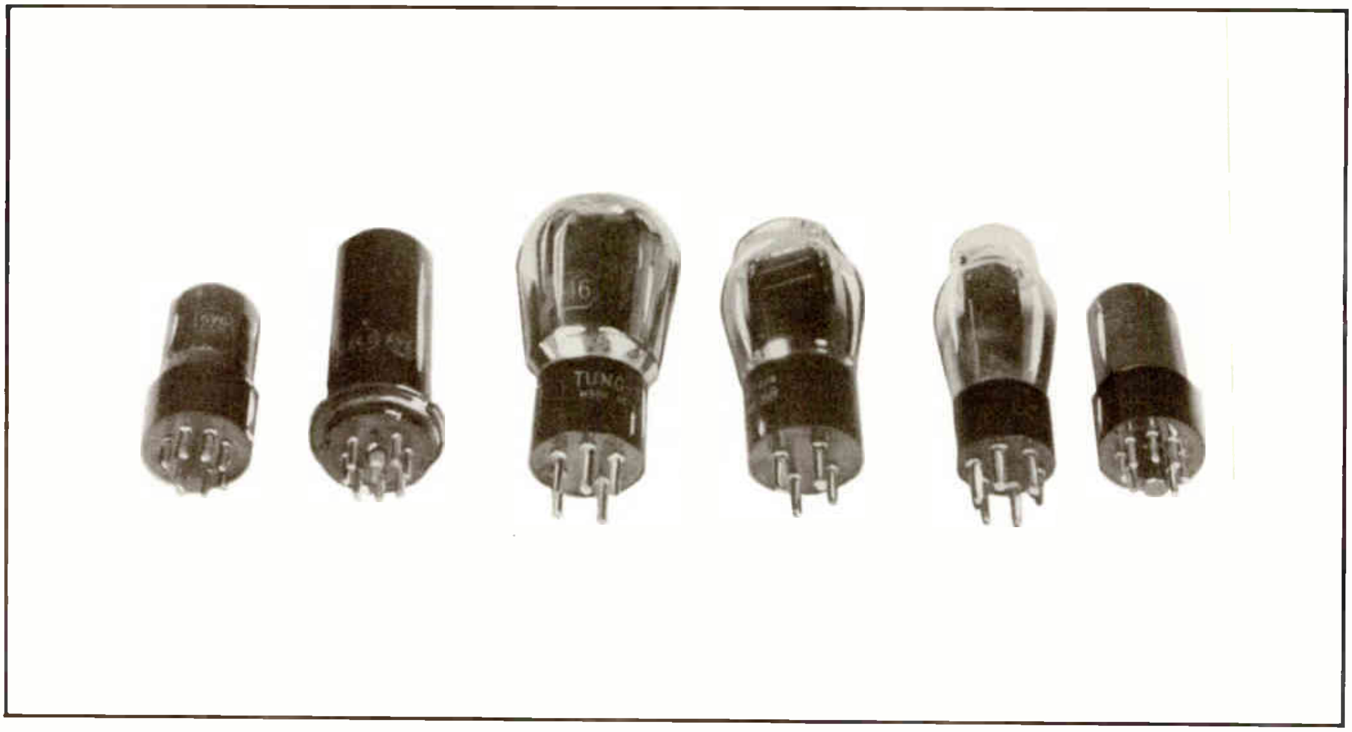

Fig.4. Common Tubes Used in Audio Section.

of any other trouble, if the speaker is defective, normal operation of the receiver is impossible.

Speaker trouble-shooting has already been discussed. Tests for determining normal speaker operation have been outlined. If we find the speaker is operating properly, our next step will be to check the stage which provides the speaker with its signal -- the output stage. If the output stage is at fault, the speaker will not be fed the proper signal.

Section 4. **THE OUTPUT STAGE**

The output stage is the link between the first part of the radio or television receiver and the loudspeaker, and should be tested for normal operation immediately after the speaker has been tested. Fig. 4 is a photograph of some of the more common types of output tubes (also called power amplifiers, or power tubes) used in various types of radio and television receivers.

It has been mentioned that all tubes, including the output tube, should be checked as a routine procedure before making any circuit tests. Defective tubes are found to be the cause of a great majority of radio troubles.

The purpose of the output stage is to accept the signal, in the form of alternating voltages from the driver stage and convert them to current changes. This current is then fed through the matching transformer (included as a part of the output stage) and energizes the voice-coil of the speaker with signal current.

Fig. 5 shows schematically a typical output stage circuit. This is what is called a "single-ended" output stage, since it has only one output amplifier tube. It is contrasted to a push-pull (or "double-ended") system employing two output tubes. The push-pull amplifier will be discussed later. Let us sketch an outline of the function performed by each component of the output stage of Fig. 5.

Section 5. **OUTPUT TRANSFORMER**

The impedance-matching transformer, more commonly known as the "output transformer", has the single function of matching the high impedance in the plate circuit of the tube to the low impedance of the voice-coil of the speaker. This is for maximum power transfer from the tube, which can be considered as a generator operating at signal frequency, to the voice-coil, which can be considered the load.

Maximum power transfer means that most of the energy originating in the output tube will be delivered to the voice-coil, with little losses in the intervening components. Maximum power transfer also means this high efficiency will be maintained throughout the entire range of audio frequencies, from the very lowest to the very highest. Operationally, this means the tone, or quality, of the signal will have retained all its original harmonic content. The result of proper impedance matching is that music and speech sound life-like and rich in quality.

An open circuit in either the primary or secondary of the output transformer will mean that not only will the original signal be absent from the speaker, but every other sound will likewise be absent. In other words, the speaker will be absolutely silent, producing no sound of any kind. An open primary will cause complete silence because of the lack of any current in it. An open secondary will cause complete silence because no current will be able to circulate through the secondary circuit to the voice-coil.

Section 6. R-F BY-PASS

By-pass condenser, *C-3* in Fig. 5, is inserted between plate and cathode of this stage to shunt unwanted harmonics, generated in the tube, away from the transformer primary. It will also by-pass that residue of R-F frequencies which squeeze past the detector stage. Should this condenser become open, these undesirable frequencies (not a part of the original signal) will impart a hissing or screeching tone to the signal at the speaker. If *C-3* is short-circuited (a common trouble), B-plus will be shorted to ground through the cathode resistor, resulting in an inoperative output stage.

It should be added here that *C-3* is sometimes connected to the screen grid of this stage, and -- in a few cases -- to ground directly. This is a matter of designer's choice. However, standard practice places *C-3* as shown in the schematic diagram. A certain amount of degenerative action adds improvement to tonal response.

Section 7. GRID LEAK RESISTOR

The function of the grid resistor, *R-1* of Fig. 5, is to leak off excess electrons from control grid to ground. If open, *R-1* will not permit electrons accumulating on the grid (actually "robbed" from the electron stream within the tube) to move off the grid. This constitutes a "static charge" on the grid, driving it much more negative than its normal Class-A operation, and ordinarily blocks the stage. A blocked stage is one in which, for some reason, no plate or screen current can flow. Of course, a blocked stage is an inoperative stage, and serious trouble is indicated when blocking occurs.

Section 8. CATHODE BIAS

The purpose of *R-2*, the cathode resistor in Fig. 5, is to provide Class-A bias for the stage, and is simply a conventional

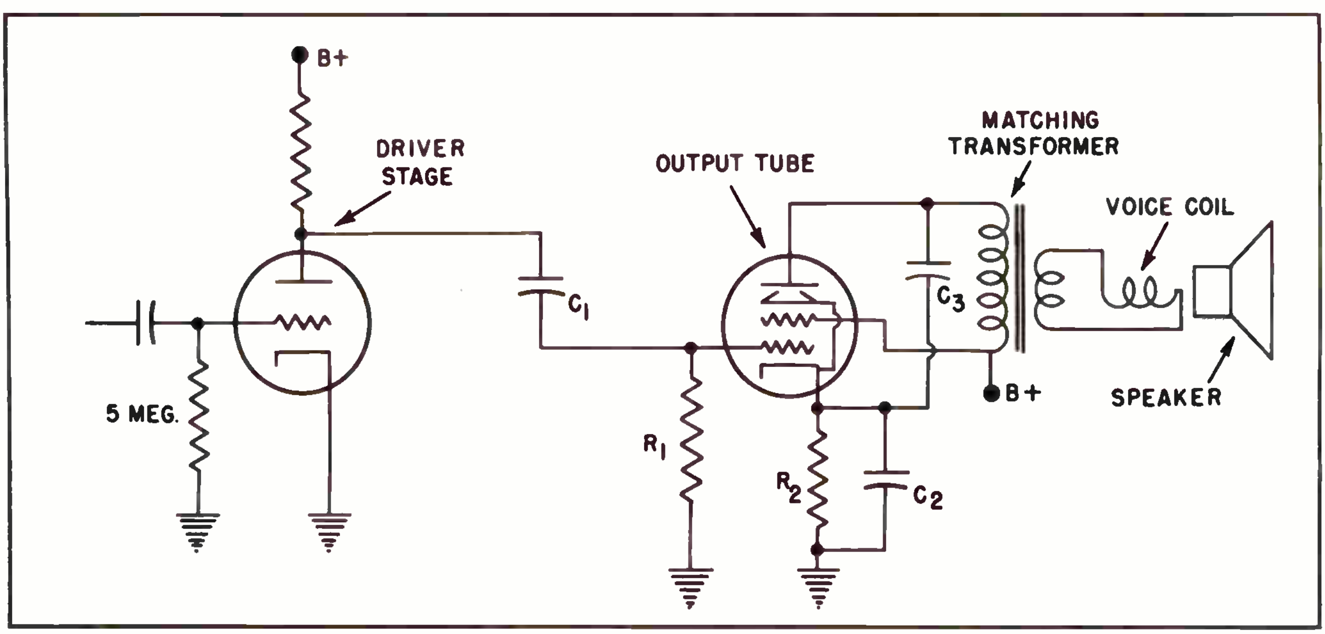

Fig.5. Typical Output Stage.

cathode-biasing circuit arrangement. Plate and screen current flowing upward from ground through the tube must first traverse the cathode resistor which is of such size as to create a drop of the desired voltage for the bias of the stage.

Normal bias on the grid of the tube for this stage is usually about 10 negative volts. Control grid bias is measured with respect to the cathode. It should be remembered that this condition is achieved not by lowering the grid with respect to ground, but by raising the cathode potential with respect to grid. Tube current, flowing through the cathode resistor, thus raises the cathode to the required number of volts.

The cathode by-pass condenser, *C-2* in Fig. 5, is employed to smooth out the pulsating D-C bias achieved by the cathode resistor. The by-pass condenser shunts the cathode resistor. This condenser is sometimes omitted from the circuit. When omitted, the bias on the stage has a pulsating value, in accordance with signal frequency, and serves to *degenerate*, or weaken, the strength of all the frequencies. The power gain of the output stage is very high. This is made possible by the high transconductance of modern tubes. It has been found that when degeneration is used in the output stage, somewhat more linearity (faithfulness) is available in signal tone.

Where the output stage favors the high frequencies, the cathode by-pass condenser is inserted as shown in Fig. 5. Its capacitance, around 10 mfd, is sufficiently high to stabilize the voltage drop across the resistor even at the very low frequencies, with the result that they are no longer degenerated and are brought to the speaker in their full strength. This effect adds depth to the tone in the speaker, and makes a small receiver sound rich and full.

It is evident, therefore, that if *C-2* is open, the receiver will sound high-pitched and very "brilliant". On the other hand, if *C-2* is short-circuited the cathode will be brought to ground potential. The tube will then go to zero-bias and become voltage saturated. The signal at the speaker will be absent altogether or will sound weak and distorted.

Section 9. COUPLING CAPACITOR

Coupling condenser *C-1*, also called the blocking condenser, is used to keep the highly positive B-plus voltage from the grid of the output stage. At this point, the signal from the driver is in the form of plate voltage changes. We are interested in the *changes*, not the D-C component of the driver plate voltage. The coupling capacitor is ideally suited for this purpose, permitting the changes (the A-C or signal component) to pass through to the output tube's grid while barring the D-C component.

It is evident that if the output tube's grid were driven highly positive by a

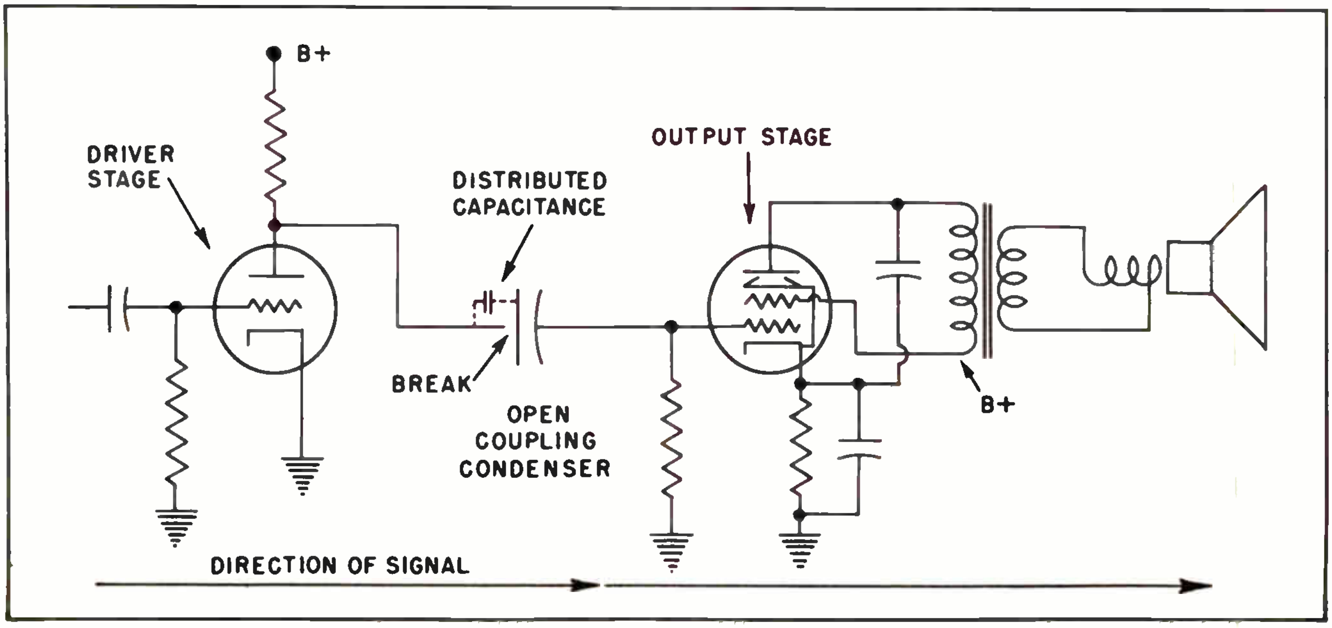

Fig.6. Action of Open Coupling Capacitor.

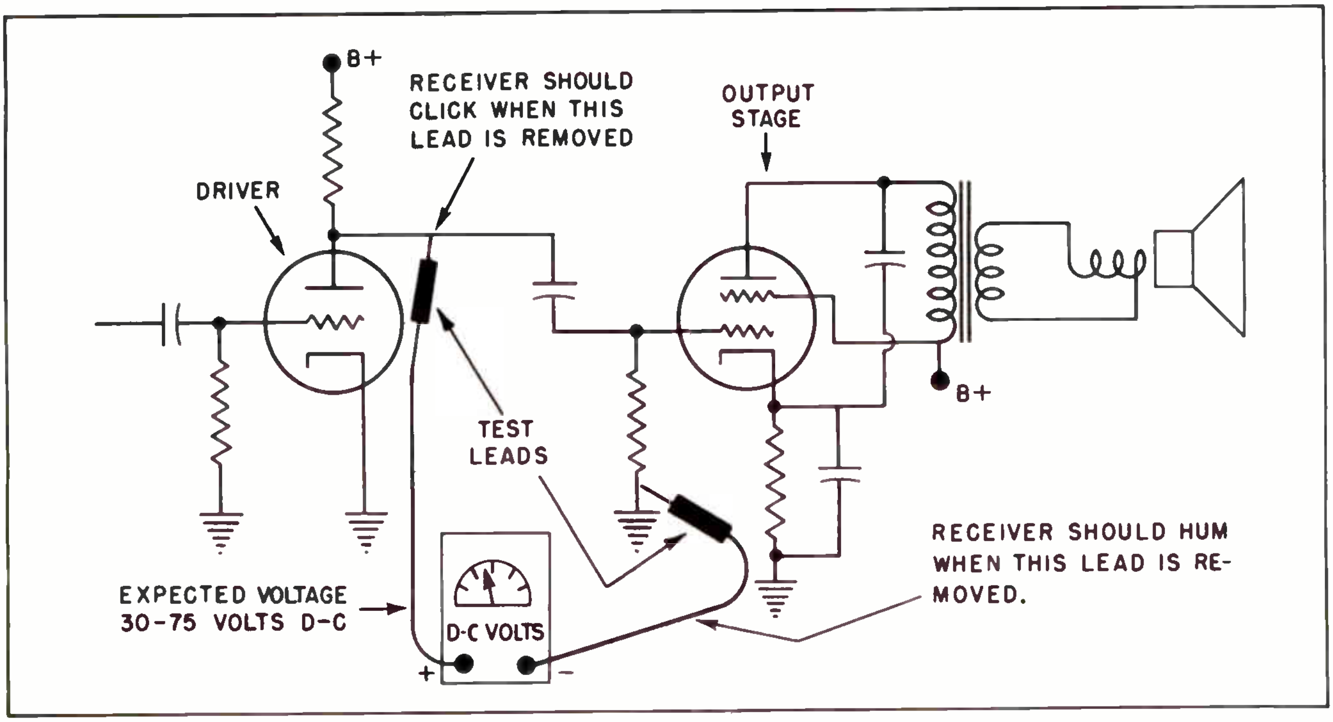

Fig. 7. Testing Output Stage with a Voltmeter.

shorted or leaky *C-1*, the output stage would at once go to saturation. The signal would then be lost completely, or badly distorted. If condenser *C-1* were open, the symptoms would be a decided drop in signal at the speaker, with a distinct favoring -- in what is left of the signal -- of the higher frequency notes.

Fig. 6 illustrates how even an open coupling condenser can permit a small amount of signal to pass through, and shows why this small amount of signal will contain only the very highest of the audio frequencies. The very low value of the distributed capacitance across the break in this unit has a high reactance to the low frequencies of the audio signal, but it has much less reactance to the very high frequencies. The lows are effectively barred, while the very highs get through in reduced strength.

Section 10. OPERATIONAL TEST FOR THE OUTPUT STAGE

Testing the output stage for normal operation is a rather simple matter, and can be done in several ways. The most effective of these methods will be described.

Place one test lead of a D-C voltmeter on the 300-volt scale, at the plate of the driver; place the other voltmeter lead at B-minus, which is the negative side of the filter condensers. In a normally operating output stage, the following actions will take place:

(1) If the meter leads are held as described, (see Fig. 7) the meter will read a D-C voltage of 30-75 volts.

(2) A sharp click will be heard in the loudspeaker at the instant the meter lead is placed upon the driver plate or removed from it.

(3) If the B-minus lead of the voltmeter is lifted from its contact, and the positive lead allowed to remain on the driver plate, a low-toned (60-cycle) hum will be heard at the speaker.

If these three steps of the procedure are found to give the results indicated, we have learned a wealth of valuable information.

The tests tell us the speaker, the speaker transformer, the output stage itself, and the coupling condenser to the output stage grid are all in good condition. Step *(1)* indicates B-plus is normal in the receiver and that the normal drop is occurring in the driver plate load resistance. Step *(2)*, the speaker click, tells us that the coupling condenser is neither open nor shorted. Step *(3)* tells us that a 60-cycle audio hum, picked up by the voltmeter leads from nearby power wiring, is accepted by the output stage, amplified there, and fed to the speaker as any low-frequency audio note should be. Moreover, the entire procedure permits us to infer that biasing in the output stage is normal, that the output tube is essentially good, and that the voltages at the pins of the output tube sockets must be normal.

This procedure fails to tell us about one possible fault; if the output tube is "gassy" neither this test nor a tube-checker test may indicate this important tube fault. Causes of distortion will be discussed later and the specific test for distortion originating in the output tube will be described.

Section 11. TESTING WITH SIGNAL GENERATOR

Another method of testing the output stage for normal operation is illustrated in Fig. 8, where a signal generator, originating audio frequencies, is connected to the output stage grid. If the signal generator output is heard reasonably loud and clear in the speaker, a normally operating output stage is indicated. If the results are as expected, every circuit component lying between the output stage grid and the loudspeaker can be accepted as being in good condition. This includes the output tube itself. By placing the "high" side of the signal generator at the driver plate, (see Fig. 8) the test can be extended to include the coupling condenser leading to the output grid.

While the voltmeter test is somewhat easier, the signal generator method is more complete. It will reveal distortion if it is present in the output stage in addition to showing the condition of the individual component parts.

If the operational test for the output stage fails; that is, if the tests disclose trouble, the trouble in this stage can be approached by voltmeter and ohmmeter checks of its component circuits. Normal output stage voltages, measured with respect to B-minus (unless otherwise specified) are illustrated in Figs. 9, 10, 11 and 12, in which voltages peculiar to each of the four major types of radio receivers are presented.

It is of utmost importance that the receiver under test be identified and comparisons made with the proper group of expected voltages. Circuits and components can be further checked by the use of an

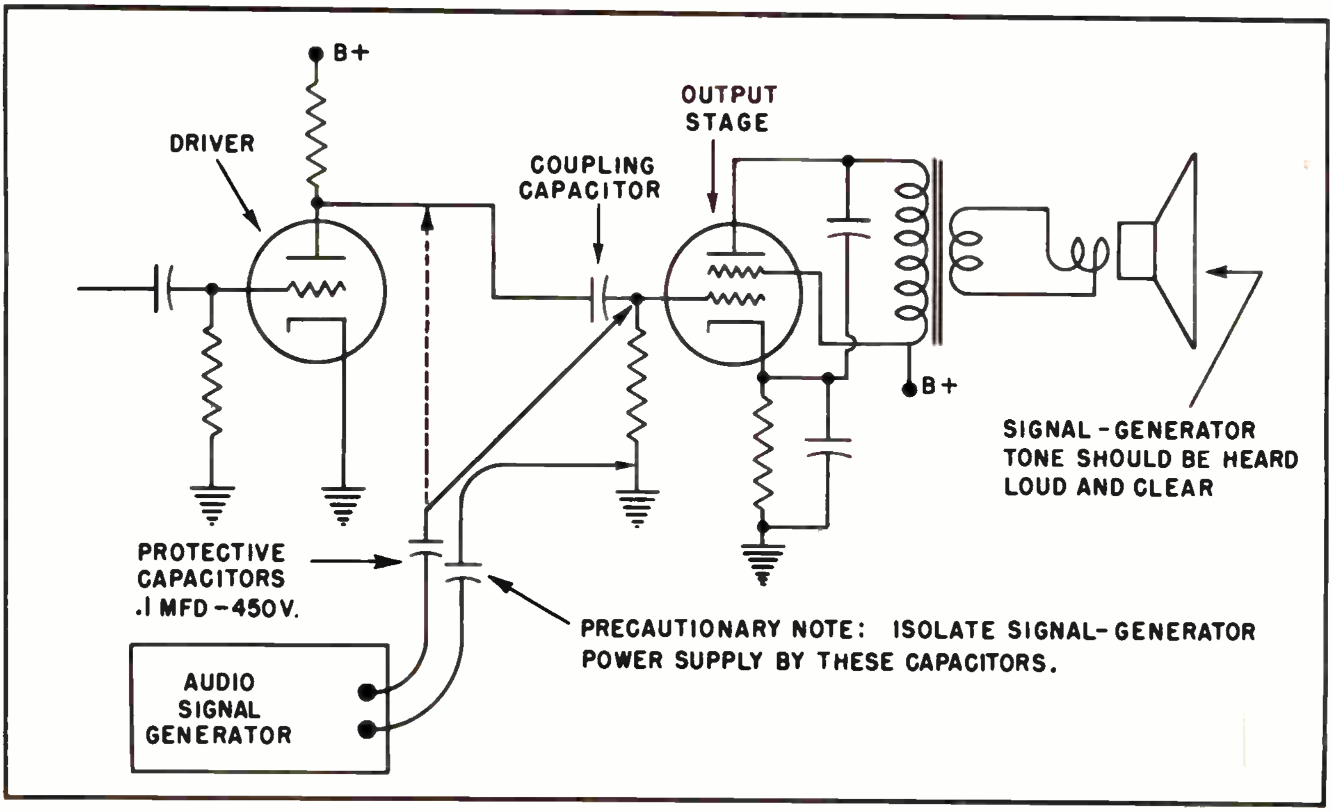

Fig.8. Using Signal Generator to Test Audio Section.

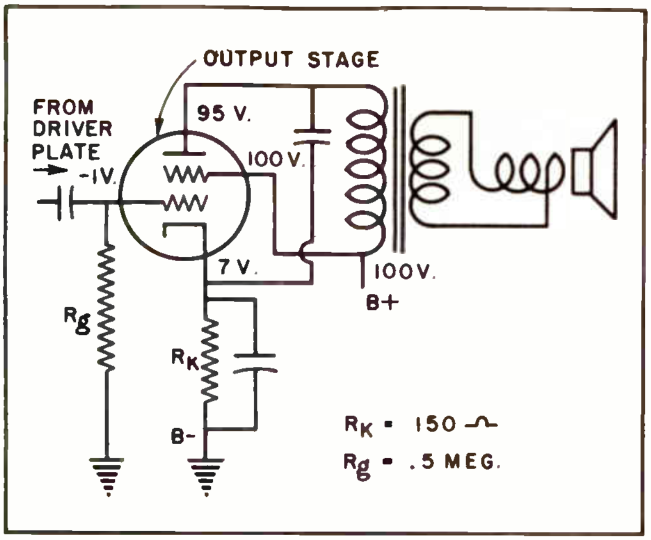

Fig.9. Output Stage of an AC-DC Receiver. The Voltages are Approximations.

ohmmeter, the expected readings of which are indicated in the illustrations. In checking the audio section of a television receiver first determine which general classification it falls into.

The failure of a receiver to operate properly can be traced to the output stage when either of the two operational tests given above do not give the results expected for normal operation. It has previously been indicated that the output stage should be operationally tested after the tubes and loud-speaker have been checked and found good.

Section 12. COMMON TROUBLES IN OUTPUT STAGE

If the tubes have been tested and found good, and if the speaker is known to be good, symptoms and conditions indicating trouble in this stage will betray themselves in certain definite ways. Output stage troubles can be suspected when the following symptoms and conditions are recognized:

Speaker is known to be good, signal is badly distorted, and a positive voltage of any value is found on the output tube control grid. Look for a shorted or leaking coupling capacitor to this grid.

If distortion begins after a 5 to 30 minute delay, the output tube, in spite of the fact that it checks good on the tube-checker will usually be gassy.

If signal is badly distorted and output stage cathode resistor is hot or appears burned, look for a shorted or leaking coupling capacitor to the output tube grid. Measure the ohmage of the cathode resistor, and compare with standard value. Replace the shorted or leaky condenser first, and replace the cathode resistor. (NOTE: If distortion occurs as soon as the receiver begins to play, the output tube need not ordinarily be suspected of being gassy.)

If signal is badly distorted and there is excessively high cathode voltage (around 25 or 30 volts, instead of the usual 7-10 volts), look for open cathode resistor, which can be measured with an ohmmeter while power in the receiver is turned off. Compare ohmage with standard value. This trouble may be more readily suspected when, in measuring the cathode voltage with a voltmeter, the signal becomes somewhat louder and clearer while the meter tests leads are across the cathode resistor. The reason for this phenomenon is that the resistance of the meter, while still a long way from being the correct cathode resistor value, provides some additional path for tube current from ground to cathode.

If signal is distorted and cathode-to-ground voltage is zero, instead of the usual 7-10 volts, look for a short-circuited cathode by-pass condenser. The capacitor can be measured with the ohmmeter on its lowest scale. This condenser need not be removed electrically from the cathode circuit to make this test, as long as you remember that in reading across this condenser the ohmmeter will also read across the cathode resistor as well. Maximum

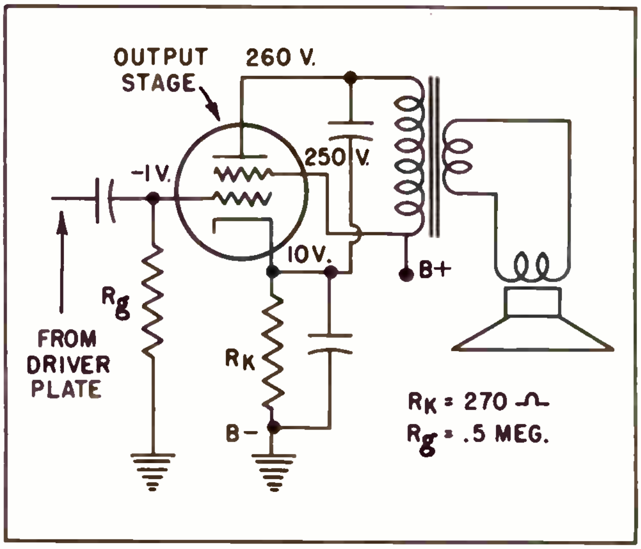

Fig.10. Output Stage of an A-C Receiver. Voltages are Approximations.

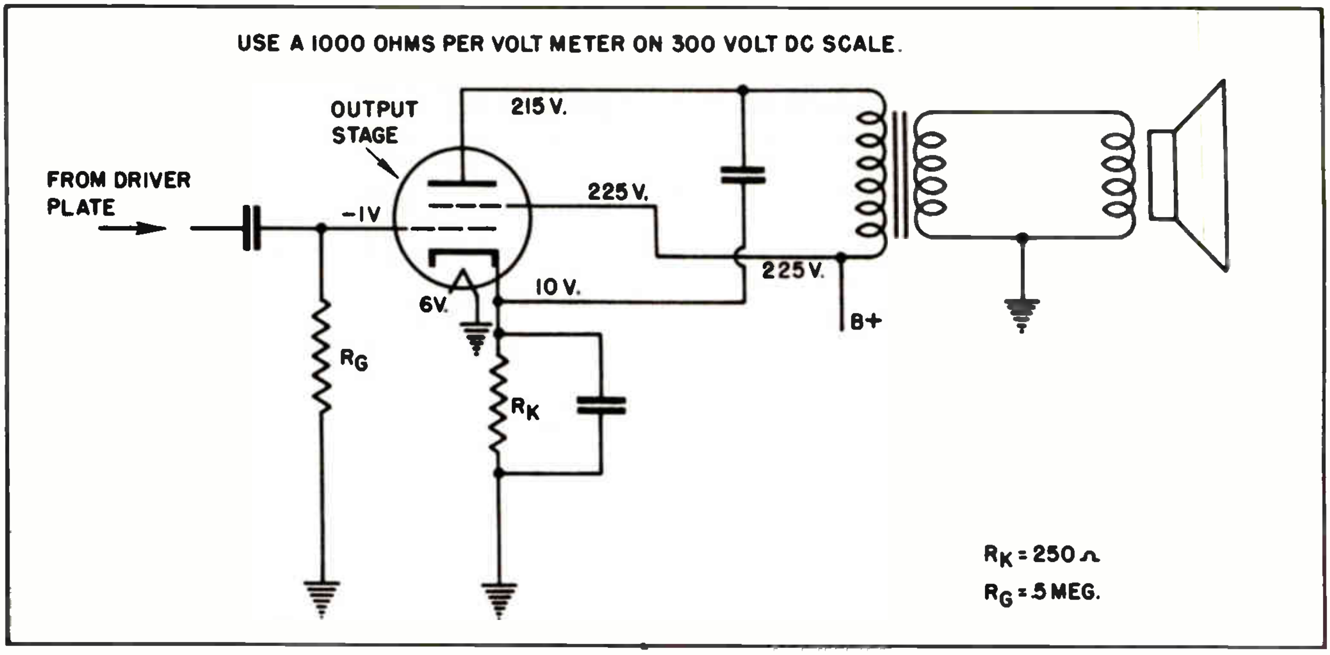

Fig. 11. Output Stage of an Automobile Receiver.

resistance on this test should be that of the cathode resistor. Zero resistance, of course, means that the condenser is short-circuited. Replace the condenser and test the receiver.

If signal is normal except that it seems to lack full volume and full tone; cathode voltage is normal. Care should be taken here to distinguish between two types of reduction in signal volume. The first is the almost complete loss of the signal, where the ear can barely hear it. The second type is the reduction which, though nowhere near a complete loss, "seems" to

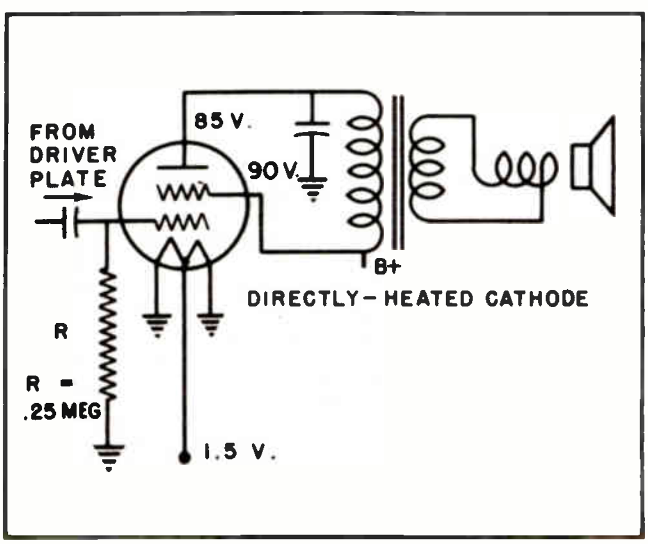

Fig. 12. Output Stage of a Portable Receiver.

the user of the receiver to be somewhat below its customary loudness and depth.

The second type of volume reduction may be due to an open cathode by-pass condenser. As mentioned previously, the purpose of this condenser is to avoid degeneration of the low audio frequencies, and thus lend fullness to the signal tone. In those circuits where this condenser is omitted, it cannot -- of course -- be defective, and reduced volume, as noticed by the user of the receiver, will be due to other causes such as mis-aligned I-F stages, weak tubes or an open screen by-pass condenser.

A simple test for an open cathode by-pass condenser is to set the receiver on a fairly strong station with the volume control moderately advanced. While the receiver is playing, shunt the suspected open cathode by-pass condenser with its equivalent in mfd and voltage ratings, making certain that the plus and minus polarities are in agreement with those of the suspected condenser. If the condenser is open, shunting its equivalent across will bring the signal volume and tone into a noticeably better condition.

Excessive hum in any position of the volume control, accompanied by clear and normally loud signal. This combination of symptoms is generally due to an open or deteriorated output filter condenser. Where replacing the output filter condenser does not correct the excessive hum, or where detailed tests indicate that the trouble does not lie in this condenser, nor in the input filter condenser, it will probably be found in the condition of the output tube. This condition is a leakage (a high resistance short-circuit) between the output tube cathode and the heater. It often will not be revealed by the tube-checker, unless this tube is allowed to warm up for a longer period of time than is ordinarily allowed in a routine tube-testing procedure. A practical hint can be given in this connection: In cases of excessive hum in a receiver, since it is easier to replace the output tube than to test or replace the filter condensers, it may be wise to try this possibility first. That is, replace the output tube before checking the filters. If a new and supposedly good output tube does not remove the excessive hum, check the filters. If a new output tube removes the hum, no further time need be spent in correcting the trouble.

Section 13. MOTOR BOATING

This characteristic "put-put-put-put" sounds like a motorboat engine, and may be fast or slow motorboating depending upon certain circuit constants. Motorboating in a receiver can be laid to an open grid leak resistor in the output stage, or one which has altered its value to a higher resistance. A simple way to trace the source of motorboating to an open grid leak resistor is to place the voltmeter leads across the suspected resistor, as if reading its voltage and note any reduction or change in the nature of the signal. If the grid resistor is open, the resistance of the meter will act as a grid leak resistor. The motorboating will stop, and the receiver will play normally.

An open grid leak resistor will also be indicated by the voltage reading on the voltmeter during this test, being around 5-10 volts negative on the grid with respect to ground. Note that in a cathode-biased output stage, this negative voltage is not normal, since the grid is essentially at ground potential and the cathode is raised to bias voltage above both grid and ground. If this double-edged test indicates an open grid leak resistor, the meter may be removed and a new grid resistor installed. Where this test fails to remove motorboating, look for trouble in mis-aligned I-F stages or in an open or deteriorated output filter condenser.

In rare cases, motorboating may be due to too much capacitance in the coupling condenser to the output stage. This trouble, however, is extremely rare and may occur when errors of assembly have been made. Radio receivers are carefully made, and

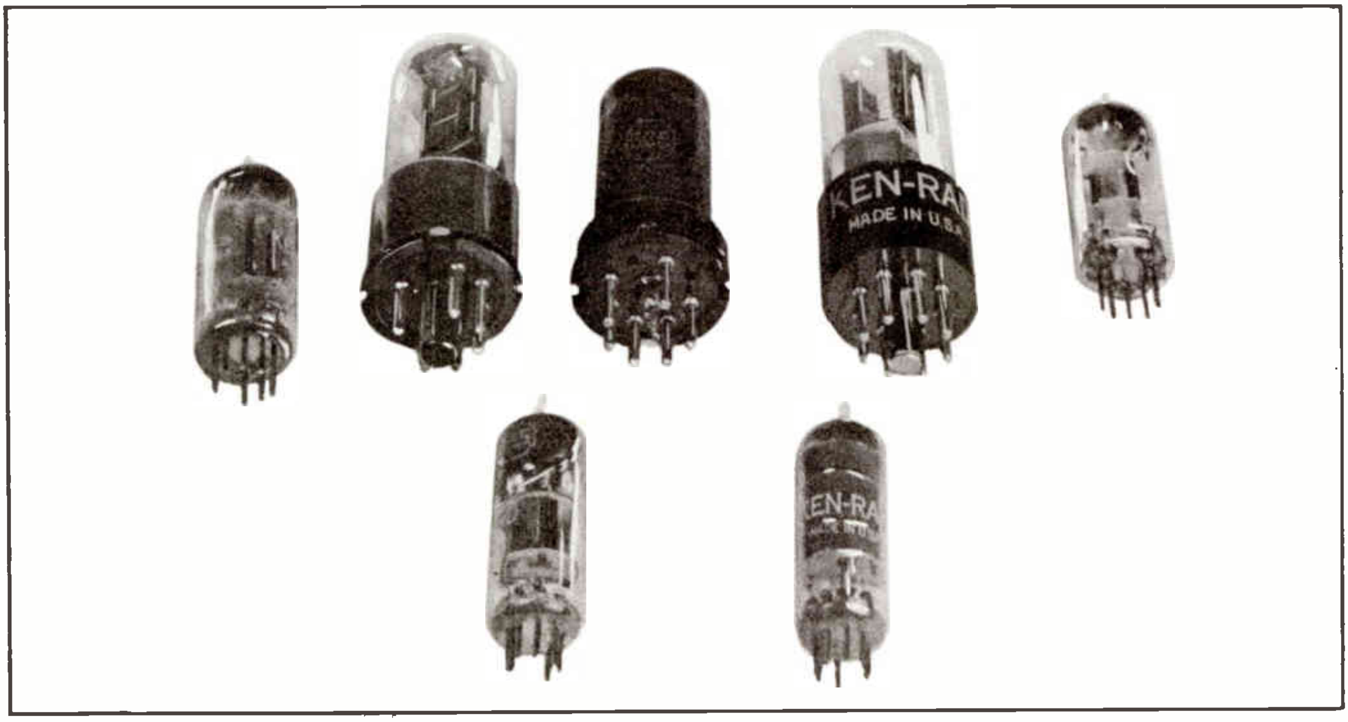

Fig.13. Typical Tubes Used as Drivers.

while it is possible that too large a capacitor may have been installed during manufacture, the condition is highly unlikely. Factory components in radio receivers are almost never wrong.

Section 14. OTHER TROUBLES AND THEIR SYMPTOMS

Signal extremely quiet, but all voltages are normal. This trouble is often intermittent, and is due, whether intermittent or not, to an open coupling condenser to the output stage grid. To confirm the suspicion of an open in this condenser, shunt it with an equivalent, noting any change in signal reception. If the trouble is intermittent, it is important that the shunt should be placed across the suspected condenser during the time that the signal is quiet, for no difference will be noted when reception is normal. If periods of poor reception are inconveniently short during this intermittent trouble, the open condition may be induced to manually twisting or pulling the suspected condenser, being careful not to destroy it if it is not defective. A good condenser will stand a certain amount of moderate twisting or pulling, but if intermittently open, such manipulation will soon show up in a sharp drop in signal volume.

Section 15. THE DRIVER STAGE

We may now turn our attention from the output stage of a radio or the audio section of a television receiver to the stage which feeds the audio signal to the output stage. This is known by various names, such as the first audio stage, the driver stage, or the voltage amplifier stage. For the sake of brevity, we shall use the term *driver* to indicate this stage, bearing in mind that it is a voltage amplifier and that it is almost universally the first audio stage of a radio or television receiver.

The purpose of the driver stage in a radio or television receiver is to accept the audio signal from the detector, amplify its voltage, and send it in faithful form to the grid of the output stage. Pictured in Fig. 13 are several tubes commonly used in the driver stage. The schematic diagram of Fig. 14 illustrates the typical driver circuit, in its relationship to the volume control, the output stage, and the power supply. Let us outline the purposes of the individual components of the typical driver stage.

Section 16. VOLUME CONTROL

The manual volume control is used to vary the audio output of the receiver by varying the amplitude of the signal voltage applied to the driver grid. The sliding tap can select any value of the signal voltage dropped across the potentiometer and pass it through the volume-control condenser *C-1* to the driver grid. Fig. 15 pictures the appearance of standard volume control

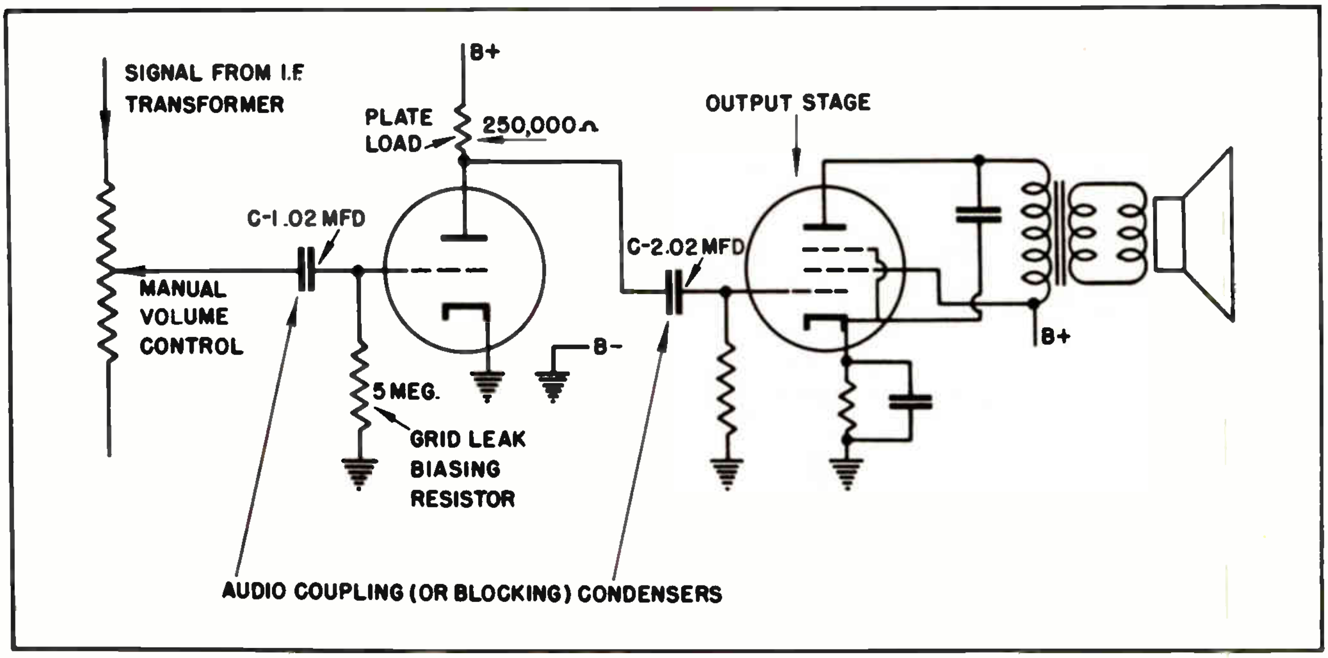

Fig. 14. Typical Driver Stage.

Fig. 15. Volume Controls.

potentiometers. Since it is a mechanical device it is subject to mechanical wear. This is especially true of the carbonized strip across which the variable tap slides. If this strip is dusty, dirty, or worn with normal use, its adjustment will create static and scratching in the speaker. If the strip is electrically open, control over the signal volume will be lost while the sliding tap is above the break. If the sliding tap is below the break, the signal will be extremely quiet.

Fig. 16 shows the electrical reasons for these audible symptoms. While the sliding tap is below the break, a small amount of signal passed across the break by the distributed capacitance will be picked up and fed through the coupling condenser to the driver grid. While the sliding tap is above the break, the signal, although loud, will be uncontrollable because of the lack of drop across section *A* of the potentiometer, which is open.

The outward effect of this condition is that when the volume control is rotated through its full range, starting at the upper end of section *A*, the signal will be at maximum loudness and will not decrease in volume as the sliding tap is moved downward approaching the break. However, as soon as the sliding tap crosses the break, the signal will drop to a very low value, being almost, but not quite, inaudible.

Careful attention to the tone of the signal at this time will reveal that when the sliding tap is below the break, the signal, far below normal loudness, will also sound tinny. This is due to the preponderance of the higher audio notes and the relative absence of the lower ones which are effectively barred from passage across the break by its extremely low distributed capacitance.

The volume control coupling condenser, *C-1* of Fig. 14, is placed in the circuit to isolate the driver grid bias from the manual volume control. *C-1* conducts the audio signal without permitting grid leak current from the driver to run through the lower section of the volume control to ground. A short-circuited volume control condenser would disturb the bias of the driver grid, which is normally grid-leak biased. Such condition would place a positive voltage on the driver grid and would drive the stage to near saturation. This would result in signal distortion.

An open volume control condenser would reduce the signal amplitude (loudness), but will not completely suppress it. This is illustrated in Fig. 17, which also shows why the signal will sound "tinny". This condenser is considered open when one of its wire leads breaks loose from the foil-plate within the condenser wrapper, without breaking loose from the wax seal. The distributed capacitance between the end of the condenser lead and the foil to which it was formerly connected is enough to pass the higher frequency components of the audio signal across to the driver grid, while at the same time effectively barring the low notes. The absence of the low notes account for the characteristic tinniness of the signal tone.

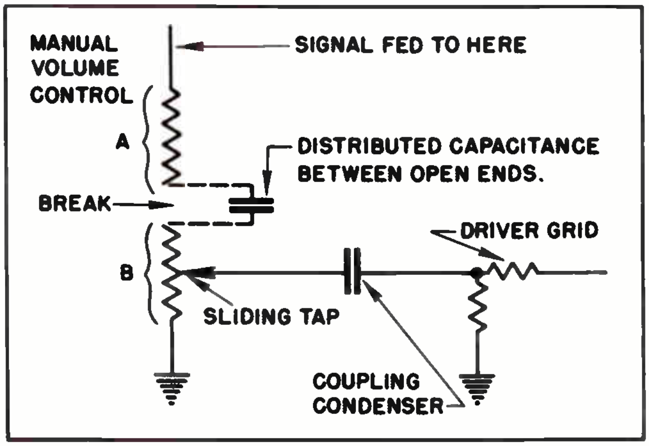

Fig. 16. Open Volume Control.

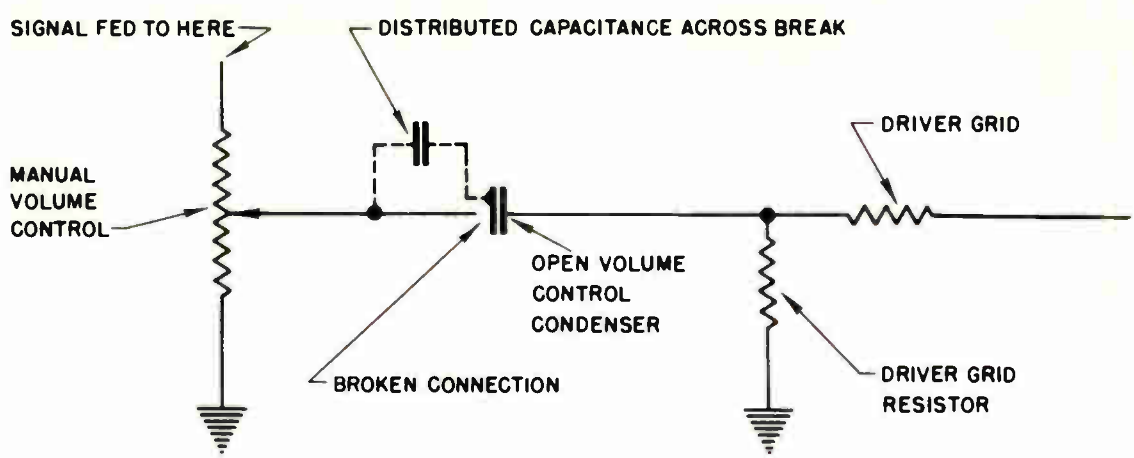

Fig.17. Open Coupling Capacitor.

The plate load resistor of the driver stage is employed to provide an amplified voltage drop at signal frequency. Its ohmage is generally upwards of 100,000 ohms, and may be as high as one megohm. Through the tube property called transconductance, a small grid signal voltage will cause comparatively large plate current changes in this stage, which operates as a "Class-A" amplifier. Since plate current in this stage must flow through the plate load on its way to B-plus, a pulsating D-C voltage drop is thus created in the plate load resistor. The frequency of this voltage drop is that of the signal applied at the grid. The amplitude of this drop is dependent, in accordance with Ohm's Law, upon the value of the current and the plate load resistance, the latter of which can be made any convenient size to provide the required increase in plate signal amplitude as compared to grid signal amplitude.

(There is also a 180-degree phase-shift between grid and plate voltages in a resistance-coupled amplifier. In the "single-ended" stage this is unimportant, but phase-shift in push-pull stages is of the utmost importance and will be discussed in detail.)

An open plate load resistor will suppress the signal altogether. An open resistor prevents B-plus reaching the plate of the driver stage. A short-circuited plate load resistor is extremely unlikely, but when it occurs, the signal will likewise be completely lost. Occasionally a plate load resistor, due to heat or some other local condition, will alter its value to a higher ohmage. In this case, the signal will be distorted and low in volume. A simple way of confirming this suspicion will be described.

The blocking condenser between the driver tube plate and the output tube grid *(C-1* in Fig. 5) serves the same function as the blocking condenser at the driver stage input; namely, to avoid disturbance of the grid bias in the output stage. If this condenser were omitted (and a direct connection made instead), the output stage grid would be driven very highly positive by the presence of B-plus voltage from the driver plate circuit. Since normal bias of an output stage grid is around minus-10 volts, it is easy to see that a positive D-C voltage of any value on this element would drive the output stage to saturation and completely block any possibility of plate current changes through the stage.

The outward symptoms of this would be the complete loss of the signal and even the "normal" hum of a speaker. In passing any change in the voltage-drop of the driver plate circuit, but barring the D-C B-plus voltage, this coupling condenser provides normal signal to the output grid without disturbing its bias. If this condenser is short-circuited, or leaky, its purpose in the circuit will be nullified -- both the desirable A-C and the undesirable D-C components from the driver plate will be placed on the output tube's grid. The tube will be driven to saturation, and "Class-A" operation, as well as the signal, will be lost.

If this condenser is open, the audible effects will be almost exactly the same as in the case of an open volume control condenser. The signal will be present in weak and tinny form, but it will nevertheless be present, due to distributed capacitance within the open condenser. Simple and effective tests to determine which of the two coupling condensers may be open will be described. It may be well to add here that open audio coupling condensers are notorious for their intermittent character, and -- like all intermittent troubles -- are handled in a special way. This will be described in detail.

The grid leak resistor to the driver stage has already been mentioned in connection with the volume control condenser. We noted this resistor (refer to Fig. 5) is approximately 5 megohms and that it has the function of providing the bias for the driver grid. Another of its functions is to provide a path for electrons on the grid to reach ground. If this resistor is open grid electrons will gather in great numbers and, without a leakage path, will render the grid negative far beyond its normal "Class-A" value. This is called a "free-hanging" grid. Such excessively negative potential on the grid is called a "static charge". In most cases it will result in complete blocking of the stage and the consequent loss of the signal.

Fig. 18. The Audio Section of a Good Receiver is Important if High-Fidelity is Attained. (Courtesy Admiral Radio.)

The audio stage of a receiver is important. High fidelity must be attained in this stage or the sound will not be properly reproduced. In a high quality receiver, such as the one in Fig. 18, the audio section is one of the most expensive parts of the entire receiver.

NOTES FOR REFERENCE

The Audio Section amplifies the sound portions of Radio and Television signals and prepares it for the loudspeaker.

The Audio Section should have reasonably high fidelity to avoid distorting the speech or music.

The Audio Section consists of one or more output power tubes, one or more driver tubes, and sometimes an inverter tube. The stage also includes the resistors, condensers and other components needed for the operation of these tubes.

The driver tube is often physically included in the same glass envelope with the detector tube.

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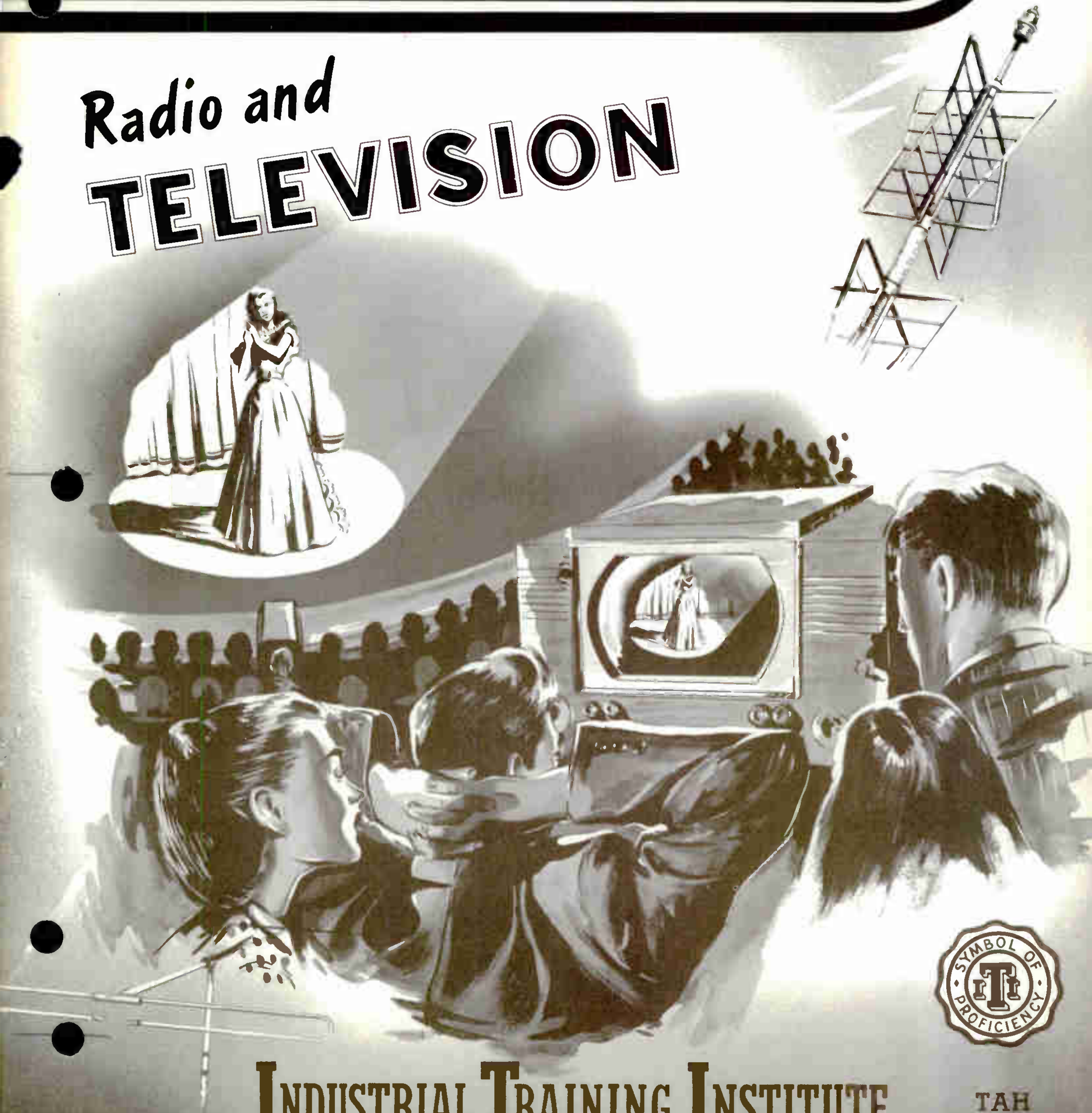

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RADIO TELEVISION

TROUBLE-SHOOTING THE AUDIO SECTION

Contents: Introduction - Operational Test for the Driver Stage - Special Audio Circuits - Push-Pull Amplification - Transformer-Coupled Push-Pull - Resistance-Coupled Push-Pull - Trouble-Shooting Push-Pull Stages - Identifying a Push-Pull System - Tone Control - Bass Compensation - Notes for Reference.

Section 1. INTRODUCTION

When trouble develops in a radio, or in the audio system of a television receiver, the first section to check is the audio. The audio must be known to be functioning properly before attempting to check the earlier stages. It is useless to check the earlier stages when the audio is defective. The reason is that no tests on the earlier stages can be conclusive when the audio is not known to be good.

The contents of this lesson are closely interlinked with that of the lesson on "The Audio Section" which immediately precedes this one. These two lessons should be studied together.

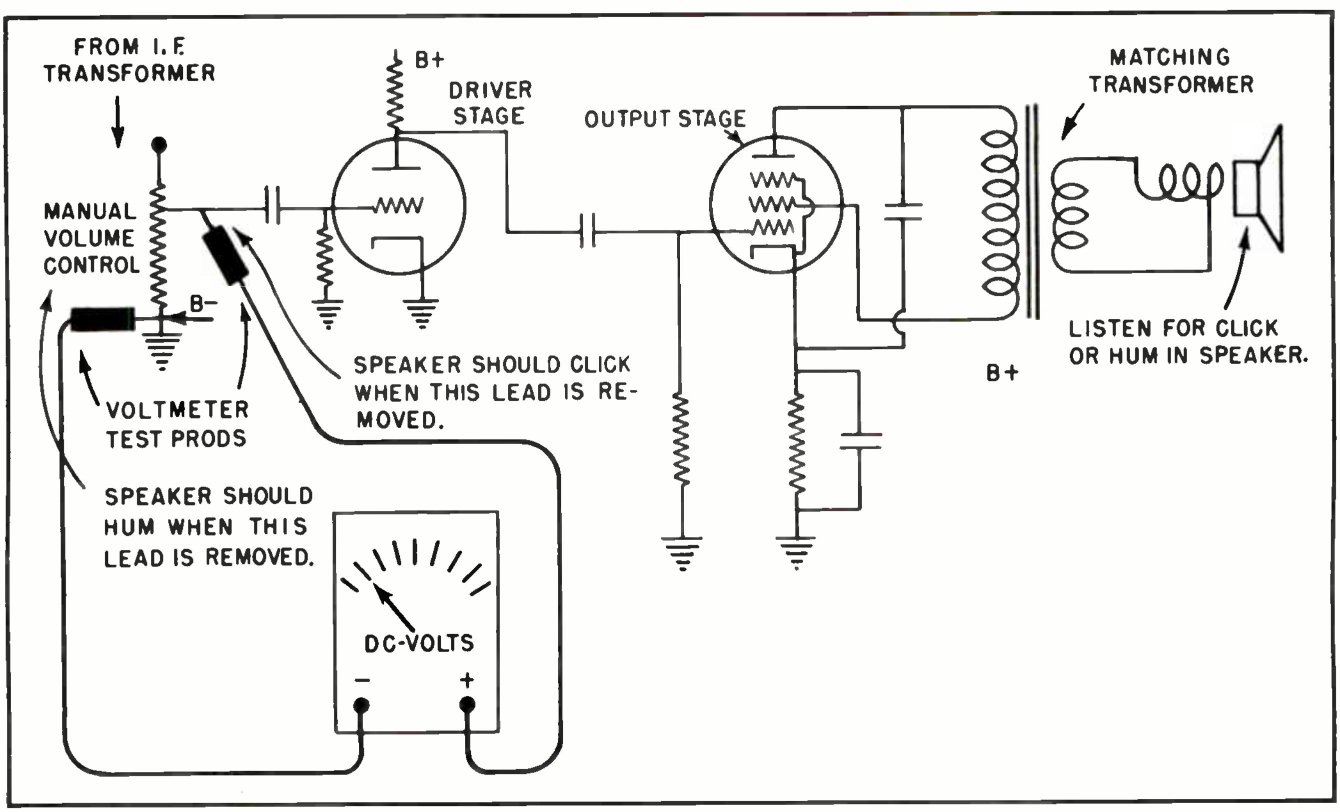

Fig.1. Using the Voltmeter to Check the Driver Stage.

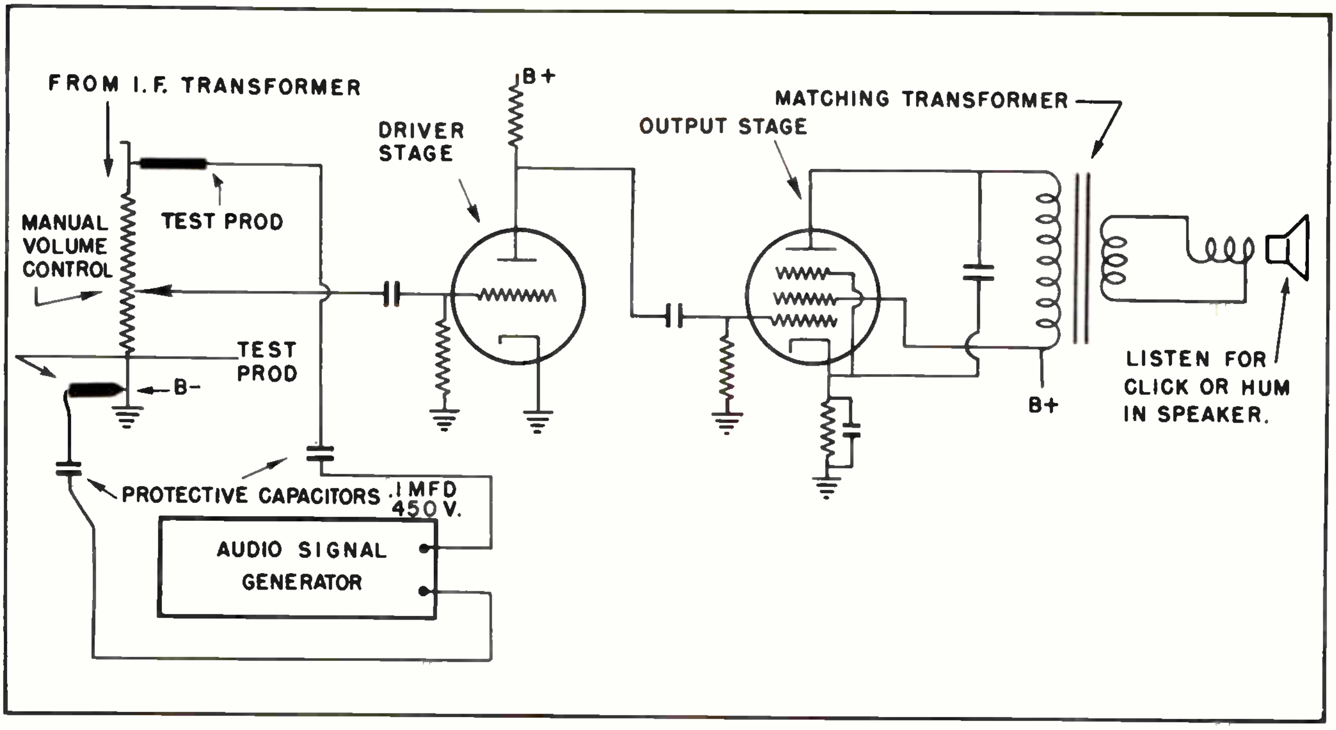

Fig.2. Using the Signal Generator to Check the Driver Stage.

Section 2. **OPERATIONAL TEST FOR THE DRIVER STAGE**

Testing this stage for normal operation is identical in nature with testing the output stage, and should be done *after* the output stage has been tested and found normal. Fig. 1 shows the method of operationally testing the driver stage with the use of a voltmeter only. (Note: if the output stage was checked with the voltmeter, it is necessary only to extend the test to include the driver stage as well.)

As indicated in Fig. 1, place the negative voltmeter lead at B-minus and the positive lead to the center terminal of the volume control. The volume control is advanced to its full clockwise position. A loud click should be heard in the speaker at the instant the positive voltmeter lead is placed upon, or removed from, the center-tap of the volume control. The voltmeter should read zero or a slight negative value.

Now, if the positive lead is left in contact with the volume control center-tap, and the *negative* voltmeter lead is lifted from B-minus, a loud hum, or growl, should be heard at the speaker. This growl is the 60-cycle hum-pickup brought to the driver grid by proximity of the meter leads to the power wiring.

Testing the driver stage with the audio signal generator. Fig. 2 shows the audio section of a receiver and the method of inserting the output of an audio signal generator into the initial audio circuit for the purpose of testing the operation of the driver stage. Here again this test for the driver stage is identical with that for testing the output stage with an audio signal generator. Now, however, the audio signal generator is placed across the two outside connections on the volume control, which is advanced to maximum clockwise position. With the receiver and signal generator turned on, the signal generator output should be heard very strongly in the speaker, and its volume should be adjustable by the manual volume control. Most signal generators are provided with a 400-cycle audio sine-wave tone for this purpose, this frequency being representative of all audio notes.

Several significant conclusions can be drawn from these tests, either or all of which can be applied for checking the driver stage. If results are good, the driver stage is known to be good. Likewise, since certain results are normally expected to come from the speaker, if they are normal they tell us *both* the output stage and the speaker are also in good order. Among our expected results we may logically note the following fact: Since the driver, or voltage amplifier,

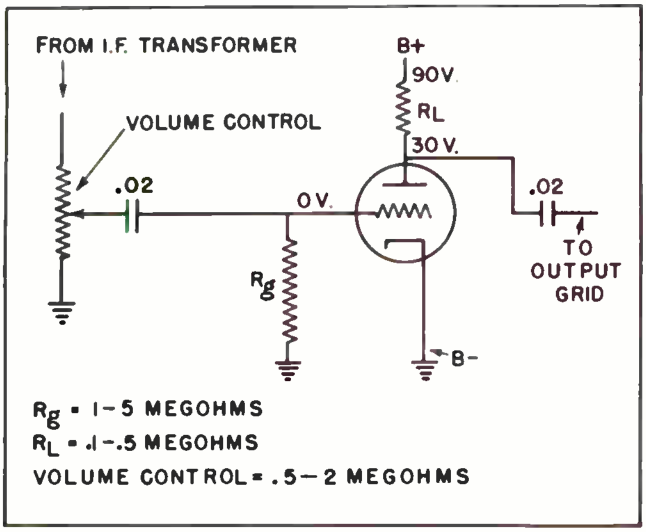

Fig.3. Driver Stage Voltages and Resistances in AC-DC Type Receivers.

is meant to provide an increase in signal amplitude, a given signal, when introduced at the driver grid, should be louder at the speaker than the same signal introduced at the output stage grid. This increase in volume is highly significant, for it serves to estimate the *gain* of the driver stage. When there is a distinct increase in the loudness of either the voltmeter "click" or the signal generator tone when input is changed from output-grid to driver-grid we can be reasonably assured that the driver stage is operating with the required *gain*.

The alert student may well ask himself this question: "If testing the driver stage involves the use of both the output stage and the loudspeaker, why not make an all-inclusive check of the entire audio system of a radio or television receiver by testing the driver stage first?" The answer to this question, of course, is rather obvious. If the driver stage checks good by either of the tests mentioned, then the entire audio section must be in good order, including the audio tubes and the loudspeaker. It should be remembered, however, that trouble may lie someplace within the audio section. In this case an operational test of the driver alone would fail to show expected results at the loudspeaker. When this occurs a stage-by-stage check of the audio system would be the next procedure.

Trouble in the driver stage can be suspected when the output stage passes an operational test, but the driver stage does not. Expected normal voltage and resistance readings for the driver stage in the four major types of receivers are shown in Figs. 3, 4, 5, and 6.

In speaking of driver stages, it should be noted that in most modern radio and television receivers the drivers are only a part (the triode section) of the tubes in which they are found. Reference to the tube manual data on the 12SQ7 tube, for instance, will show that it contains not only a triode (the driver) within the glass envelope, but also a pair of diode plates using the same common cathode the triode uses. This is for compactness only. The diode and triode sections of this tube are electrically independent of each other.

The various functions of a multi-purpose tube, such as the 12SQ7, can be analyzed separately, just as though they occupied different glass envelopes. Electrically equivalent in most ways, the 12SQ7 tube performs in the same manner as would a 12H6 followed by a 12J7. In like manner, the 6SQ7 is the equivalent of a 6H6 followed by a 6C5.

In measuring critical voltages in a driver stage, therefore, the diode sections of the tube may be ignored for the moment. They will be measured in the process of checking other stages in the receiver, of which they form an integral part. The diodes, for instance, in a 6SQ7 tube are a part of the *detector* stage, while the triode (located in the same glass envelope) is a part of the *driver* stage. The 6SQ7 or the 12SQ7 makes it possible to use one tube to do the work two tubes formerly did.

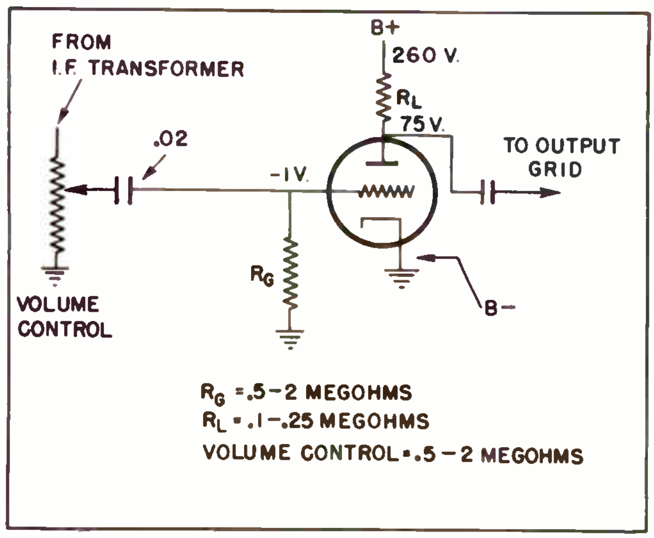

Fig.4. Driver Stage Voltages and Resistances in A-C Type Receivers.

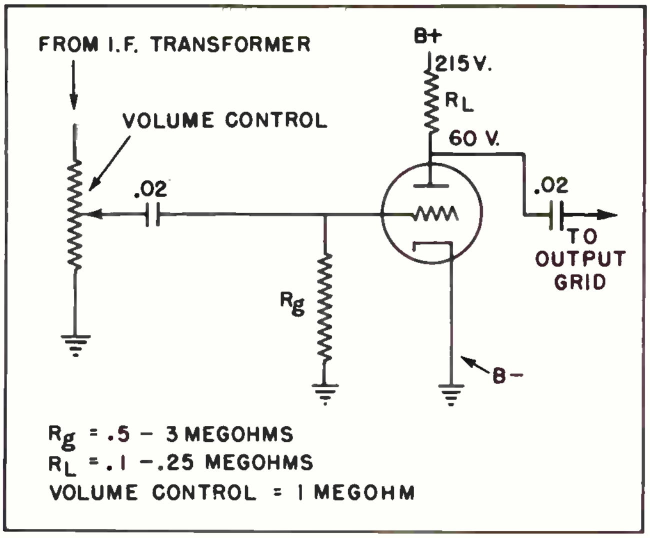

Fig.5. Driver Stage Voltages and Resistances in Automobile Receivers.

In examining Figs. 3 through 6, one is struck by the comparative simplicity of these driver stages. They contain few parts, and the voltage and resistance readings are easy and simple. Component troubles in the driver stage make themselves known by certain audible symptoms and critical meter readings. In the following discussion on driver stage troubles, and the symptoms they cause, we are assuming that tubes in the receiver have been checked and found good, and that the output stage and speaker are in proper working order.

Signal volume very low and sounds "tinny", but stage voltages and readings are normal. Look for an open volume control coupling condenser from the center-tap of the manual volume control to the driver grid. This trouble may be intermittent. Verify by shunting the suspected condenser with an equivalent. If the trouble is intermittent, make this test only during the period of *low volume.* If the signal returns to normal loudness during this test, replace the faulty condenser.

Signal low in volume, and distorted. Measure the voltage at the plate of this stage and compare to standard value. If lower than normal, look for an open, or an increased resistance, in the plate load resistor. Verify this suspicion by placing the negative lead of the voltmeter at the driver plate and the positive lead at B-plus.

If the plate load resistor is open, the meter resistance will now act as a shunt and the signal will clear up and become louder. If so, replace the plate load with a duplicate resistor.

Signal is absent altogether, but normal hum is present in the speaker. Look for an open grid leak resistor in this stage. To verify this suspicion, place the voltmeter leads across the grid resistor and see if the signal is brought through by this action. If so, replace the grid leak resistor with its duplicate. (Note: In performing this test, the meter resistance acts like a grid leak resistance in that it conducts excess electrons from grid to ground, relieving the "blocked" condition of this grid and permitting current to again flow through the stage.)

It may be noted that an open volume control condenser will act the same as an open coupling condenser to the output stage with this important exception: In the case of an open volume control condenser, the driver stage will fail its operational test; in the case of an open coupling condenser to the output stage, the operational test involving this condenser will fail, while one not involving this condenser will show the stage to be good *following* this defective condenser.

The method of distinguishing between open circuits in these two components (which reveal themselves so similarly at the speaker) is not difficult. Since in the test each is shunted *separately* with its equivalent the signal will be brought through normally whenever the bad condenser is shunted with a good one.

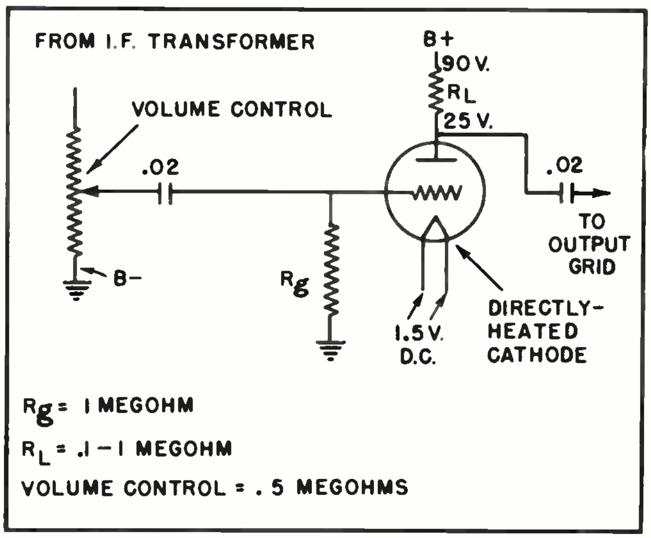

Fig.6. Driver Stage Voltages and Resistances in the Portable or 3-way Receiver.

Fig. 7. Push-Pull Applied to Timber Cutting. The Lumberjacks Can Each Take a Rest While the Other is Pulling the Saw. Push-Pull Amplifier Systems Operate in a Similar Manner.

In performing any dynamic test on the driver stage, it is a wise precaution to set the volume control at *maximum*. The reason for this is obvious: if the volume control is set at minimum, any artificial test signal introduced to the driver input circuit will be shunted to ground and lost, and the stage will not pass an operational test while this condition is present. Much time and energy may be wasted in looking for a trouble that does not exist.

Section 3. **SPECIAL AUDIO CIRCUITS**

There are several important special audio circuits found in radio and television receivers which should be mentioned. While most of the smaller radio receivers do not contain these special circuits, they are invariably a part of the larger and more expensive radio and television receivers and should therefore be recognized when present. These circuits will be discussed under such headings as *push-pull amplifiers, tone control,* and *bass compensation.*

Section 4. **PUSH-PULL AMPLIFICATION**

For the sake of superior tone response in an audio amplifying system -- and such would include radio, television, phonographs, and public address systems -- the so called *push-pull amplifier* was designed. Its success was at once recognized as outstanding in high-fidelity music reproduction and today it forms a part of most of the high quality audio equipment. More than this, it can be shown that in a push-pull amplifier the operation is quite efficient in comparison with that of a single-ended stage. This follows from the fact that push-pull stages operate as Class-B amplifiers, whereas the single-ended stage must operate as Class-A.

Push-pull amplifiers come in two groups: transformer-coupled and resistance-coupled. They both accomplish the same results, but in slightly different manners. In both types, as will be shown, it is necessary to invert the phase of the signal voltage on one tube by 180 degrees to accomplish the desired result. Fig. 7 shows the push-pull principle applied to a mechanical device such as a cross-cut saw.

Section 5. **TRANSFORMER-COUPLED PUSH-PULL**

Fig. 8 shows the circuit components and connections in the transformer-coupled

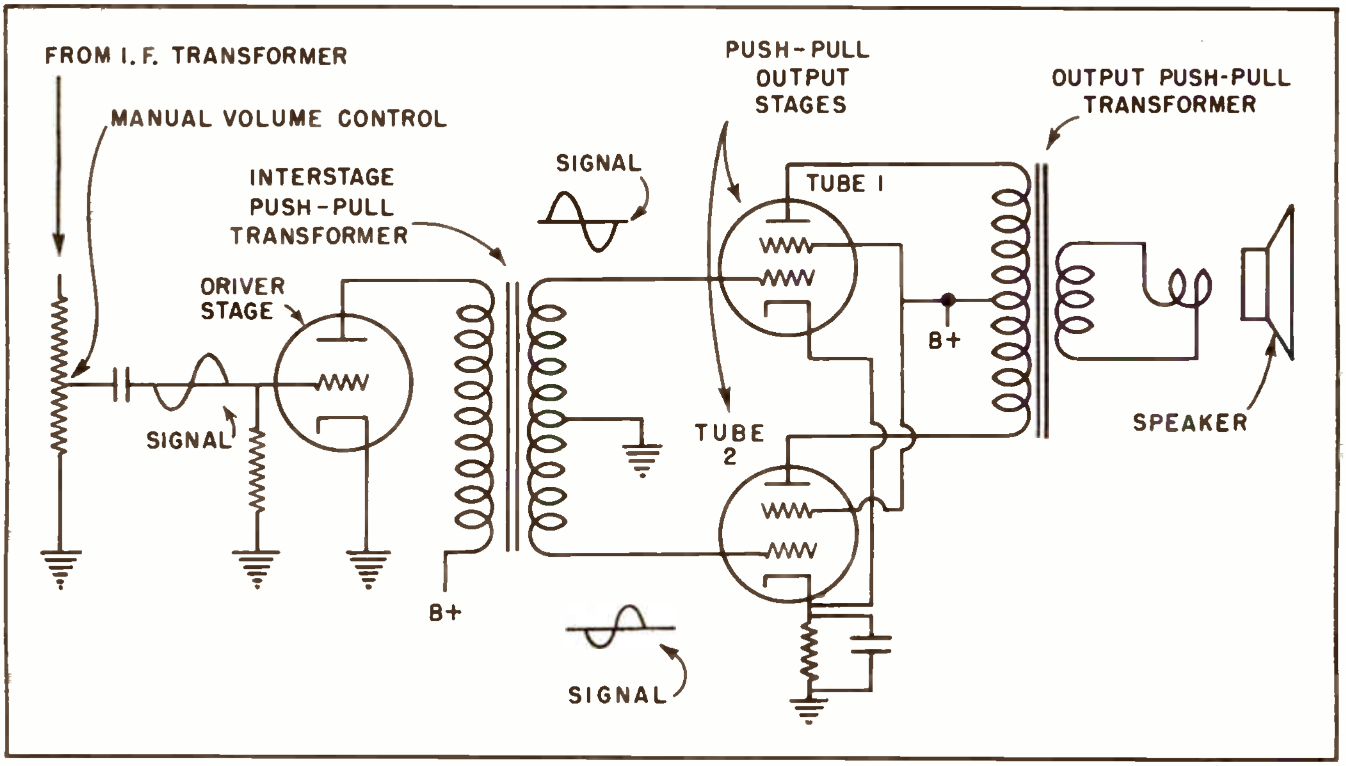

Fig.8. Transformer-Coupled Push-Pull Amplification.

push-pull amplifier system. Note the two coupling transformers, and their names; also note that the *secondary* of the interstage push-pull transformer is center-tapped while the *primary* of the output push-pull transformer is center-tapped. Also note that the entire system is driven by the signal from the driver stage which in turn gets its signal from the manual volume control. In Fig. 8 action takes place in this manner:

An alternating signal voltage is applied to the driver grid and causes current to flow through this stage in accordance with signal impulses. This current must traverse the primary of the interstage push-pull transformer and induce voltages, at signal frequency, in the secondary of this transformer. Since the control grid of each of the two output stages is connected to opposite ends of the interstage transformer, secondary, and ground connected to its center-tap, it appears that grid of tube 1 will become *positive* with respect to ground, at the same time grid 2 will become *negative* with respect to ground.

Let us assume the transformer polarity is such as to make grid of tube 1 go positive at the same time the driver grid goes positive, that is, on the first half cycle of the signal. Both output tubes are biased, through a common network with respect to ground, to operate as Class-B. Therefore, when grid of tube 1 goes positive tube 1 conducts current. While tube 1 is conducting, tube 2, whose grid is now negative, cuts off and conducts no current. We therefore, on this half of the signal cycle, have current flowing in the upper output tube, through its half of the output push-pull transformer primary, to B-plus.

No current will be flowing in the lower half of the output transformer primary. The surge of current in the upper half of the primary winding will induce a voltage in the secondary which will send current through the voice coil of the speaker and cause it to move.

The second half of the input signal cycle creates exactly the opposite set of conditions. If a negative-going signal voltage is present at the driver grid, the control grid of tube 1 is driven negative by the voltage induced by driver plate current in the interstage transformer. Tube 1 therefore cuts off and no current passes through it or through the upper winding of the output transformer primary. At this time, however, grid of tube 2 is being driven positive. Tube 2 begins to conduct current through itself and through the *lower* half of the output transformer primary. This, of course, induces a voltage in the secondary of this transformer, and this voltage sends current into the voice coil of the speaker. The rapid alternations of signal voltage at the driver grid results in the equally rapid vibration of the speaker cone, producing the sound which constitutes an audible signal. A review of this electronic action will emphasize certain important facts:

1. The opposite ends of the interstage transformer winding are 180 degrees out of phase with each other.

2. If the transformer winding is center-tapped to ground, ground potential must always be halfway between the potentials at the two ends of the winding. Ground will be more negative than the positive end and more positive than the negative end.

3. In a push-pull amplifier, one of the two tubes is *conducting* at the same time the other is *cut off*. This means that only one tube conducts at any given time. Their common cathode, except for bias voltage, is at or near ground potential and their grids are alternately raised above and below ground for alternate conduction by each tube.

4. If the driver stage is defective, neither of the two push-pull stages will operate. The signal will be lost.

5. If one of the two push-pull tubes is removed from its socket, the other will still conduct the signal and the receiver will continue to play, but at reduced volume and will be deficient in tone quality.

6. The secondary of the interstage push-pull transformer serves to change the phase of the incoming signal so that one of the output tubes will be fed with a negative-going signal at the time the other will receive a positive-going signal.

While transformer-coupled push-pull systems were extensively used in early radio receivers and in P.A. systems, and while they are still found in some equipment, they have gradually given way to the more modern, lighter, less bulky and less expensive type of push-pull amplifier known as resistance-coupled push-pull. However, understanding the operation of transformer-coupled push-pull should not be minimized by the repairman, for modern resistance-coupled push-pull systems operate on principles very similar to those of the transformer-coupled systems and -- especially for trouble-shooting -- a thorough working knowledge of both systems is required. Furthermore, many high-power amplifiers still use transformers.

Section 6. **RESISTANCE-COUPLED PUSH-PULL**

The circuit diagram of the essential parts of a resistance-coupled push-pull system is presented in Fig. 9. Comparison with the circuit of the transformer-coupled system will show the following similarities: Both systems have one driver stage and two push-pull output stages. They both have their output tube cathodes biased as Class-B through a common cathode biasing network. Only one output tube conducts at any given time; at this time the other output tube is cut off. Grid signals at the output tubes are 180 degrees out of phase with each other in both systems. Both systems serve to substantially increase the quality of the signal and the efficiency of the receiver.

In like manner we may now point out the chief *differences* between transformer-coupled push-pull and resistance-coupled push-pull.

In resistance-coupled push-pull only *one* transformer is used; the interstage push-pull transformer has been replaced by the phase-inverter stage.

The driver in a resistance-coupled system has a plate load resistor rather than a plate load inductance.

The grid voltage at tube 1 of the push-pull output stages is subdivided in the ratio of 1:10 and fed *in phase* to the phase-inverter grid. (The reason for this procedure will be explained.)

The resistance-coupled system involves fewer heavy and expensive parts, completely eliminating one of the two transformers.

Action in the resistance-coupled push-pull system may be described as beginning with a positive-going signal voltage at the driver grid. This causes current to flow in the driver tube and this current must flow through the plate load of this stage on its way to B-plus.

This current causes a voltage drop in the plate load resistor of the driver stage and reduces the voltage on this plate by the

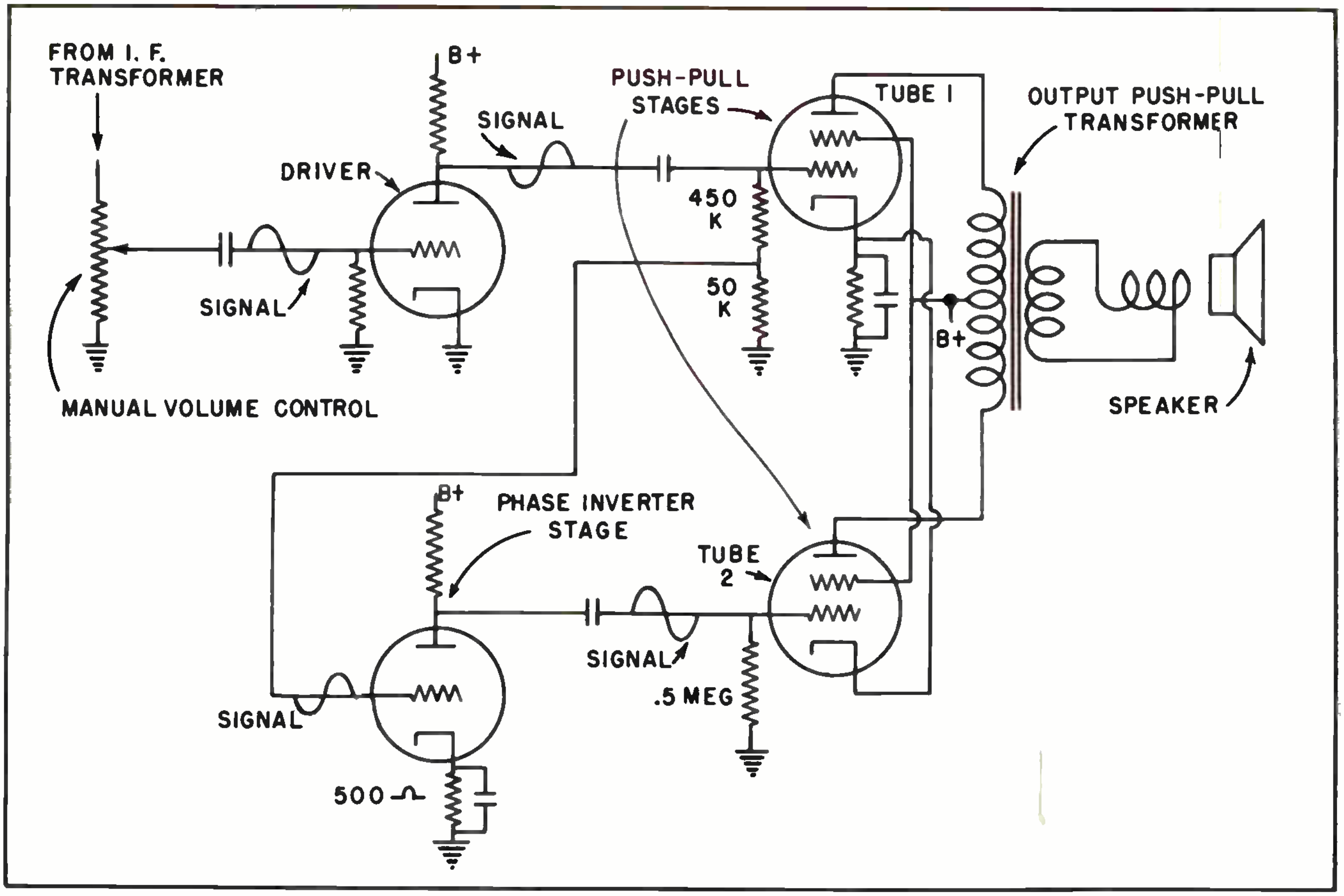

Fig.9. Resistance-Coupled Push-Pull Amplification.

extent of the plate load drop. If the drop amounts to about 10 volts, the coupling capacitor leading to the grid of output tube 1 will be driven negative by this voltage difference. A *negative voltage* at this grid will cut off tube 1. This 10 volt signal, at the same time it is cutting off tube 1, is divided by the tapped grid resistor of this tube into two parts: 9 volts above the tap and one volt between the tap and ground. A one-volt negative-going signal is therefore fed directly to the grid of the phase inverter; this one-volt negative going signal reduces plate current in the phase-inverter and permits its plate voltage to rise by about ten volts, due to the gain of this stage. As the plate voltage of the phase-inverter rises, this rising voltage is fed through its coupling capacitor to the grid of the output tube 2, which is made 10 volts more *positive*.

What is the situation at this time? We have a 10-volt negative-going signal at the grid of tube 1, and a 10-volt positive-going signal at the grid of tube 2. The amplitudes of these two voltages are the same, but their phases *differ* by 180 degrees. Consequently tube 1 will cut off, and tube 2 will conduct current through itself and through the lower half of the output transformer primary. This will induce secondary voltage which drives current through the voice coil, deflecting it.

If we now consider what occurs when the voltage at the driver grid is negative-going (at the second half-cycle), we shall find exactly the opposite conditions. If the driver grid goes *negative*, its tube current, and therefore the drop in its plate load, is reduced. Its plate voltage goes more positive by an amount equal to the difference in drop, let us say 10 volts more positive. This *rising* voltage is now fed to the grid of tube 1, which begins to conduct current through its half of the output transformer primary. This, as we know, serves to deflect the speaker cone. However, at this time, a subdivided positive voltage is being fed from the tapped resistor of the grid of tube 1 to the extent of one positive volt. This one-volt signal, through the gain of the phase-inverter tube, is built up into a 10-volt negative-going voltage. The 10-volt negative going signal serves only to cut off tube 2 and prevent current from passing through the lower half of the output transformer primary.

The rapid succession of alternating voltages at the driver grid are thus found, as in the case of the transformer-coupled push-pull system, to result in an equally responsive vibration of the speaker cone all in exact accordance with the input signal impulses.

It is not within the scope of this discussion at this time to show rigorous proof of the high fidelity and efficiency of push-pull amplifiers. However, it is readily demonstrable that two tubes working in push-pull will deliver more signal power *per tube* than if they were connected in parallel. Also, through the cancellation of stage-generated (and therefore undesirable) *even harmonics*, tone fidelity is remarkably improved. Even harmonics, such as the second, fourth, sixth, eighth, etc., normally and unavoidably generated by a single-ended stage, are completely cancelled out by the electrical action of push-pull stages.

Section 7. **TROUBLE-SHOOTING PUSH-PULL STAGES**

The individual components of push-pull output stages, whether they are part of a transformer-coupled or resistance-coupled system, can be investigated individually or together. Individually they may be considered as single-ended output stages, and appropriate tests, such as those discussed previously, may be applied. In making such tests you should expect to find standard voltages and resistances normally found in single output stages.

Analyzed together the two sides of a push-pull stage indicate their defects in special ways. A simple test for checking the normal operation of a push-pull stage is to adjust the receiver for a normal signal and remove first one, and then the other, of the push-pull output tubes. If the stage is operating properly, a distinct drop in signal volume will be noted. (If the listener is alert, he will also notice a "flattening" of the tone.) Should the speaker output remain *unchanged* when a tube is removed, the stage from which the tube has been removed is at fault. Or, what is most likely, the tube itself is defective.

If distortion is originally present in the receiver, and *disappears* when one of the push-pull tubes is removed, the obvious conclusion is that the stage from which the tube was removed is at fault. In this case it would be wise to look for a shorted or leaky coupling condenser to the grid of this tube. Also make sure the tube has been carefully checked for shorts or leakage, and is in good condition.

If a 60 or 120 cycle hum (the characteristic "filter hum") is present in a receiver employing push-pull, and if a careful check does not indicate filter condenser trouble as previously described, then test the output tubes for emission. Emission, or transconductance (if a G_m test is available), should be exactly equal for both tubes. Any discrepancy between the quality of the two push-pull tubes will show up in the speaker as an annoying hum.

It has been the sad experience of many repairmen to look for electrolytic trouble in a receiver, often spending fruitless days at the task, when the only trouble was mismatched output tubes in the push-pull stages. For this reason experienced repairmen, when confronted by excessive hum in a receiver with push-pull stages, often check the quality of the output tubes before attempting filter condenser repairs. Such experiences, however, bitter though they may be at the time, can be a valuable lesson. The experience will show up as increased speed and efficiency in future repair work.

In addition to the many possible troubles already mentioned which occur in single-ended output stages, possible troubles in transformer-coupled push-pull stages have special characteristics of their own. The plate and grid windings of the interstage transformer may open up. In the case of the grid winding, which we recall is center-tapped to ground or B-minus, an open in one half would make useless the tube to which this half should supply a signal. The system will then operate as a mis-biased Class-A single-ended amplifier, with its characteristic flat tones and comparatively low volume output. Hums are likely under these conditions. An ohmmeter check will determine whether or not there is an open grid winding in the interstage transformer.

An open plate (primary) winding in the interstage push-pull transformer would suppress the signal to both the output stages, but the speaker would produce the normal residual hum of a "live" receiver. Here a voltmeter check at the plate of the

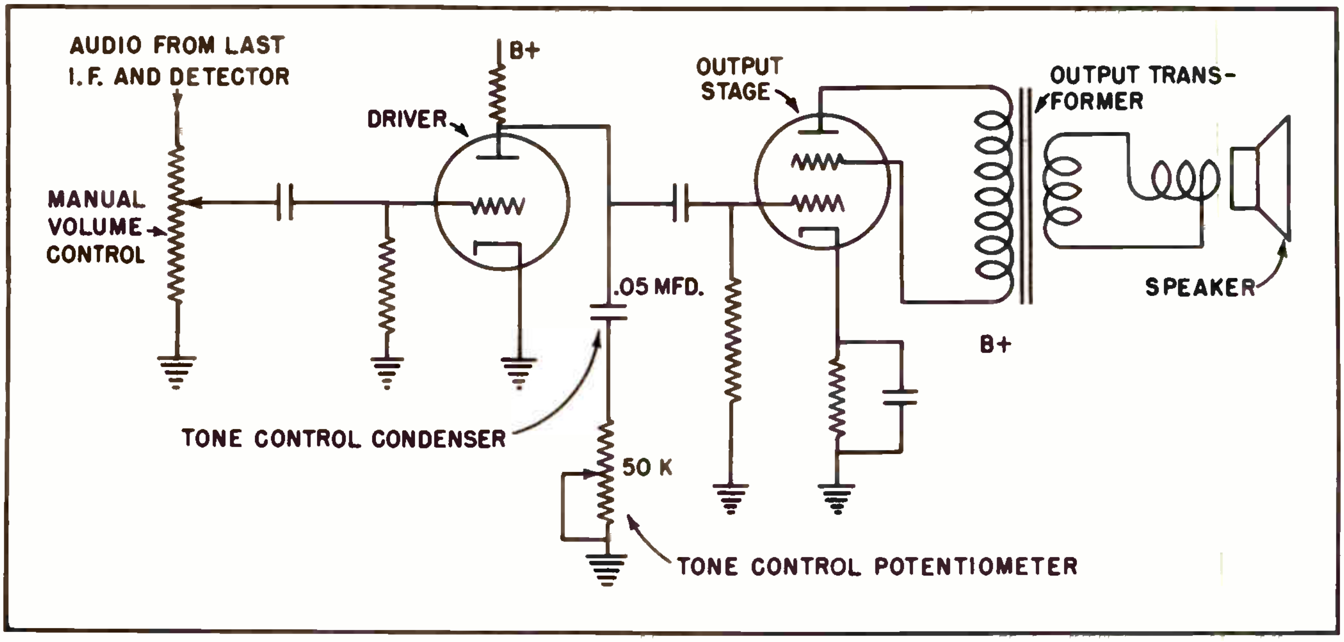

Fig. 10. Tone-Control Circuit.

driver would reveal the absence of the normally-present B-plus.

Since in resistance-coupled push-pull the interstage transformer is replaced by the phase-inverter stage, this stage must also be checked for normal operation and for troubles. A phase-inverter stage is identical with the average resistance-coupled driver stage, and a check for normal operation is likewise identical. Pin voltages at this tube socket should be the same as those of the driver stage.

With the exception of the grid-leak resistor, which is the 50,000 ohm portion of the tapped grid leak of one of the output stages (See Fig. 9), and the cathode biasing in the phase-inverter, resistance readings are also the same as those of the driver stage. Bias is provided in the phase inverter by a 500-ohm resistor parallel with a by-pass condenser. An ohmmeter reading between the phase inverter cathode and ground, therefore, should read somewhat in the vicinity of this resistance. Zero resistance at this point will indicate a shorted by-pass condenser. An abnormally high resistance here will indicate an open biasing resistor; this can be further confirmed by an excessively high voltage between this cathode and ground.

Section 8. IDENTIFYING A PUSH-PULL SYSTEM

The push-pull system will readily reveal itself by the presence of a *pair* of output tubes in a receiver. In modern receivers, these output tubes may be *pairs* of 6L6's, 6V6's, 6K6's, 6F6's, 7B5's, 7C5's, 6AQ5's, 6AG7's, or 6AK6's. While these by no means exhaust the types of tubes used in push-pull output stages, they are good clues in identifying this type of output circuit. Generally, only those receivers equipped with push-pull are those which use tubes with 6-volt heater ratings.

While there is no direct relationship limiting push-pull to 6-volt heater ratings, an incidental fact makes this true. Six volt tubes are mostly used in A-C and automobile receivers. Both these types of receivers lend themselves to push-pull amplification because of the fact weight and cost are relatively unimportant where high tone quality is desired. But in portable receivers, as well as in the AC-DC type, space, weight, and cost are all important considerations. Since the great popularity of portables and AC-DC receivers is due to their compactness and low cost, push-pull is seldom found in these models. Nor does the average user of the small receiver expect from it the excellent tone response found in the more expensive receiver. This indicates an important fact: **Push-pull stages are seldom found in portable or AC-DC receivers,** *hence we should not bother to look for push-pull troubles in such receivers.*

The value of the above conclusion seems almost too obvious to be mentioned, yet its recognition may save the repairman a lot of time and effort. When the repairman can eliminate from his analysis a complete family of possible push-pull troubles, the remaining number of possible troubles is effectively reduced. Radio and television trouble-shooting is as much a matter of *eliminating the impossible troubles as confirming the possible ones.*

Section 9. **TONE CONTROL**

Tone control is a refinement added to an audio amplifier which permits the listener to adjust the quality of the audible signal to meet his own tastes. The tone control knob is generally located on the control panel of the receiver, and can be manually adjusted. It can be adjusted to suit the type of signal being received (whether music or speech), and to other local conditions. If, for instance, a combination radio-phonograph is being switched from a newscast to its record-player, the tone control, which had been adjusted for voice reception, is generally changed to bring out the best performance of the record-player.

The schematic diagram of a popular tone control circuit is shown in Fig. 10. Its operation is extremely simple. Its operation rests on the principle that a condenser offers low reactance to a high frequency. The signal, appearing as audio at the driver plate, contains both low and high audio frequencies. If the highs are strong in comparison with the lows (resulting in a "brilliant" quality), the tone control sliding arm may be raised upward, effectively shorting out the potentiometer resistance. This gives the fullest shunting effect to the capacitor, which leads the high frequencies to ground and away from the output grid. The highs are thus reduced in strength and the lows appear to be louder by comparison.

If, on the other hand, "brilliant" tonal quality is desired, the sliding arm may be brought downward closer to ground, placing the full potentiometer resistance in series with the capacitor. This reduces the effectiveness of the capacitor's shunting ability. The high frequencies, instead of being shunted to ground, are led to the output stage grid in their full strength. Now, by comparison, the high frequencies are more noticeable. This latter condition is more favorable for speech, such as newscasts and lectures.

The sliding arm of the tone control potentiometer can, of course, be set at any intermediate point between its extremities, thus providing a smoothly changing adjustment from the most brilliant tone to the strongest bass quality.

Another type of tone control, using the same basic principles, but differing in application, is shown in Fig. 11. Here the potentiometer is replaced by a three-point selector switch, which can be set to connect to any one of three *separate* condensers for by-passing the higher frequencies. Each of

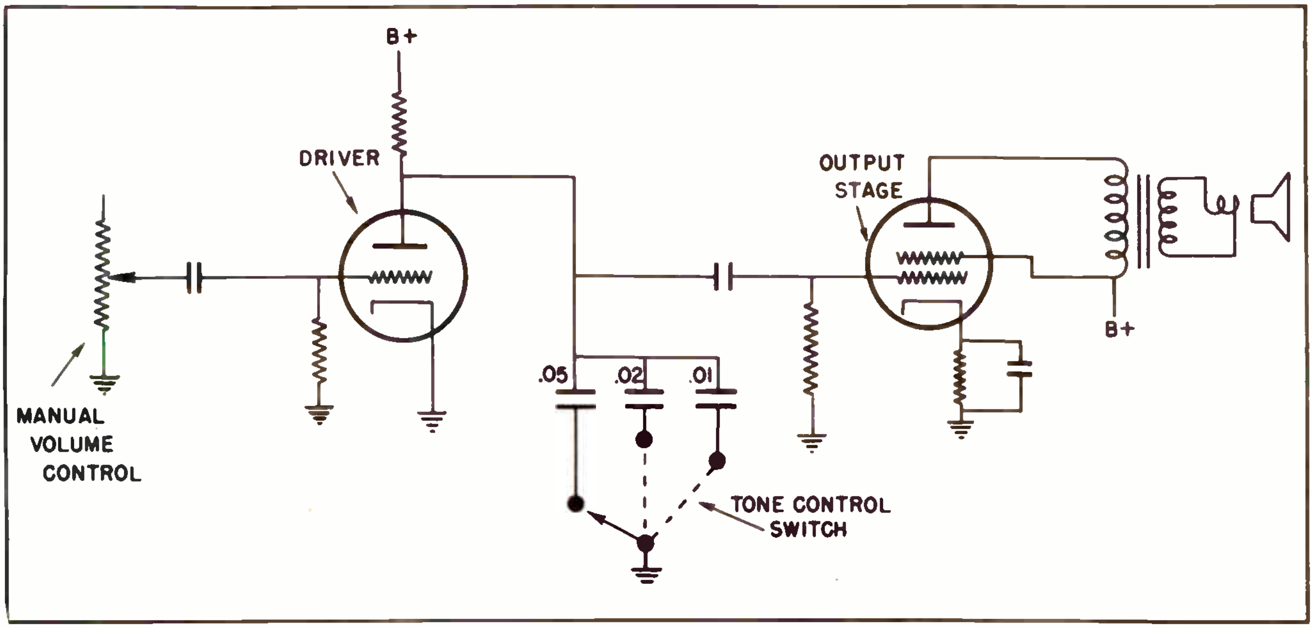

Fig.11. Switch-Type Tone Control.

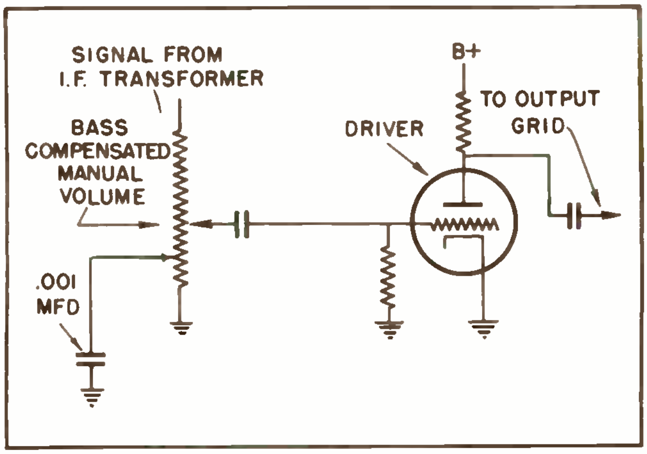

Fig.12. Bass-Compensated Manual Volume Control.

the condensers will have inherently different values of reactance. This manner of tone control is not capable of *smooth* adjustment, as was the previously mentioned potentiometer type, but would progress in steps as the switch is turned through its contacts. Modern receivers are not inclined toward the switch type, but favor the potentiometer type.

From the trouble-shooting point of view, the tone control circuits described present rather interesting, yet simple problems. If, in the potentiometer type, the tone control condenser becomes short-circuited, the signal will be absent in the most advanced position of the tone potentiometer, but present -- in very quiet and distorted form -- when this control is brought to its retarded position. An open potentiometer or an open condenser will render the tone control ineffective.

In the switch type tone control, if any one of the condensers is short-circuited, the signal will be suppressed only at the time the selector is connected to it, and will react normally in all other positions.

Tone control potentiometers, being electromechanical devices, are subject to mechanical wear. With normal use such a potentiometer will show signs of wear after several years. Indications of this condition are an audible scratching sound when the control is turned, and lack of tone control in certain positions. Their troubles, and corrections, are identical with those of volume control potentiometers. The best remedy is to replace the unit when it is known to be defective.

Section 10. **BASS COMPENSATION**

Bass compensation, a further refinement in audio amplifiers, is built right into the electrical construction of the special manual volume control used for this purpose. The receiver may also include a separate tone control, as previously described. Fig. 12 illustrates the essential circuit for bass-compensating an audio signal so that it reaches the human ear to greatest advantage.

It is characteristic of the human ear that we hear most effectively those frequencies around 1,000 cycles per second, especially at low volume levels. This means that while our ears are sensitive to those frequencies both below and above this value (within the limits of the audio range -- 15 to 15,000 cycles per second), our ears favor those around 1,000 cycles. In a radio or television receiver, or in a P.A. system, the effect of reduced volume is to noticeably decrease the tonal quality of a signal. This effect is cancelled out by the bass compensator, which makes possible an overall improvement in signal quality at low volume levels.

Referring to Fig. 12, notice that the volume control potentiometer is tapped near the low-volume end. This is a fixed tap and is therefore not adjustable. The condenser connected between this tap and ground is comparatively low in capacitance, and will tend to shunt the high frequencies of the signal to ground while leaving the low frequencies relatively untouched. When the volume control is set to maximum, the tap is relatively ineffective. It is separated in that position by much potentiometer resistance between it and the sliding arm which picks up the signal for the grid of the following tube. However, as the sliding arm is brought downward toward the tap, as would happen when the volume of the receiver is being reduced by this control, the tap becomes effective in shunting the high frequencies of the signal to ground. The result is that when the driver tube grid is being supplied with a signal from a point on the potentiometer near the tap, the high frequencies will be shunted to ground. This makes the bass notes seem more pronounced, achieving the desired effect of compensating for the loss of the bass notes when the volume control is at the low volume position.

Trouble-shooting this circuit is simply a matter of observing the results of varying the volume control. If the condenser is open there will of course be no compensation and the signal will sound "flat" while the volume control is in the retarded position.

If the condenser is short-circuited, the lower portion of the potentiometer will also be shorted, and in addition to lack of bass compensation the *signal will drop to zero before the control is completely counterclockwise.*

In rare cases the same principle is applied to a double-tap compensating circuit providing for bass compensation at two separate volume levels. Fig. 13 is a photograph of a bass-compensating potentiometer with one tap.

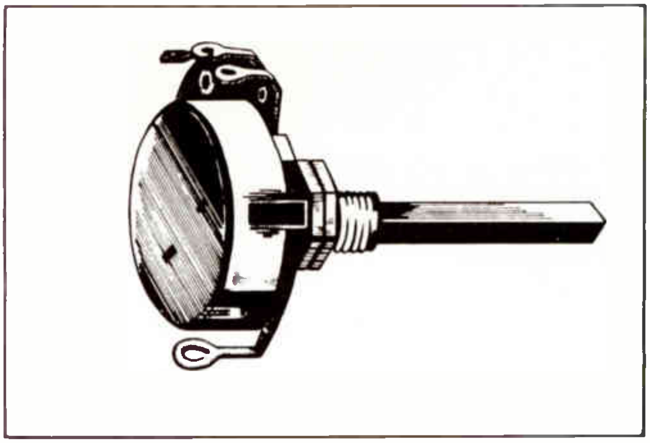

Fig.13. Bass-Compensating Manual Volume Control.

NOTES FOR REFERENCE

In trouble-shooting a receiver first identify its power supply, see that the tubes are in the correct sockets, notice if it contains a push-pull system.

Make a routine check of all the tubes, being certain to return them to their correct sockets.

Test the loudspeaker. Make operational tests for the output and driver stages.

Where the audible symptoms of the defective receiver justify suspicion of trouble in an audio stage, measure significant voltages, such as B-plus, driver plate potential, cathode potentials, etc.

Confirm an open condenser by *shunting it* with an equivalent.

Confirm a shorted condenser by *replacing it* with an equivalent.

Confirm an open resistor or an open coil by an ohmmeter check, and compare measured voltages with a standard value as given in the text.

NOTES

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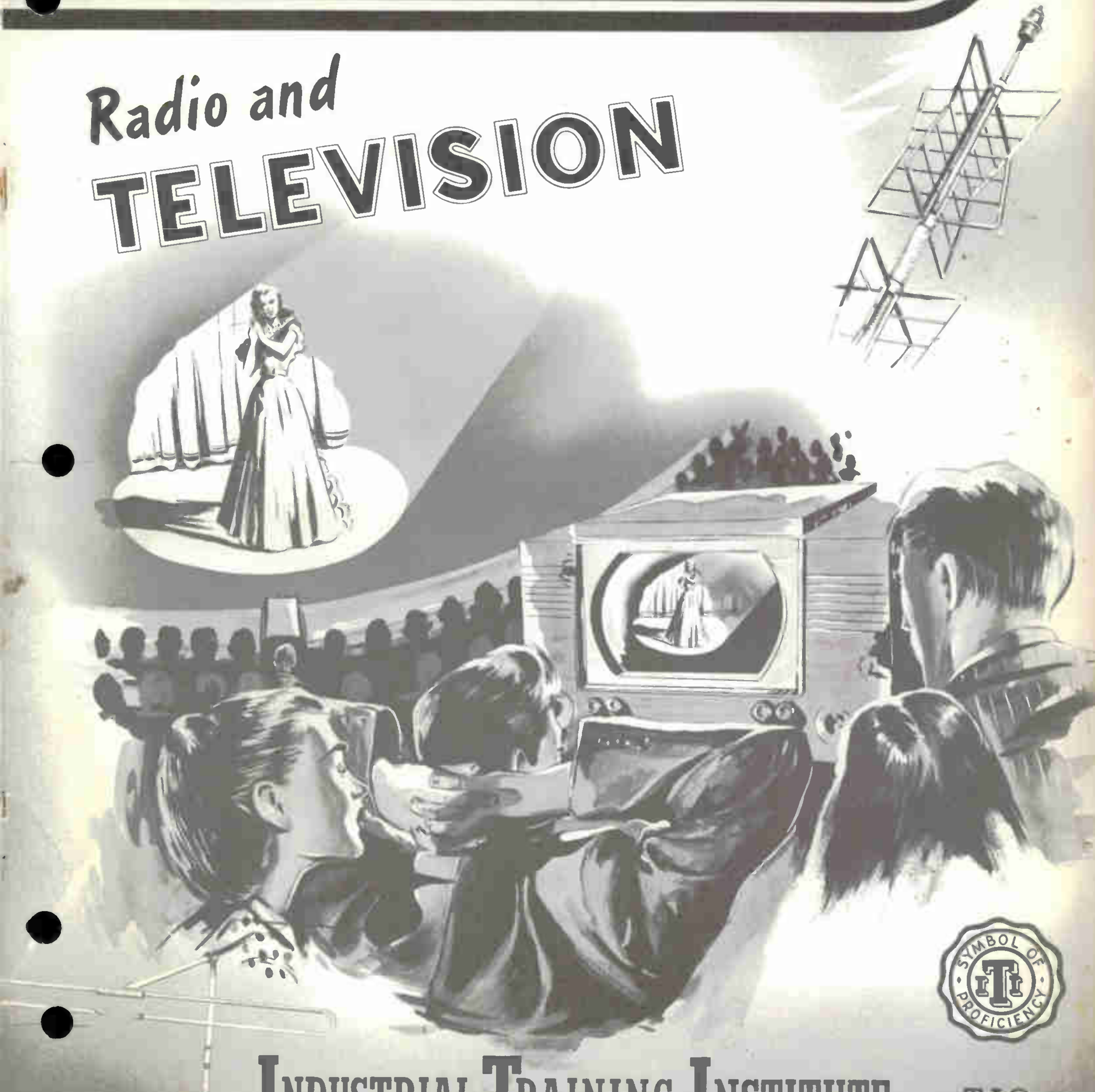

INDUSTRIAL TRAINING INSTITUTE

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TECHNICAL TRAINING SERVICE

REVISED 1955

RADIO TELEVISION

DETECTORS

Contents: Introduction - Demodulators - Detectors which are not Demodulators. - The Signal at the Receiver - The Crystal Detector - Demodulation by Rectification - The Diode Detector - Triode Detectors - The Linear Plate Detector - Triode Grid Detectors - Pentode Detectors - Detector Characteristics, Advantages and Disadvantages - Reviewing Detector Action - Notes for Reference.

Section 1. INTRODUCTION

We have previously discussed the fundamental problem of transmitting and receiving radio and television signals. The problem revolves around the nature of the frequencies involved. Audio frequencies, those which can be heard by the human ear, are not capable of speed-of-light transmission through space. Radio signals, while capable of such transmission through space, are not audible to the human ear.

Actually, the problem resolves itself into two important and complementary questions: (1) How can a transmitter radiate audio and video signals which are incapable of being radiated directly? (2) How can the radio or television receiver, responding to the inaudible, invisible, radiated signal produce sounds which the human ear can hear, and pictures which the eye can see? These questions are basic; their answers contain the key to the entire science of radio-transmitted communication of audible and visible intelligence.

The answer to the first question is discussed in other lessons of this series. They explain how audio and visual signals -- whose frequencies are too low to be radiated directly -- are impressed upon the transmittable radio carrier by the process of modulation.

The answer to the second question is the subject of this lesson. We will show how radio carrier frequencies, modulated by the audio or visual frequencies, are caused to give up the audible and visual components by the reverse process of demodulation.

Amplitude modulation means changing the amplitude of a radio carrier in accordance with an audio signal. By "changing the amplitude" we mean changing the voltage

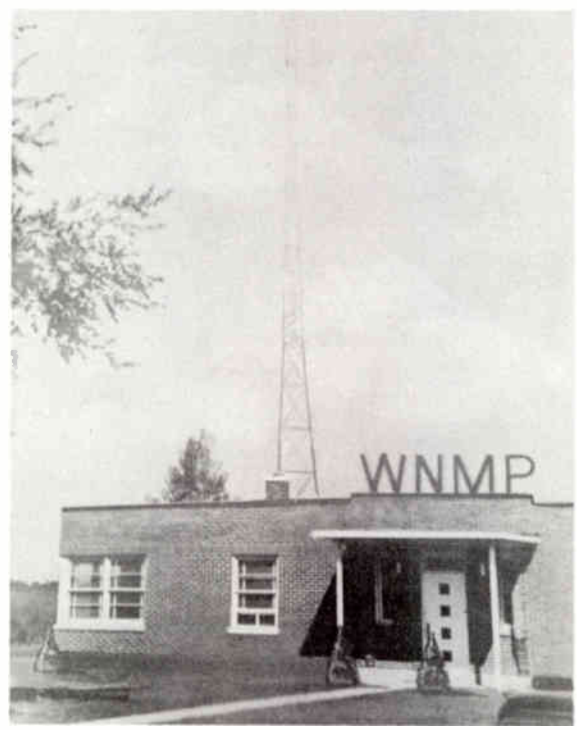

Fig.1. AM Radio Broadcasting Station.

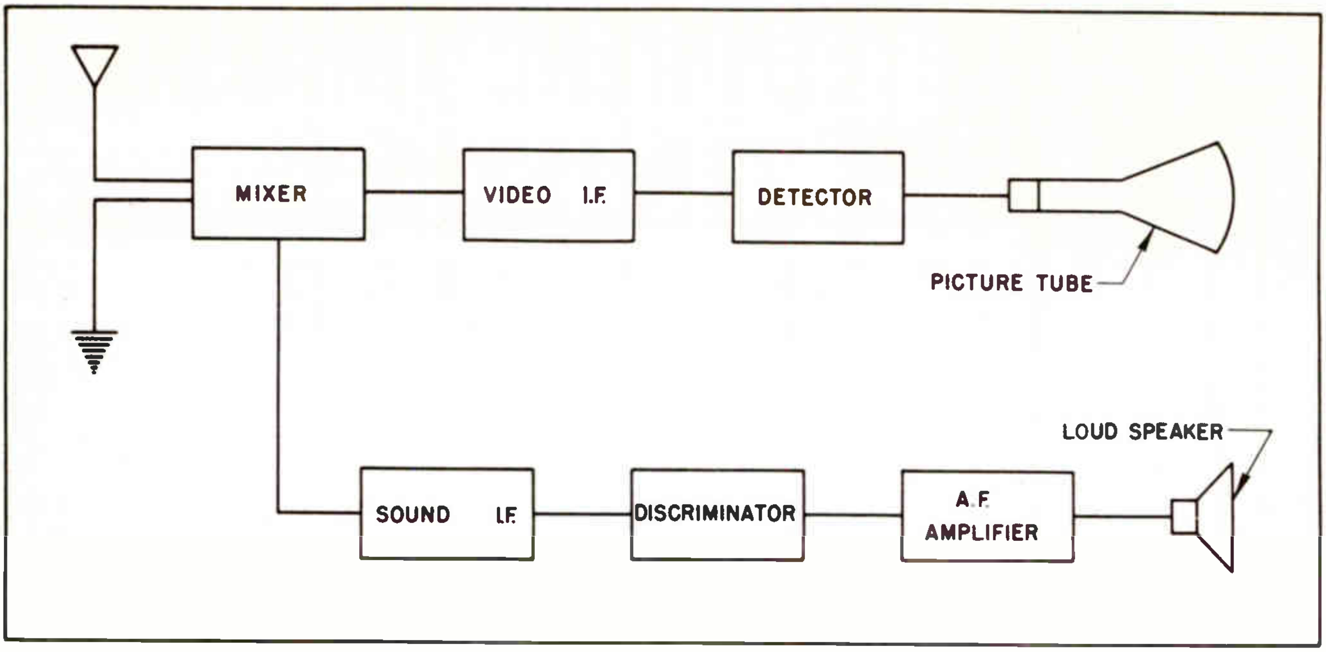

Fig. 2. Both AM and FM Demodulators are Used in a Television Receiver.

strength of the carrier wave. The voltage of the carrier is varied to correspond with the varying voltage of the modulating audio or visual signal voltage.

Section 2. DEMODULATORS

Demodulation is the process of recovering, or extracting, the audio or visual signal from the modulated radio carrier as the carrier signal passes through the receiver. The stage which does this is called the demodulating stage, or more commonly, the detector stage. Amplitude modulation is the most common type of broadcast reception.

Frequency modulation involves changing the frequency of the radio carrier in accordance with the audio signal, but keeps the amplitude constant. Frequency modulation is better known as the increasingly popular FM transmission.

Frequency-demodulation is the process of recovering, or extracting, the audio signal from a frequency-modulated radio carrier as it passes through the receiver. The stage that does this is called the discriminator, or the discriminating detector.

In television, the picture signal is carried as amplitude modulation of the carrier frequency. The accompanying voice is transmitted by means of frequency modulation. The television receiver, therefore, contains a detector for recovering the picture signal, and a discriminator for recovering the sound signal. (See Fig. 2.)

It might be well to keep in mind that modulation, of any type, takes place at the transmitter. Demodulation always takes place at the receiver. This applies to amplitude modulation, frequency modulation, phase modulation, or any other type which might be developed. This lesson, while often touching upon the many relationships of the subject of demodulation, will be devoted primarily to the description and operation of amplitude demodulators -- the detector stages found in popular radio receivers and the video channel of television receivers.

Before progressing to a convenient classification of the types of amplitude demodulators -- detectors -- let us direct our attention more closely to names and terminology. We will avoid much confusion in later discussions if these are cleared up now. Common usage, through the period of growth of radio science, has attached certain meanings to these terms used by radio men. Some of these terms are not entirely descriptive from a technical standpoint, but they have the weight of long usage.

Section 3. DETECTORS WHICH ARE NOT DEMODULATORS

We have said that the stage which recovers the audio component from an amplitude-modulated carrier is the detector. While this statement is technically true, common usage and custom have qualified this meaning somewhat. In Tuned Radio Frequency receivers (TRF's), a pioneer type of receiver which is now becoming extinct, the term *detector* was descriptive as well as being technically accurate. The TRF receiver contains only one detector, and its sole purpose is to extract the audio component from the amplitude-modulated carrier.

However, in the superheterodyne circuit which has grown to a high state of popularity, the term *detector* has gradually been altered to second detector. There was a good reason for this change, of course. One of the circuits of a superheterodyne receiver has the special function of converting the radio carrier to a somewhat lower frequency, without losing the modulating component. This circuit involves the converter stage. The converter stage is also known as the mixer or first detector. Whether or not we agree with the wisdom of applying the term *first detector* to the converter stage, we must still face the fact that the stage is known by that name. The demodulating stage had to be distinguished from the first detector by qualifying it as the second detector.

Let it be emphasized here that the first detector of a superheterodyne receiver is not a demodulator -- it does not extract the audio component from the radio carrier. That task still remains the responsibility of the second detector, the real demodulator. The details of the converter, or first detector, are discussed in complete detail in a separate lesson in this course.

Another departure from the technical meaning of the term *detector* is the so-called heterodyne detector found mostly in communications receivers, which are designed primarily for reception of code signals. Here again we may question the wisdom of applying the term *detector* to such stage. But we cannot get away from the fact the term is widely used to indicate this circuit, which is not a demodulator. The heterodyne detector, on the contrary, accepts an unmodulated (continuous wave) signal. A local oscillator beats, or *heterodynes*, against this signal and their difference in frequency produces the audible note heard as the code signal. The heterodyne detector is discussed at length in another lesson in this course. The term "beat frequency oscillator", or "BFO" is now being applied more and more frequently to the heterodyne detector. It is probable the latter term will eventually disappear from common usage.

We have seen that any stage which extracts audio signals from a radio carrier may be called either a demodulator or a detector. A stage which converts one frequency to another, or mixes two frequencies together to produce their difference, may be called a detector but not a demodulator. There is an increasing tendency to call the

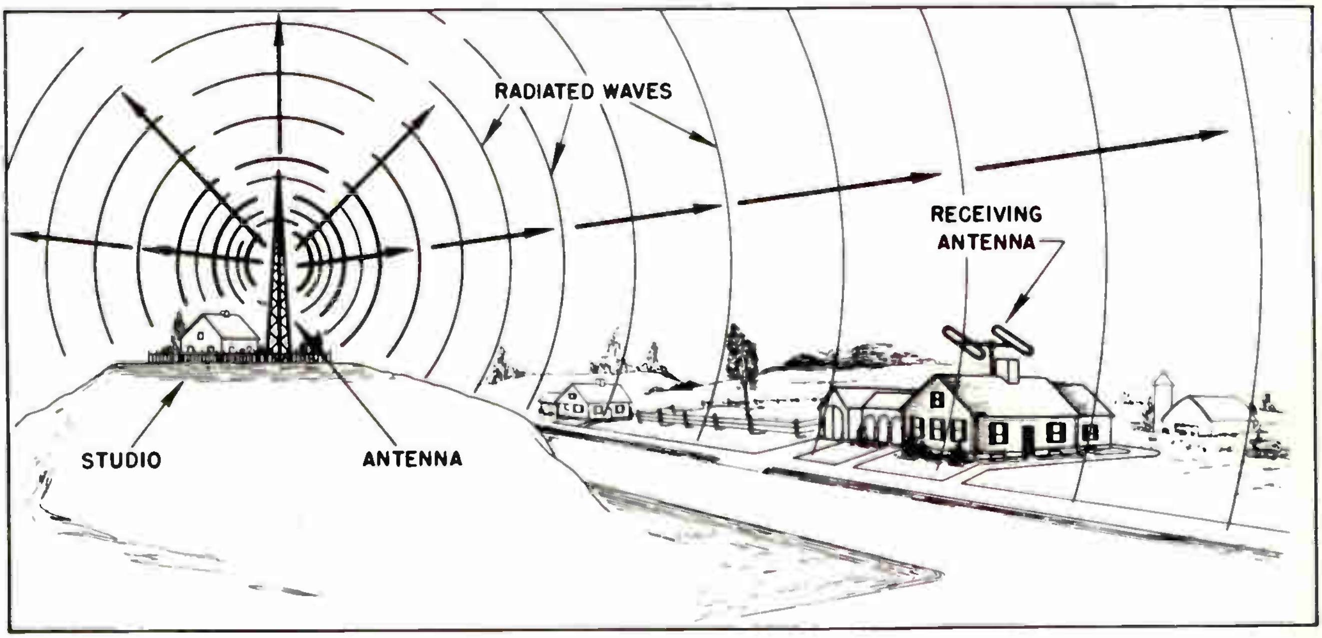

Fig. 3.

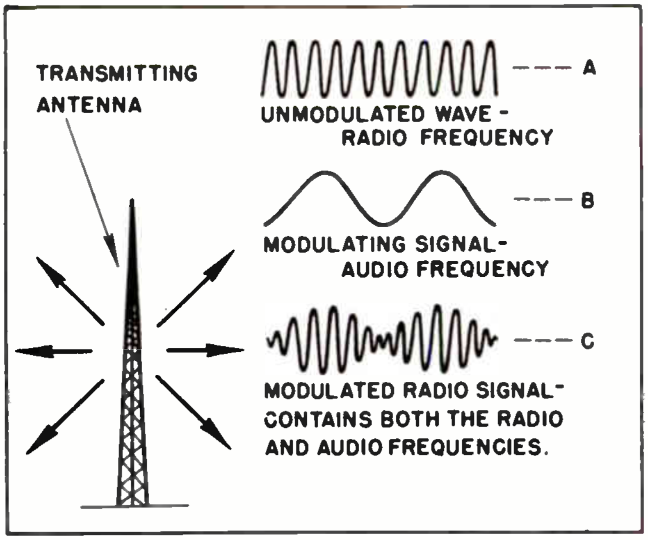

Fig.4. The Audible Modulating Signal Tends to Constantly Change the Strength of the Carrier Signal.

first detector the "mixer stage", or the "converter stage". There is strong hope that soon the term "Detector" will be reserved for the demodulator stage only.

We are now ready to arrange detectors (amplitude demodulators) into a classification convenient for study. This classification is arranged in a sequence which is a compromise between their popularity and their comparative simplicity.

Detectors may be divided into the following types:

1. The crystal detector.
2. The diode detector.
3. The triode detector.
   a. The plate detector.
      I. The square-law plate detector.
      II. The linear plate detector.
   b. The grid detector.
      I. The grid leak detector.
      II. The regenerative detector.
4. The pentode detector.

It will be shown that the four major classes of detectors, with their subdivisions, have the common function of recovering the audio component of an amplitude modulated R-F signal, and that their ability to accomplish this function depends upon their rectification properties.

Section 4. THE SIGNAL AT THE RECEIVER

As the amplitude modulated radio signal leaves the transmitting antenna (see Fig. 3) it takes the form of rapidly changing magnetic and electrostatic fields. These fields, moreover, are rising and falling in their strength, in accordance with the audio signal which they carry with them through space at the incredible speed of light.

Fig. 4 shows the voltage pattern of the radiated wave, and indicates the changing amplitude into which the radiated signal is molded by the modulation process. As we already have learned, the radiated signal, using free space as a medium, travels at the speed of light in all directions until it is absorbed by whatever it may strike. This would include buildings, bridges, trees, hills and mountains, the earth itself, and receiving antennas.

When the radiated signal strikes a receiving antenna, its pattern is a duplicate of that which left the transmitter, except that it has been considerably weakened by intervening distance and absorption by objects on the way. Fig. 5 shows the voltage pattern at the receiving antenna. Comparison with the wave-form of Fig. 4 reveals that the wave-pattern at the receiving antenna conforms in its characteristics to the wave-pattern at the transmitter. In other words, the pattern is the same. The only difference is the strength of the signal is less at the receiver than at the transmitter.

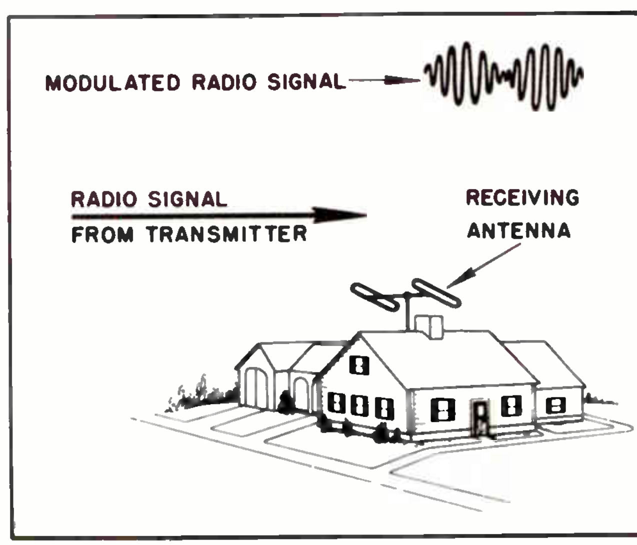

Fig.5. The Signal Voltage Induced in the Receiving Antenna is an Exact Duplicate of One Radiated from the Transmitter.

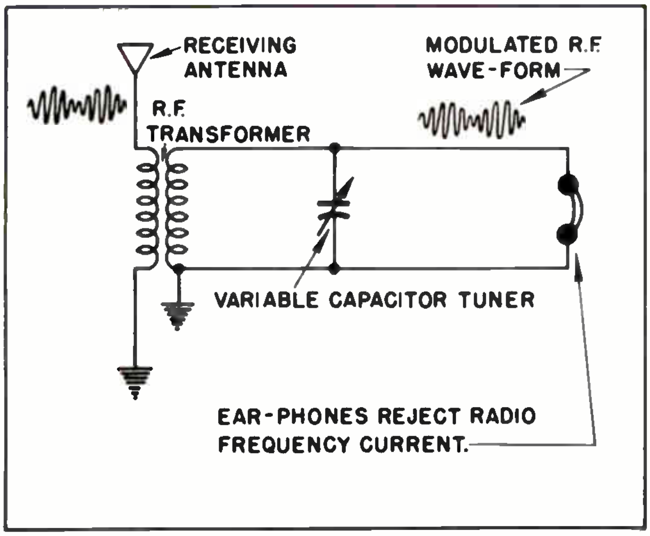

Fig.6. The High-Frequency Carrier Signal Cannot Pass Through the High Impedance of the Head Phone.

Fig. 6 is a circuit for tuning, or selecting, the antenna signal. By changing the variable capacitor in the transformer secondary circuit, a specifically desired radio signal can be separated from all other signals which are present in space at that time. The voltage at the receiving antenna is alternating at high frequency. At the same time the amplitude of this voltage varies in accordance with the original modulating signal. This means that the transformer primary will carry current corresponding to these changes. The secondary of the transformer being driven by the primary current changes, will have induced in its winding a voltage identical with that at the antenna. This is shown by the wave-forms in Fig. 6.

Will the ear-phones now respond to the incoming signal? The answer to this is no. There are two easily understood reasons why this should be so:

(1) At the high frequencies used in radio transmission the impedance of the ear-phone coils would be so high as to prevent even a small amount of signal current to flow through them.

(2) The ear-phone diaphragms cannot vibrate at radio frequencies; their physical inertia prevents them from moving back and forth at such a high rate of speed.

And even if some signal current entered the ear-phone coils -- even if the diaphragms could vibrate at such a high rate -- the human ear still could not hear the signal, for it is far beyond the range of human hearing.

Let us now examine Fig. 7. This is a diagram of the same circuit as in Fig. 6, but we have now added a crystal detector. One is usually greatly surprised at the radical change in the operation of the circuit brought about by the addition of such a simple device.

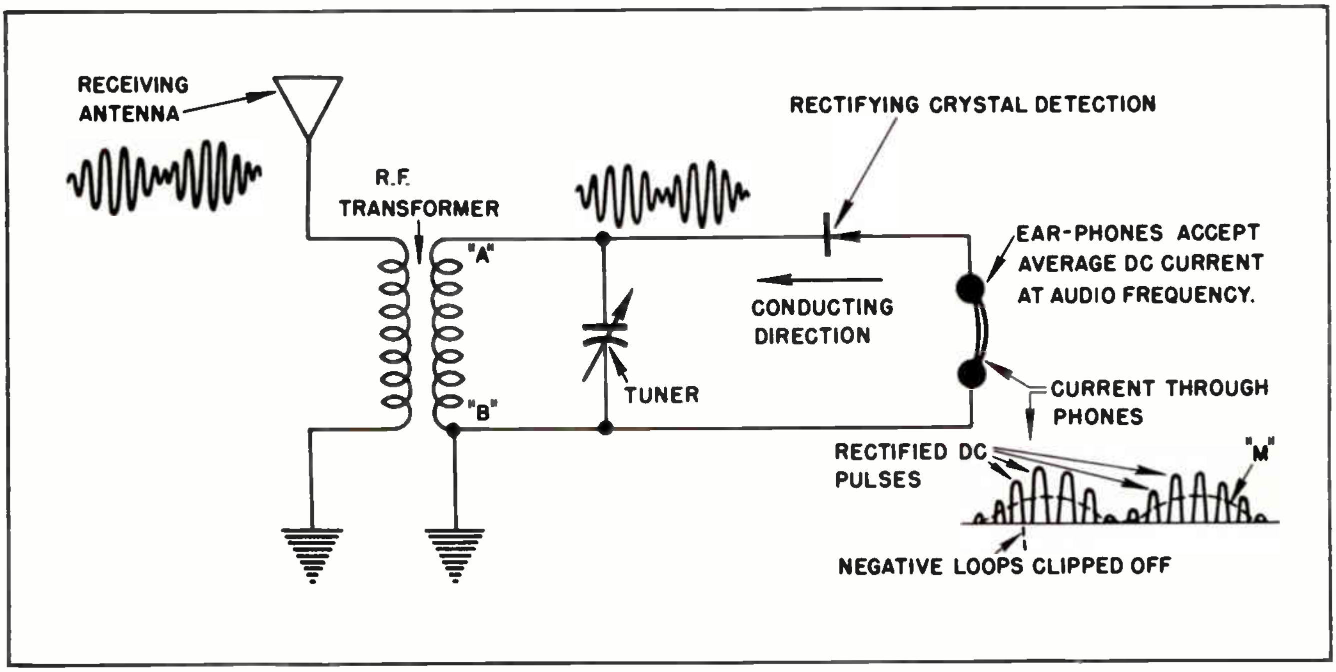

Fig.7. Effect of Adding a Crystal Detector to a Circuit.

Fig.8. A Rectifying Crystal.

Section 5. THE CRYSTAL DETECTOR

Certain crystal minerals, such as galena, selenium, and copper oxide, have the property of permitting electrical current to flow through them in one direction while practically prohibiting current flow in the opposite direction. This is the property of rectification with which we are already familiar. A crystal possessing such property is called a rectifying crystal. Its symbol is shown in Fig. 7, and Fig. 8 is a photograph of the crystal and its mounting.

In Fig. 7, when point *A* is positive (as it must be on every alternate half-cycle), point *B* is negative. Current will tend to flow from point *B* through the phones, across the crystal in its conducting direction, and will arrive at point *A*. This will produce a single pulse of current through the ear-phone coils. On the next half-cycle, when point *A* is negative with respect to point *B*, current will try to move backwards in its previous path, but will be prevented from doing so by the crystal, which is non-conducting in this direction. On this half-cycle, therefore, no current will flow in the circuit. If we continue to repeat the alternating half-cycles, we can see that the negative part of the signal wave has been cut off, and that only the positive part remains as a series of pulses, all in the same direction, through the series circuit consisting of the transformer secondary, the ear-phone coils, and the crystal detector.

Fig. 9 represents the wave-form of the current through the ear-phones. Notice that while the positive half-cycles are retained, the negative half-cycles are clipped off. This is the familiar phenomenon of rectification, and we may now observe the completely altered response of the ear-phones to rectified current.

The broken line marked "M" in Fig. 9 is the average amplitude of the positive half-cycles only, and its variations represent the audio component of the original radio signal. While we recognize the line "M" as strictly imaginary, it best illustrates the action that takes place in the ear-phones:

(1) Unidirection pulses only are now fed to the ear-phone coils; since reverse current is prohibited by the crystal, ear-phone current cannot take a backward path. No alternations of ear-phone current can take place. The reactance of these coils, extremely high at the radio frequencies, is comparatively low at the average audio frequencies of the rectified signal. Current will flow, at the audio rate, through the coils. This current will move the ear-phone diaphragms in response to the changing *average* current which flows through the coils.

(2) With rectified, unidirectional current flowing through the ear-phone coils, the metal diaphragms are not required to respond to first a positive, and then a negative, current. They are pulled in one direction only. Since the inductance of the coils has opposed the radio frequency changes, the ear-phones are activated by the average D-C audio component which is alternately stronger and weaker as the *average* current is greater or less. Since

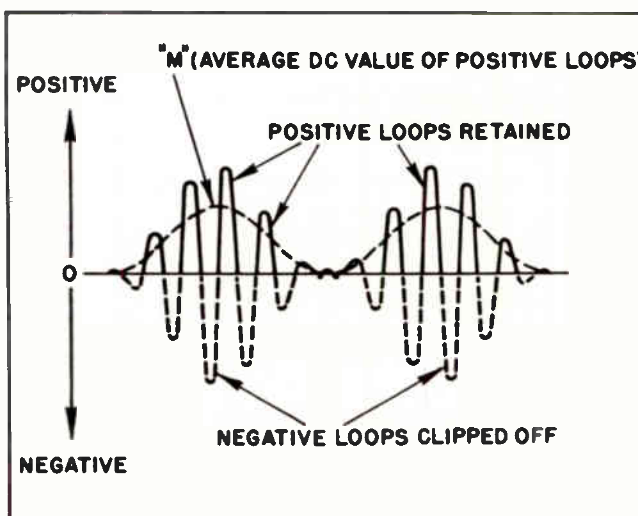

Fig.9. How the Rectifying Crystal Clips Off the Negative Portion of the H-F A-C Loops.

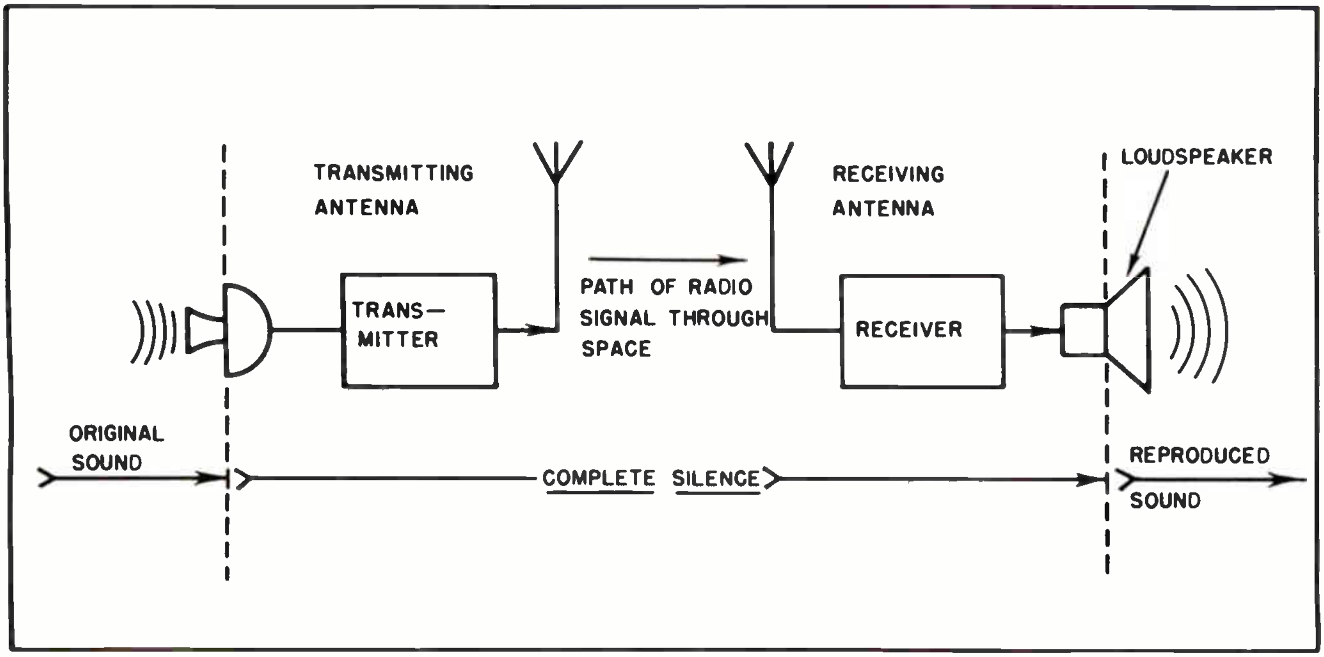

Fig.10.

these variations in current strength takes place at comparatively low frequencies the inertia of the diaphragms is easily overcome. The diaphragms will impart movement to the air at the audio rate. Thus they impart to the surrounding air a reproduction of the modulating signal which was "saddled" to the radio carrier wave at the antenna. The audio component of the radio-borne signal is thus reproduced at the ear-phones. Our ears, located near the vibrating ear-phone diaphragm, react to this reproduction just as they would to the original sound wave striking the microphone in the broadcasting studio.

Section 6. DEMODULATION BY RECTIFICATION

It is noteworthy that any sound broadcast by radio is inaudible from the time it strikes the microphone, through all the transmitter circuits, through the space that carries the signal, through the receiver circuits, and only becomes sound again when it reaches the ear-phone or loud-speaker. Fig. 10 illustrates this interesting sequence of events.

The process of demodulating an amplitude-modulated radio signal is always done by a rectifier of some kind. Stated in briefer form, AM detection is accomplished by rectification. While such rectifying devices differ in their circuits and applications, and while they may be crystals or vacuum tubes, they all achieve detection by means of rectification. The basic principles exemplified by the crystal detector are also used by diodes, triodes, and pentodes in their detecting action.

We have already seen how the crystal rectifier detects the radio signal. We may also note the crystal rectifier, due to its low-current-carrying ability and instability, is no longer practical where greater amounts of signal power are required. It has been useful to us, however, in illustrating the basic method of AM detection, and today remains of interest only for its historical and informative value.

Section 7. THE DIODE DETECTOR

Probably the most popular of all modern detectors is the diode detector, whose operation is as simple as that of the crystal type detector, but whose advantages are distinctive. The diode detector will be found in practically all present-day receivers.

Fig. 11 is the block diagram showing the relationship between the detector stage (here called the second detector) and the rest of the stages of the superheterodyne receiver. The second detector is shown in this figure to accept a modulated I-F signal (within the radio frequency range and therefore inaudible to the human ear), to demodulate or detect this signal, and deliver

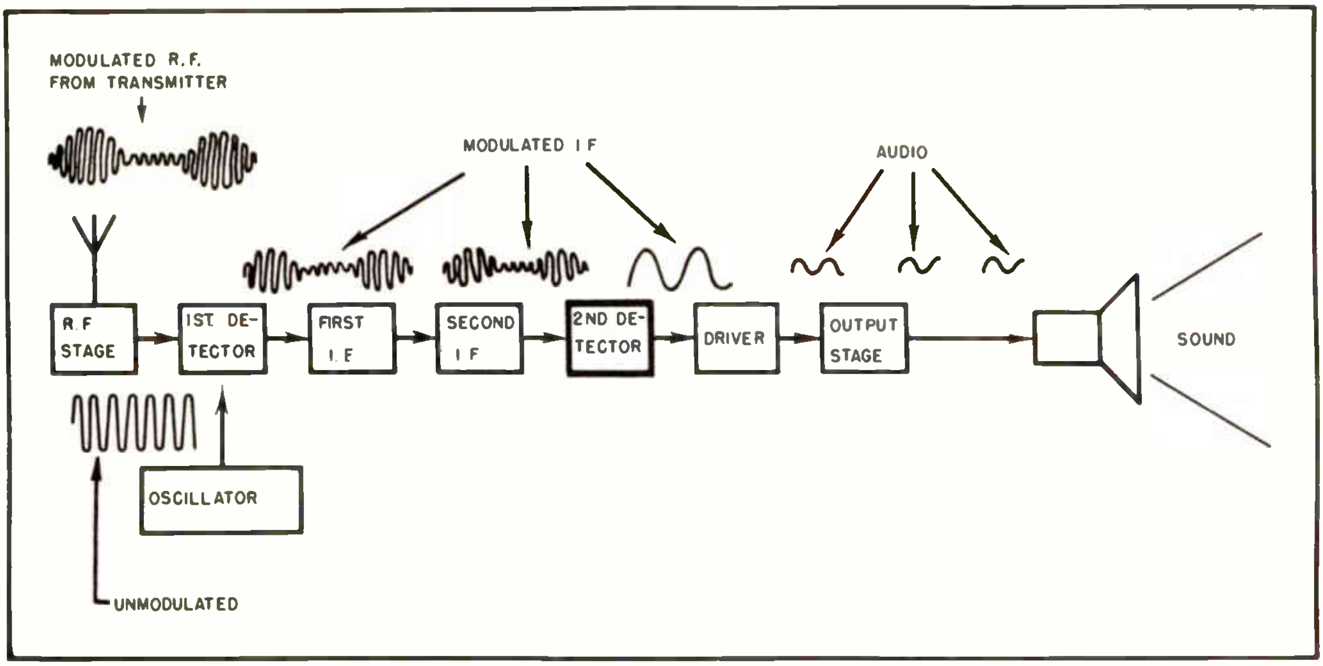

Fig. 11. Signal Wave Forms Present at Various Points in a Superheterodyne Receiver.

the audio component to the driver stage. (The purpose of the first detector -- not a true demodulator -- was pointed out earlier; it converts the modulated R-F signal to the modulated I-F signal.)

As is pointed out in the discussion of the Audio Section, the triode driver stage in most modern superheterodyne receivers consists of a resistance-coupled amplifier involving only the triode section of a multi-purpose tube. The rest of this multi-purpose tube is one diode plate, or a pair of them, using the same cathode as the triode. Reference to a tube manual will show the 12SQ7 tube, for example, to be a triode with two diodes located within the same glass envelope. Modern receivers contain many other similar multi-purpose tubes.

Where we were concerned with the *triode* portion of this multi-purpose tube in our

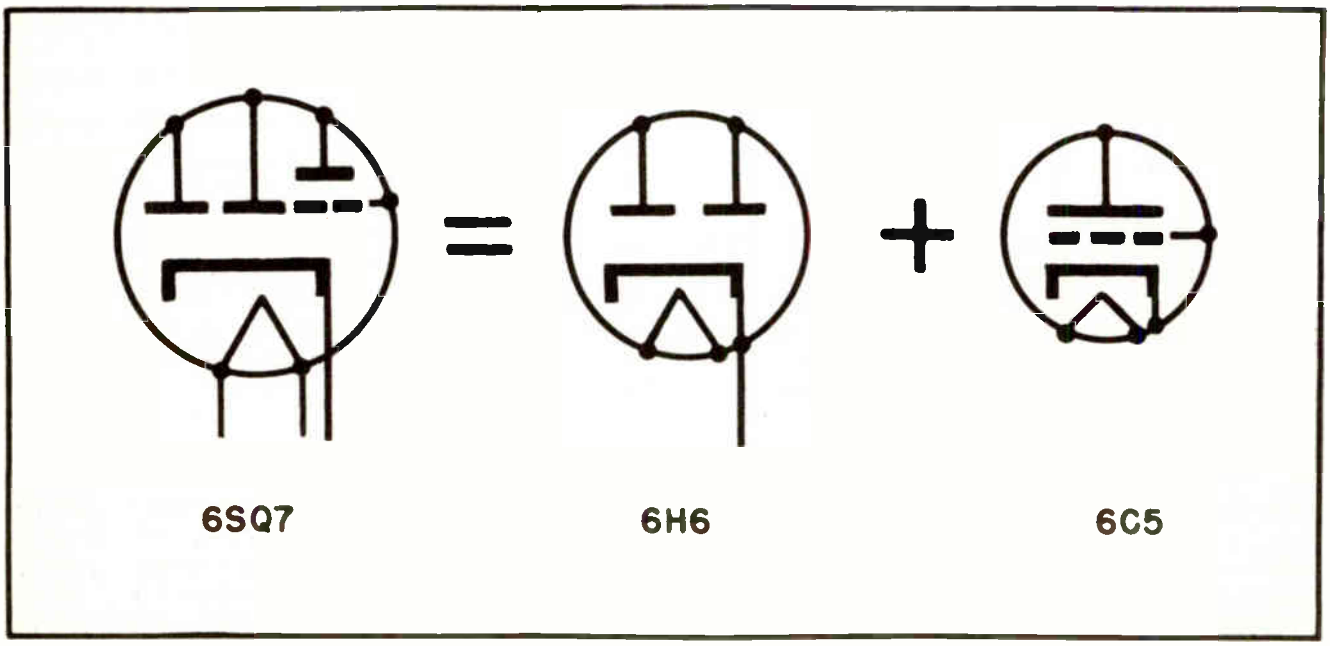

Fig. 12. A Modern Tube Such as the 6SQ7 is Actually Two Tubes in One.

discussion of the Audio Section, we are now interested in the *diode* portion. While both portions of the tube are contained in a common envelope, and use a common cathode, they may be treated separately as a diode tube followed by a triode tube. (See Fig. 12.) Their inclusion within the same glass envelope has some rather obvious advantages in the way of economy of space, weight, power consumption, and cost. Electrically, however, they are separate stages each having an entirely separate purpose.

In our analysis of second detector stages, therefore, we will find it wise to temporarily disregard the triode section of these multi-purpose tubes and direct our attention to the diode section only.

the reverse action does not take place. This, as we can see, makes all vacuum tubes act as rectifiers.

In Fig. 13, when point "A" becomes positive, as it must do at every other half-cycle of the radio signal voltage, current will flow from point "B" in the direction of the arrows, through the phones, through the diode in its conducting direction (cathode to plate), and arrive at point "A". This constitutes a pulse of current through the phones. The reverse action will not take place during the next half-cycle when point "A" is negative with respect to point "B". If the reverse were true, it would mean current would travel backwards through the diode, a condition that cannot occur. The

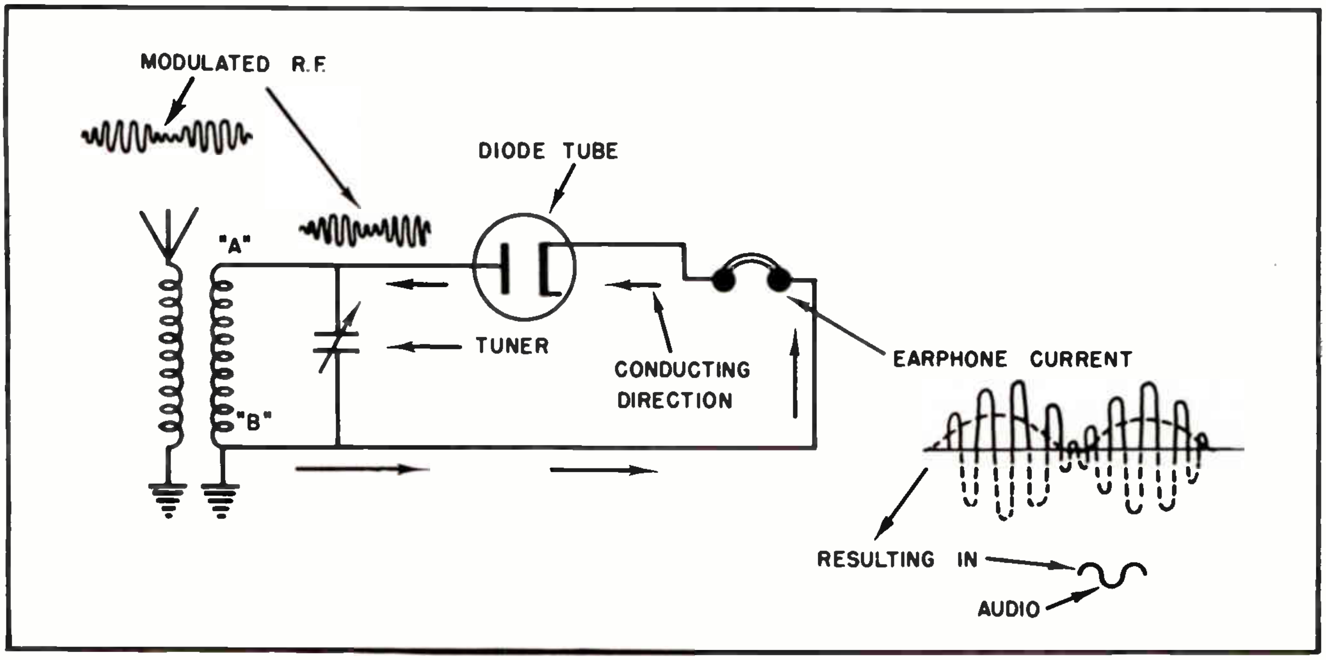

Fig. 13.

Fig. 13 shows a schematic diagram of a simple radio receiver, which you will recognize as quite similar to that utilizing the crystal detector. (Refer again to Fig. 7.) In Fig. 13, however, it will be noted that the crystal detector is absent and the diode detector has been inserted in its place. If one understands the action taking place in the crystal detector, the operation of the diode detector is easy to understand.

Like crystal detectors, the diode detector -- and indeed all vacuum tubes -- are unidirectional in their current-carrying ability. Electrons are emitted from the cathode and flow toward the plate, but

succession of half-cycles will result, therefore, in the retention of the positive portion of the signal and the omission -- clipping -- of the negative portion. This wave-pattern is shown in the illustration and is identical with that of Fig. 9, where the crystal detector is described.

The same audible results are accomplished. The phones, which reject the high frequency radio signal, will accept the average pulsating D-C component of this signal. Since this average is a reproduction of the original modulating signal, the phones will reproduce a copy of the original sound and the ear will hear it as the audible signal.

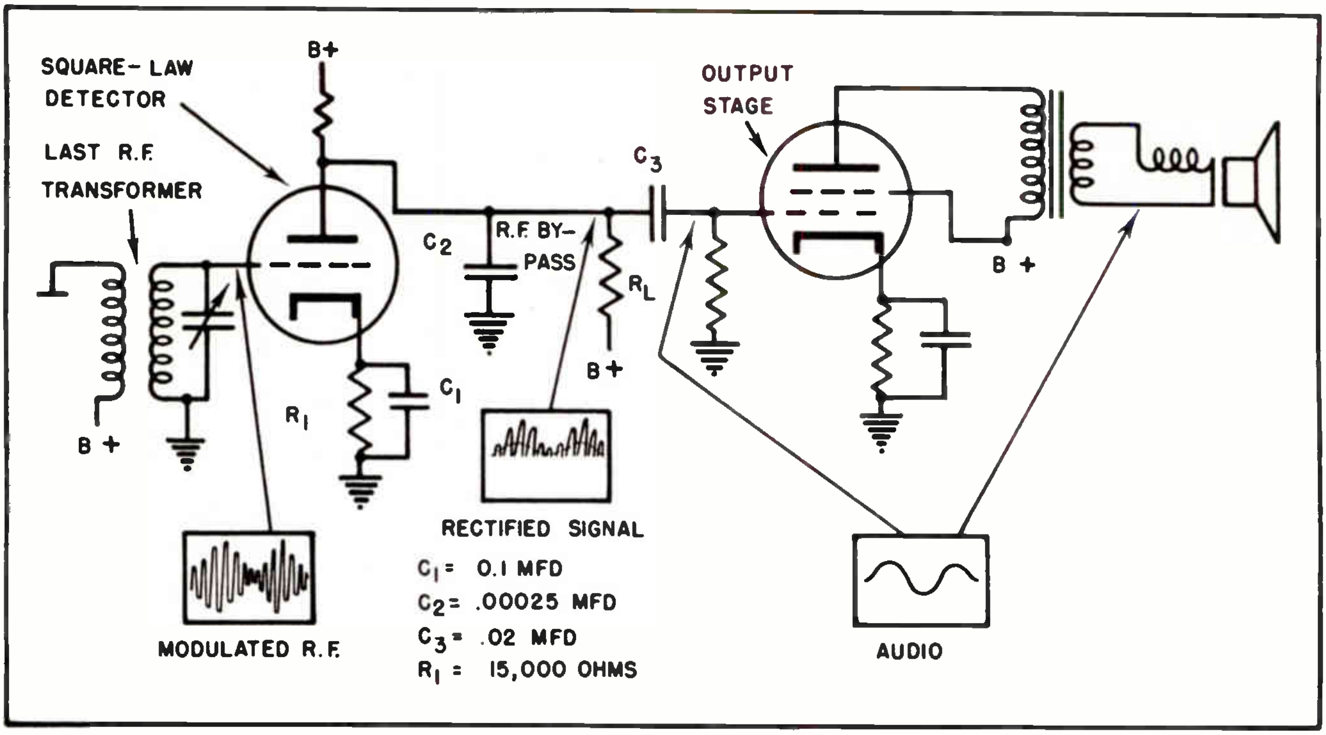

Fig.14. Frequencies Present at Various Points in a Square-Law Detector.

Because of its great popularity, and its many applications, much important discussion will be devoted to the diode detector in a separate lesson. For while its operation is relatively simple, its uses are manifold. It has been touched upon briefly at this time as a means of showing the similarity between various types of detectors, and because it links the family of crystal detectors with the larger family of vacuum tube detectors. Trouble-shooting modern detectors, as well as the subject of special circuits involving detectors, will revolve around the diode detector in the superheterodyne receiver.

Section 8. TRIODE DETECTORS

The Square Law Plate Detector. In receivers where voltage gain is required in addition to detection by rectification, the triode tube is used. If detection can be accomplished while a voltage gain is simultaneously provided in the same tube, it becomes possible to increase the strength of the signal substantially, thus permitting a roomful of people at the receiver to listen to a program which was previously limited to one person wearing a pair of phones.

Fig. 14 is the schematic diagram of the square law plate detector, which provides the described requirements.

Since the tube used in this circuit is a triode, it is capable of a certain amount of amplification. This means, first of all, that any signal introduced at the grid will result in an amplified signal at the plate. The stage gain for the square law plate detector is approximately 15 times. This means the output of the stage is about 15 times stronger than the input.

In addition to voltage gain in this detector, demodulation is performed by the unidirectional character of its current flow -- from cathode to plate only. The tuned grid circuit voltage (modulated R-F) causes plate current changes in the tube that are in accordance with the modulated R-F signal.

The plate load, a pure resistance, will produce voltage drops in accordance with plate current. Since the plate current is modulated R-F, so the plate voltage drop will be modulated R-F. However, there will be an increase of amplitude in proportion to the gain of the stage. So far the stage has acted exactly like an ordinary R-F amplifier, with no demodulation taking place as yet.

Now, however, let us point out differences between the square law plate detector and the R-F amplifier it so closely resembles. The square law plate detector is *biased* practically at cut-off, which means that a signal swinging both above and below this bias point will permit tube current to flow during the positive half-cycle of signal at the grid, but will drive the tube to cut off during the negative half-cycle at the grid. The negative portion of the input cycle, therefore, will be effectively rejected by the stage. This means that the plate load drop will lack one side of the amplified signal wave-form. (Refer to wave-forms in Fig. 14.)

Except for the gain provided in this stage, this action is essentially the same as that of the diode detector. The signal in the plate circuit divides into two paths. The R-F component (high-frequency), no longer useful in the receiver, is shunted to ground through capacitor *C-2*, which has a high reactance to audio frequencies while offering low reactance to the radio frequencies. The audio, barred from passage to ground by the high reactance of *C-2*, is fed through *C-3*, a much larger capacitance, to the grid of the output stage. As the diagram indicates, the gain in amplitude of the audio during this demodulation process is sufficient to drive the loud-speaker with a strong signal.

The bias in this stage is determined by the value of the cathode resistor, usually around 15,000 ohms. *C-1* is usually 0.1 mfd, while *C-2* is .00025 mfd and *C-3* approximately .02 mfd. To illustrate the operation of this square law detector graphically, Fig. 15 shows the input and output voltages as they relate to the characteristic curve of the tube.

Note that at no time does the grid signal drive plate current much past the lower "knee" of the characteristic curve. This means that plate current is not proportional to the grid voltage, but to the square of the grid voltage. This peculiarity justifies the name of this detector as a square law detector.

The use of capacitor *C-2* in Fig. 14 deserves some attention at this time. As mentioned before, it is used to by-pass to ground that portion of the signal no longer

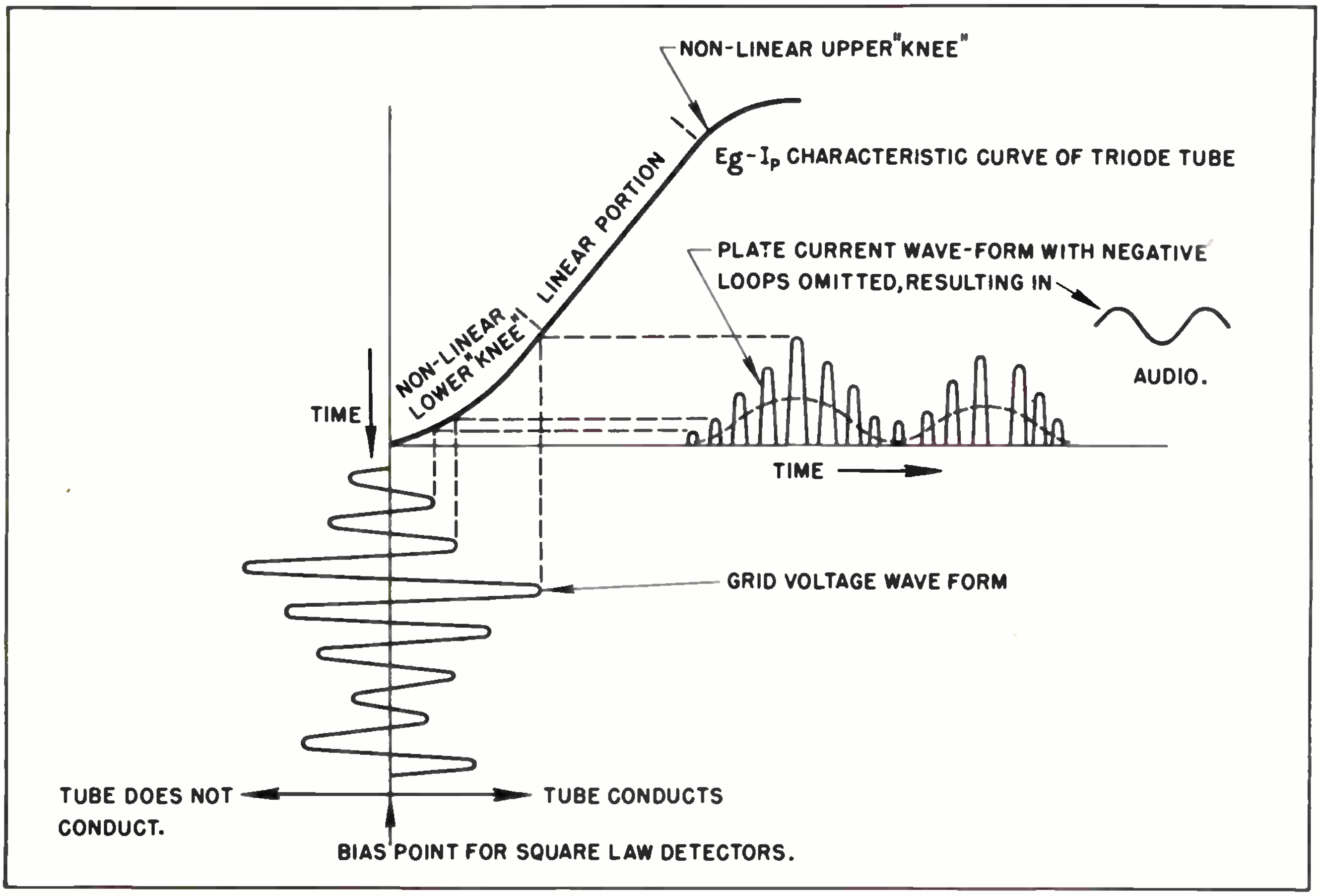

Fig.15. Biasing for Square-Law Detector. Note that Class "A" Biasing Is Not Used.

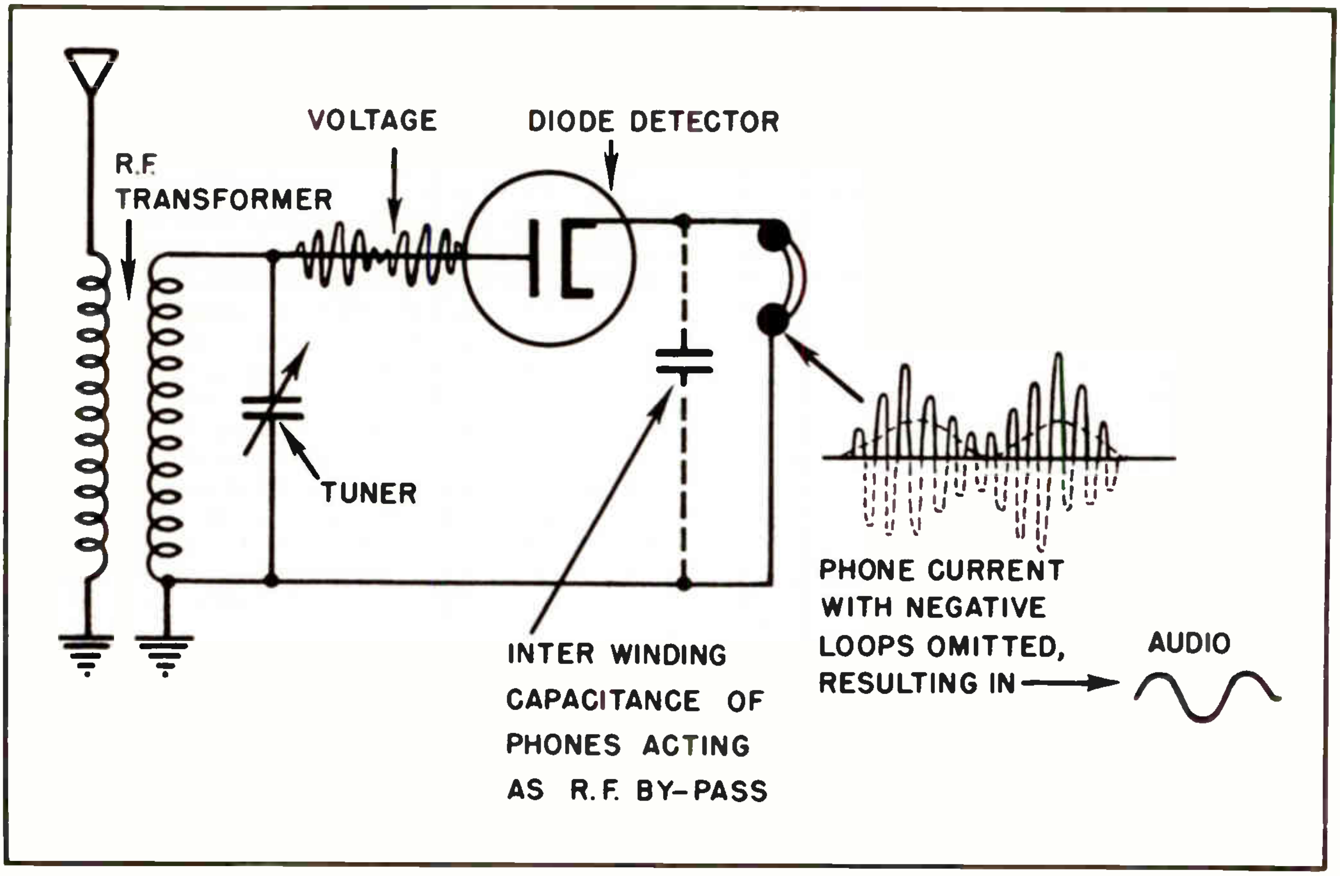

Fig. 16.

desired, the R-F component. Why, then, is there no by-pass condenser shown in the circuit diagrams of the crystal and diode detectors? Reference to Figs. 7 and 13 will show that the by-pass capacitor has been omitted from these circuits.

The ear-phone coils consist of many turns of very fine wire, and each of these turns are insulated from all others. This constitutes a system of conductors separated by a non-conductor (the enamel insulation surrounding each wire); such an arrangement is capable of accepting an electrical charge and will have the nature, if not the appearance, of a capacitor. In this case, the capacitance is called "inter-winding capacitance" and is closely related to the more general type of "distributed capacitance." The by-pass capacitor can be installed across the phones in these circuits, but it will simply add to the already existing interwinding capacitance which performs the same function of shunting the unwanted R-F away from the phone coils and delivering them -- their usefulness spent -- to ground. Fig. 16 duplicates the essential characteristics of the diode circuit of Fig. 13 with the additional symbol of distributed capacitance shown as the broken-line condenser across the phones.

The square law triode plate detector does not possess this distributed capacitance to a sufficient degree to omit the capacitor itself, since the many turns of an inductive load do not appear until the signal reaches the matching transformer primary. Like all triode detectors except those that feed a pair of phones directly, the square law plate detector output will need the R-F by-pass condenser to lead unwanted R-F from plate to ground.

Section 9. THE LINEAR PLATE DETECTOR

Up to the time that radio tube engineers developed the high-gain R-F tube, the square law detector was commonly used. The development of tube improvements, however, permitted a stronger modulated R-F signal to drive the square law detector, and changed its response in an important way. Due to the fact that the square law plate detector operates within the limits of the lower non-linear "knee" of its characteristic curve, a certain amount of signal distortion takes place.

Newer tubes with higher gain in the radio frequency stages which build the signal up to higher amplitudes, permit driving the triode detector up past the non-linear curved portion of the characteristic curve, and well into the linear portion. Cut-off bias was maintained, however, since clipping the negative loops from the incoming modulated R-F was still required for demodulation. The result was that with a stronger input signal, more of the linear portion of the curve could be used, and therefore a greater fidelity could be achieved. This added linearity (faithfulness) in reproducing the audio component of the radio-borne signal is accomplished with practically no changes in the detector circuit.

The more linear response of the detector gave rise to the term *linear plate detector*. It is also commonly called "Plate" detector. It should be borne in mind that the circuits for the square law detector and the linear plate detector are identical, but their difference is due only to the amplitude of the signal introduced on their grids.

Fig. 17 shows the wave patterns of grid and plate voltages in the linear plate detector, as relating to the characteristic curve of the tube used. The differences may be further clarified by comparison with Fig. 15.

The Infinite Impedance Detector. The linear plate detector has been modified to provide even less distortion in the detecting process. Fig. 18 shows a schematic diagram illustrating the necessary changes. The plate load, formerly in the plate-to-B-plus circuit, has now been reduced in value and placed in the cathode circuit. In actuality, it simply means that the plate resistor has been completely omitted, and that the cathode bias resistor now acts as the tube load. The output signal, as is evident from the diagram, is available not at the plate of the stage, but at its cathode.

This is called an infinite impedance detector because the stage, no longer operating with a plate voltage which changes through the modulation cycle, maintains a constant transconductance, permitted by a constant

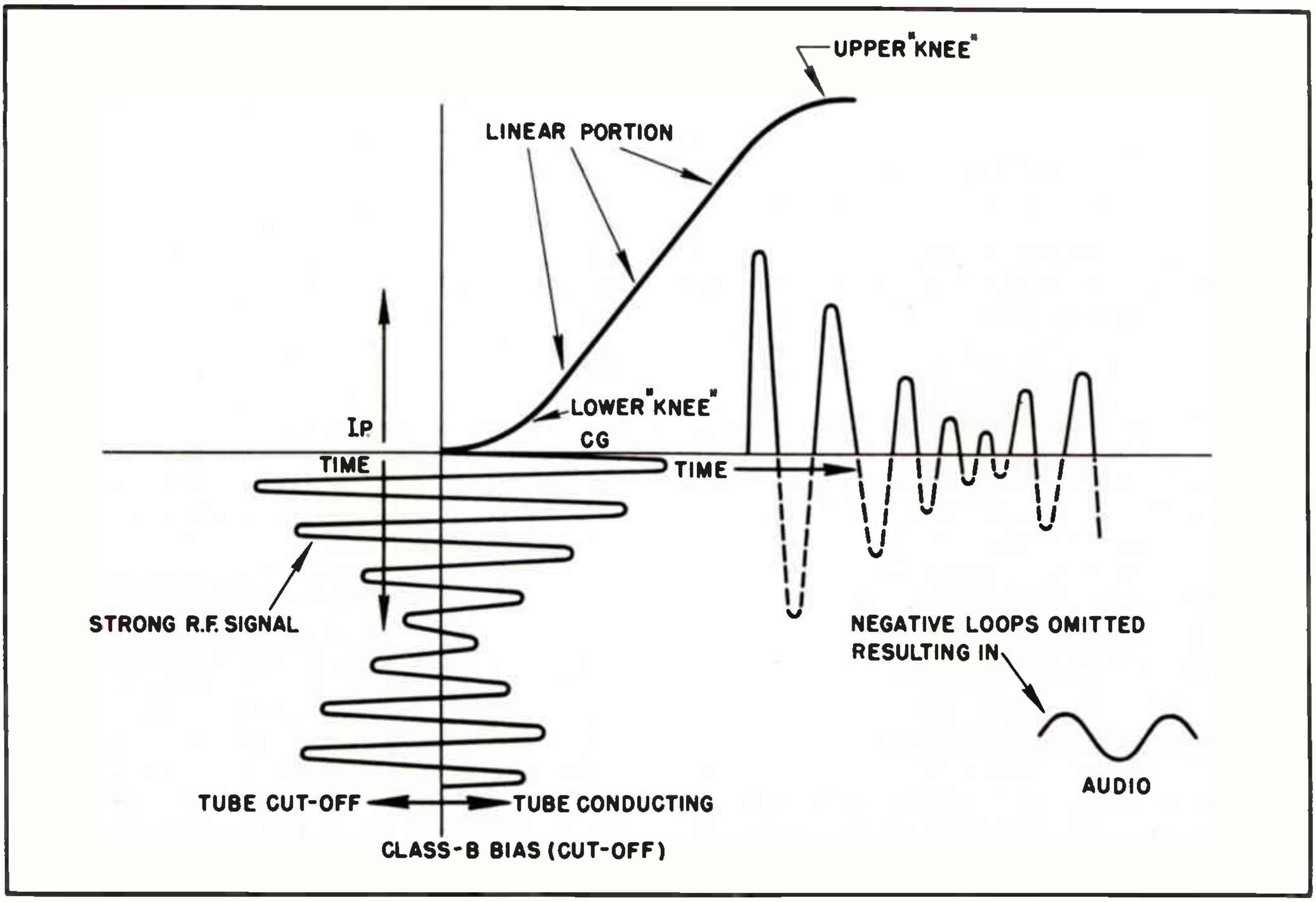

Fig. 17.

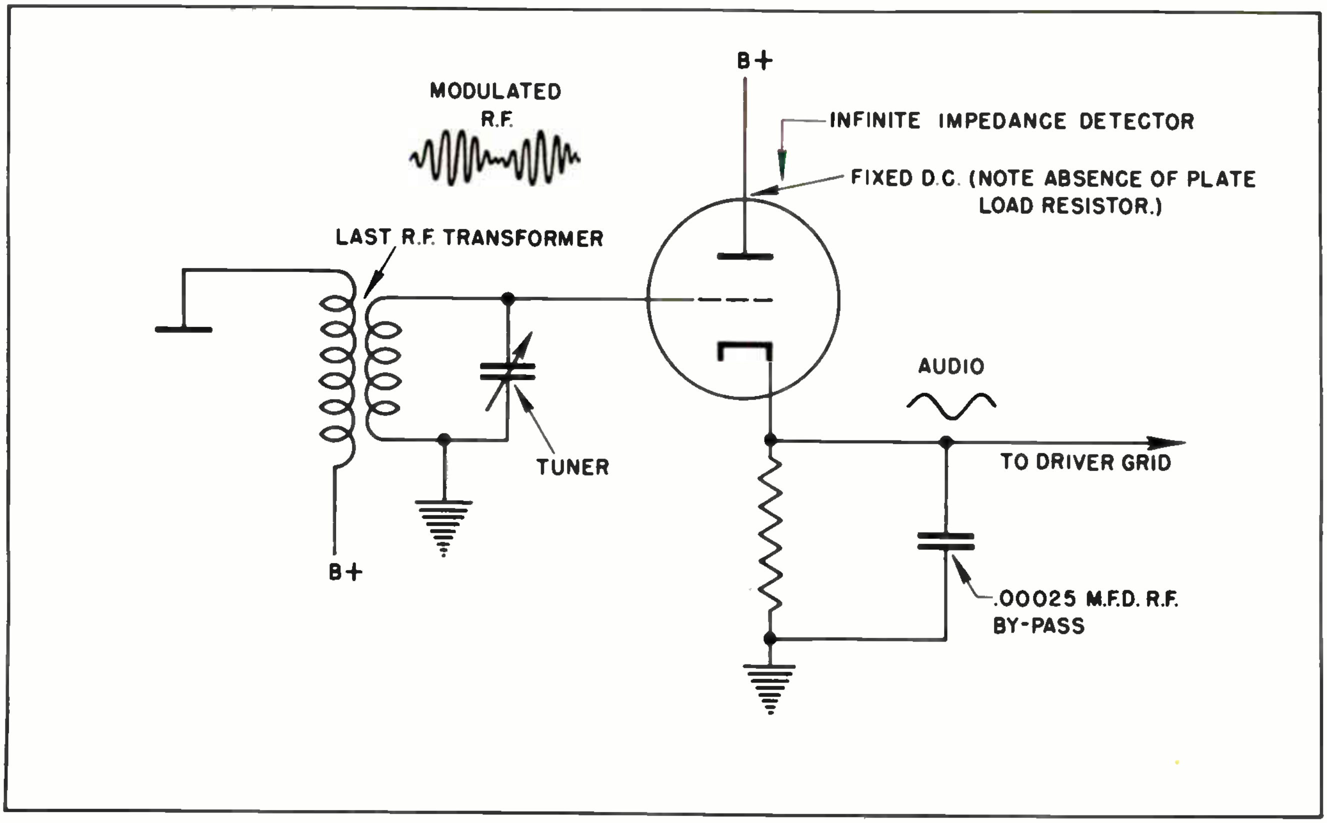

Fig. 18. Circuit of an Infinite Impedance Detector.

plate potential, B-plus. For this reason the grid circuit presents a fixed high impedance, which, for convenience rather than for strict accuracy, is called infinite.

Gain in the infinite impedance detector is limited, of course, since the cathode signal voltage can never exceed the grid signal voltage, and the advantage of this type of detector is chiefly that of linearity. It may be interesting to note that sometimes this type of detector is shown with a plate resistor. However, on examination, this plate resistor will be seen to be of comparatively low ohmage, and, to maintain a constant plate voltage, will be by-passed to ground through a capacitor large enough to handle audio frequencies. Such a network in the plate of this circuit acts as a decoupler. It is often used in television circuits.

Section 10. TRIODE DETECTORS

Another group of triode detectors are those where rectification of the modulated R-F signal takes place in the grid circuit, rather than in the plate circuit. Grid detectors are also called grid leak detectors. Their main advantage is their increased sensitivity over the plate detectors. Fig. 19 illustrates the typical grid leak detector circuit.

The grid leak detector is biased as a Class "B" amplifier. In this respect it differs from the Class-B bias of the plate detector only in the method of achieving the bias. The plate detector is cathode-biased, while the grid detector is grid-biased. In the latter, grid bias is developed as follows:

The modulated R-F signal is impressed across the last R-F transformer secondary by primary current. When this A-C signal is first introduced to the detector grid, current flows in this stage from cathode to plate and through the plate load to B-plus. The grid, being immersed in the stream of electrons of this tube will gather some of them upon its surface, much the same as your hand becomes wet when you dip it into a flowing brook.

Electrons, however are negatively charged and repel each other. They will tend to force each other from the grid upon whose surface they are gathered, and those forced from the grid will take any available path to ground. This path is provided by the grid resistor, which will readily conduct excess electrons from the detector grid leftward through the grid resistor. A momentary voltage drop occurs when these electrons move through the resistor. The polarity of this voltage drop is indicated in Fig. 19.

The grid condenser paralleling the resistor will be charged up by this momentary voltage drop, and will hold the charge, at the same amplitude and in the same polarity as that across the resistor. Part of this charge will still be held by the time the next positive-going pulse arrives at the grid from the transformer secondary. The net result is that the resistor places the grid at a potential more negative than ground, and the condenser holds this potential between half-cycles of the signal.

We recall that a D-C potential difference between grid and cathode (which here is tied to ground and is therefore always at ground potential) means bias. The class of bias is easily controlled by using a grid resistor of such a value as to create the required voltage drop when a known amount of grid current flows through it. Common values for the grid resistor and grid condenser are 2 meghoms and 200 mmfd, respectively. The grid leak detector is seldom or never used on modern receivers. But many amateurs and other experimenters often use it because it is very sensitive. Fig. 19 includes the wave-patterns from point to point in this circuit.

The Regenerative Detector. The regenerative detector operates in a manner similar to the ordinary grid leak system described above. It has the added advantage, as shown in Fig. 20, of feeding back a portion of the amplified signal to reinforce the grid signal. The result is extremely high sensitivity. This circuit is used primarily by amateurs and hobbyists to pull in very weak trans-oceanic foreign broadcasts.

As Fig. 20 reveals, the regenerative detector depends for its rectifying action upon the grid leak resistor and condenser network, with signal regenerated (fed-back in phase) before R-F by-passing has taken place. The variable inductive coupling in the feed-back path permits adjustment of the strength of the fed-back signal to attain sufficient sensitivity without driving the system into oscillations which are undesirable. The cathode gain control assists in this function. Although this circuit is very similar to the Armstrong oscillator, the difference lies in the control over the

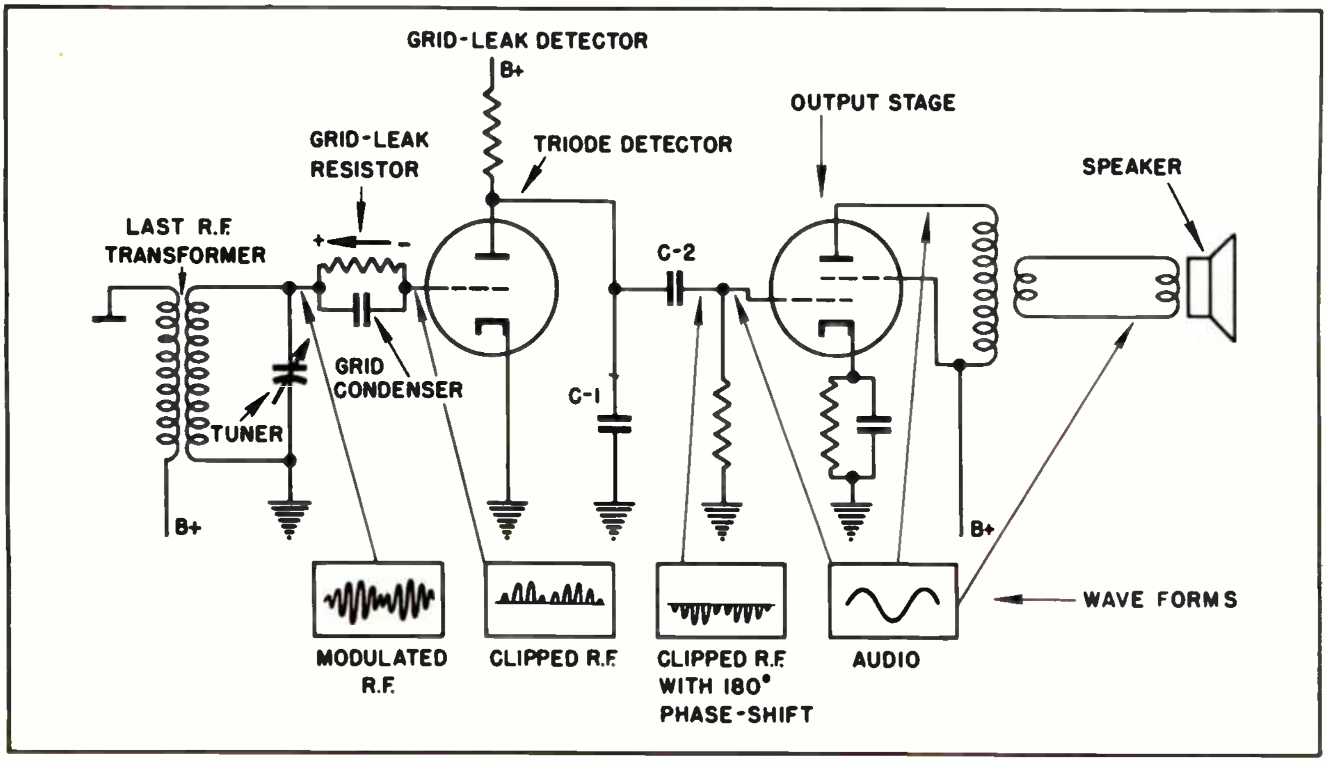

Fig. 19. Grid Leak Detector.

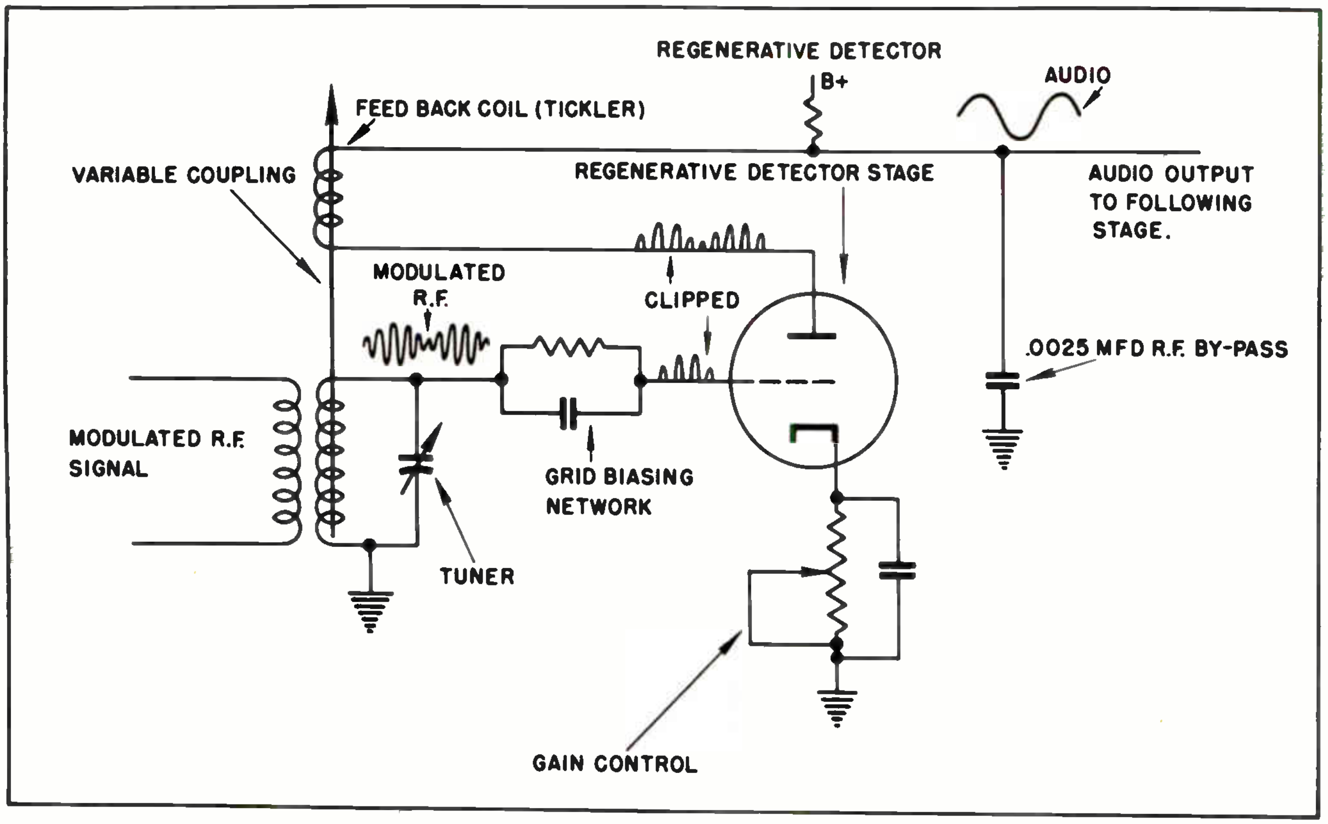

Fig.20. Regenerative Detector.

feedback signal. The detector is so adjusted as to obtain maximum gain, but feedback is kept just below the point of oscillation.

Section 11. PENTODE DETECTORS

When the high-gain pentode tube was applied to radio receivers it was immediately put to work as a detector as well as an amplifier. Typical examples of these tubes are the 6C6 and the 6J7, with their counterparts in other heater voltage ratings. These tubes are described as "sharp-cut-off pentode R-F amplifiers and detectors", the term, *sharp-cut-off* referring to the steepness of the characteristic curve near the cut-off point.

In addition to the very high gain of which these tubes are capable, their sharp-cut-off characteristics render them especially suitable for detector-amplifiers, offering advantages over triode detector-amplifiers in the amount of gain available, and in the linearity of the audio response. Since linearity increases with the ohmic value of the plate load resistor, and since the pentode plate load can be extremely high, due to the presence of its screen-grid and suppressor grid, excellent results are achieved with the pentode detector.

A circuit employing the pentode as a detector is shown in Fig. 21. Typical values are indicated in the diagram. Its closest relative in the detector family is the plate linear detector, as comparison will indicate. Note the wave-forms in this circuit, as they show that rectification takes place in the plate circuit.

Pentode detectors have been used extensively in TRF receivers, and many of them are still in use and are operating well. The practice of employing pentode detectors, however, is today dwindling with the progressive obsolescence of the TRF receivers and their replacement by superheterodyne circuits. Most of the present pentode detectors are found in small table-model TRF's whose useful life has been remarkably long.

Section 12. DETECTOR CHARACTERISTICS -- ADVANTAGES AND DISADVANTAGES

For your convenience we will repeat the classification of the four major types of detectors, show the applications relating

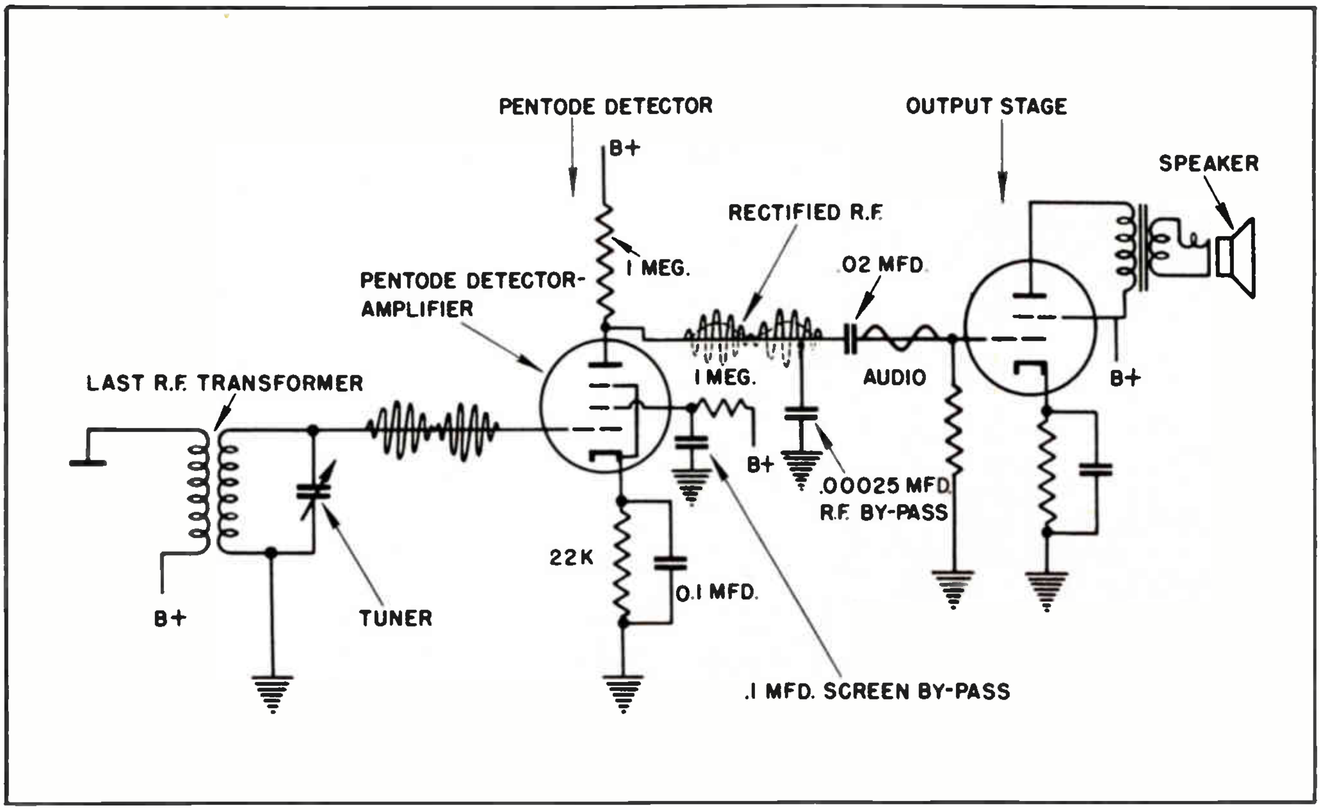

Fig.21. Pentode Detector.

to their advantages and disadvantages, and draw general conclusions about them as a family.

1. **THE CRYSTAL DETECTOR.** Except for certain special applications in which we are not concerned, the crystal detector is a rudimentary type whose current-carrying ability is limited to local radio reception with ear-phones.. While its interest today is historical and instructive, the basic method of operation of the crystal detector is an integral part of any detector.

2. **THE DIODE DETECTOR.** This is by far the most modern and the most important type, its applications are broad in both radio and television circuits. In radio, the diode is used as a detector in modern superheterodynes almost exclusively. In television, the diode detector is a fundamental component of the video -- or picture -- section. Most diodes occur, in the modern receiver, as a part of a vacuum tube, the remainder of which is utilized as a triode (or pentode) amplifier.

The diode has no amplification and is therefore used where the previous stages have especially high gains. High gain is typical of modern I-F amplifying stages. Diodes are reasonably faithful detectors, and can be satisfactorily used in precision circuits where high fidelity is required. Another lesson of this series will be almost entirely devoted to diode detector trouble-shooting and auxiliary circuits.

3. THE TRIODE PLATE DETECTOR. *(a)* The Triode Plate Detector.

I. The square-law plate detector is a triode stage in which detection takes place in the plate circuit. Since a triode is used, amplification of the resultant audio signal is available to the extent that the receiver can be used to drive a loud-speaker with considerable strength. The square-law plate detector, while providing this gain over the diode and crystal detector, causes distortion of the audio signal, especially at low input signal amplitude. It generally takes up a whole vacuum tube by itself, not being a part of a multi-purpose tube. Its sensitivity is reasonably good, and its fidelity has proved sufficient for most of the TRF receivers in which it is found.

II. The Linear Plate Detector, a triode stage, is closely related to the square-law detector in that essentially the same circuits are employed in both types. However, with the introduction of a stronger signal at the grid, and the same Class-B bias maintained, the linear detector permits the fidelity of the audio signal to suffer less distortion than in the square-law type. Chronologically, the linear plate detector follows the square-law detector, over which its linearity is an improvement. It will be found in some of the TRF receivers still in operation.

(b) The Grid Detector.

I. The grid leak detector is a triode detector providing gain and detection in the same stage, in this respect differing little from the plate detectors. Its chief departure from, and advantage over, the plate detector being that it is more sensitive. This is especially true at low signal amplitudes, since its grid-generated bias varies directly with grid signal amplitude. It provides reasonably faithful audio output in the TRF receivers in which it is to be found.

II. The regenerative detector is applied mostly to amateur and communications receivers. Its detecting ability is identical with that of the grid-leak detector, but it also provides regeneration by the use of plate-to-grid feed-back (in phase) in the same stage. This, of course, renders its sensitivity extremely high, and accounts for its popularity in the small "ocean-hopper" receiver. The regenerative detector will seldom be found in a modern commercially built receiver.

4. **THE PENTODE DETECTOR.** Being provided with screen and suppressor grids, the pentode detector is capable of gain far beyond the limits of that attainable in triode tubes. The minimization of both inter-electrode capacitance and secondary emission, characteristic of the pentode tube, enables this type of detector to deliver surprisingly strong audio signals with very little R-F signal input. Its chief application is in table-model TRF receivers of the midget type, where the tube complement consists of two R-F pentodes (the second performing the additional job of detection), one power output tube, and one power rectifier. Since many of these receivers are still in operation, despite their respectable age, they are still frequently encountered by service men.

Section 13. REVIEWING DETECTOR ACTION

This lesson has taken us into the operation of numerous different detector circuits, falling into four major divisions. We may now, with a better understanding, draw important conclusions regarding detectors which would have been difficult to grasp if mentioned before a working knowledge of detectors were attained. Let us, in these concluding paragraphs of this lesson, "stand back" a little from the subject of detectors and see what they look like from an all-inclusive point of view. We shall recognize certain family resemblances which -- though present -- may not be so evident when we examine each detector in minute detail.

We will note that all detectors (amplitude demodulators) serve the function of extracting the audio component from an AM signal. This is accomplished by a modification of the process of rectification, in which one side of the alternating R-F wave-form is clipped off, leaving the other side to be integrated (averaged) into the audio component. We see that the process of rectification splits the wave-form into two halves, one of which is discarded, while the other is molded into a signal audible to the human ear.

Rectification, then, is the first step in detection. Each of the detectors described in this lesson performs the act of rectification.

We also see another step which has been performed. In each of the detectors discussed, we find the R-F component was by-passed to ground through a component described as an "R-F by-pass" condenser. It usually has a capacity of about .00025 mfd. Comparison will show that this R-F by-passing was done in all cases, although in those detectors feeding directly into ear-phones a separate capacitor was not needed, since the "inter-winding capacitance" of the phones provided this by-passing effect automatically. We may now conclude that in addition to the process of rectification, a detector must also separate the audio component from the radio component.

Separation is the second step in detection. Each of the detectors described in this lesson performs the act of separation. After separation of the audio component from the R-F component, the former is sent as a signal to the stage following the detector. There it is further amplified and eventually used to drive the loud-speaker. The R-F component is directed to ground, where it will be harmless. No longer useful, the R-F component, which faithfully carried its modulated message with the speed of light from the audio stages of the transmitter to the audio section of the receiver, finally expires in the peace and quiet of the .00025 R-F by-pass condenser.

As later discussion of trouble-shooting detectors will show, should the .00025 R-F by-pass condenser be open, the audio section will be fed with the R-F component which has no path to ground. This will result in a characteristic "hissing" of the signal in the loud-speaker.

NOTES FOR REFERENCE

Detectors are those stages in an AM receiver which extract the audio component from the carrier signal.

In superheterodyne receivers, the demodulating stage is called the second detector; the first detector in these receivers is better described as the mixer, or converter stage.

In TRF receivers, there is only one detector. It is a true amplitude-demodulator.

In FM receivers, demodulation is accomplished by the discriminator stage. This is discussed in detail in other lesson.

In television, the audio signal is extracted by a discriminator, since television sound is FM. The picture signal, however, is AM and is therefore extracted by a detector, usually a diode.

While detectors may take several different forms, their operation is identical in principle. The process of rectification rejects one side of the modulated R-F signal. The audio component is separated from the R-F, the former being fed to audio circuits, and the latter by-passed to ground.

Among the detector types are:

The diode detector, used in modern superheterodyne receivers.

The triode detector, used in early TRF's.

The pentode detector, used in later TRF's.

The crystal detector, used in the pioneer days of radio.

The heterodyne detector and the regenerative detector, both used in amateur and code communication.

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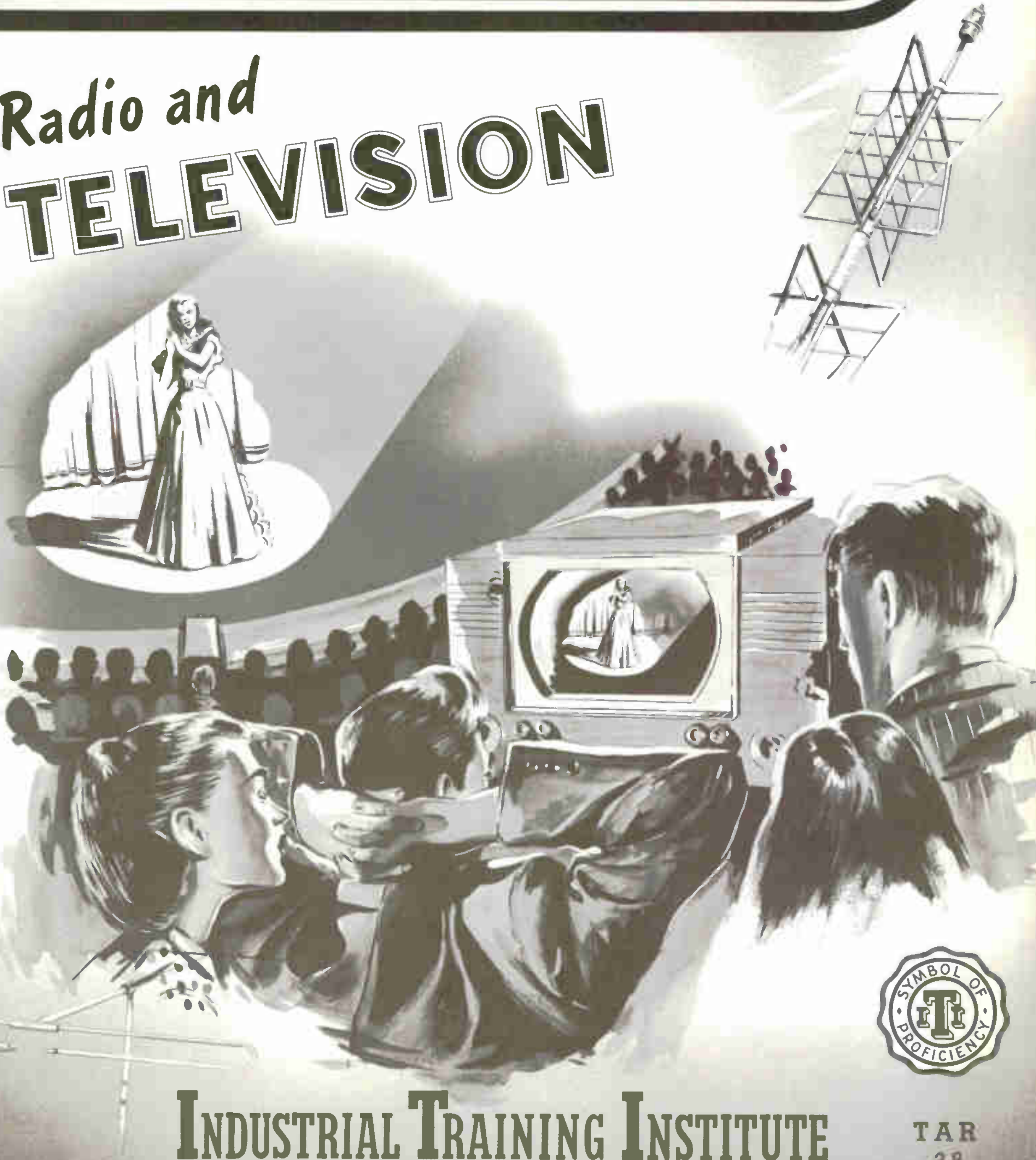

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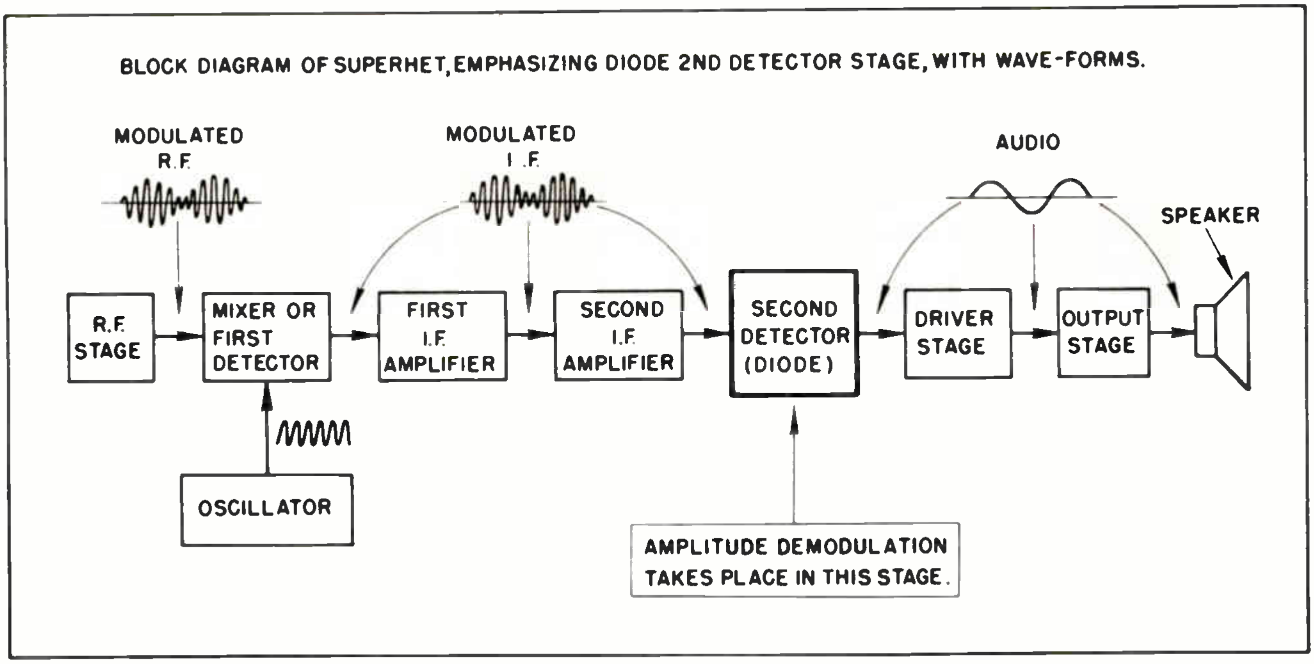

Fig. 2. Block Diagram Showing Relationship of Diode Detector to Other Stages in Superheterodyne.

same time it lends itself to other auxiliary purposes, such as automatic volume control (AVC), tuning indicators, automatic frequency control (AFC), and -- in television receivers — to special wave-shaping circuits.

In this lesson our attention will be directed to the details of diode detection as applied to AM receivers, to the variety of circuits associated with this stage, and to the trouble-shooting of diode, triode, and pentode detectors. For emphasis, let us re-state the main characteristics of detectors:

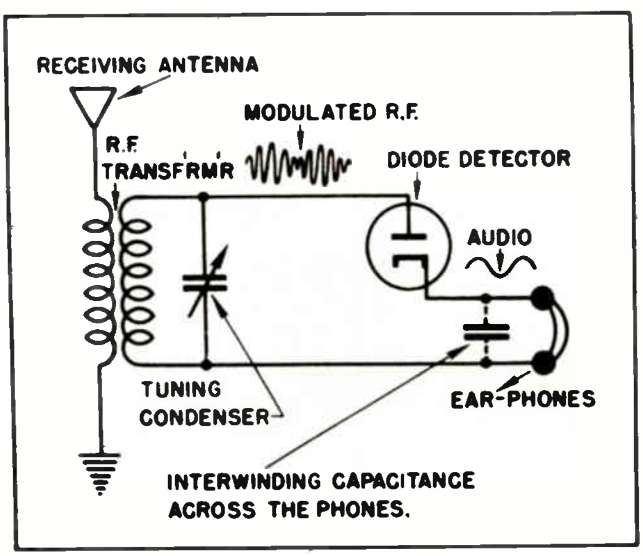

Fig. 3.

1. The purpose of a detector is to recover, or extract, the audio frequency component of a radio-borne amplitude-modulated signal.

2. The first step of the detection process is rectification, where one side of the AM signal is rejected and the other molded to a form suitable for human perception.

3. The final step in the detection process is separation of the audio frequency component from the radio frequency component, and consists simply of by-passing the latter to ground while the former is directed to audio stages following the detector.

Section 2. THE DIODE DETECTOR

Inspection of Fig. 2, the block diagram of a typical superheterodyne receiver, will show the electrical location of the diode detector in this popular receiver circuit, and its relationship to the other component stages. In the superheterodyne receiver, the detector input voltage may be described as modulated intermediate frequency (I-F), and its output signal as pure audio frequencies (AF). The wave shapes are evident in the illustration.

Fig. 3 reproduces the sketch of an earlier lesson, showing the function of the diode detector as applied to a simple receiver using a pair of earphones. We know that this circuit will accept a modulated RF signal, tune it, and recover the audio signal for the benefit of the listener.

Let us now turn our attention to Fig. 4-A, which illustrates how a modulated RF signal, originating at any source whatever, may be fed to the diode for detection. The action here is identical with that of the circuit in Fig. 3. However, we may notice that the output of the audio component from the diode in Fig. 4-A is not sent to a pair of phones. It may be fed to wherever we may desire. We shall soon see where this signal will be sent. Attention is called to the diode load in the Figure. We have removed the phones, but have put the diode load resistor in their place. Any audio signal current which would have displaced the phone diaphragms will now produce voltage drops at audio frequency across the diode load. By suitable coupling, the signal voltage developed across the diode load may be delivered to the stage following -- the driver stage. There it is amplified before being sent to the output stage, and eventually to the speaker.

Fig. 4-B is an exact electrical duplicate of Fig. 4-A, with the exception that a source of modulated signal has now been indicated. This signal source, as shown, is the secondary of the last I-F transformer. Because of what is to follow, the artist has re-arranged the location of the component symbols of this circuit, and has drawn in a ground connection at both the diode cathode and the lower end of the load resistor. Note, however, that in both Figs. the diode, the transformer secondary, and the diode load resistor are in series, and that the .00025 RF by-pass condenser is across the load. Current flows in the direction indicated by the arrows of both diagrams, and it is evident that since the uni-directional diode is in the series circuit, current cannot take a reverse direction.

You may now ask why there are two plates to each of the diodes shown in Fig. 4, and only one plate in the diode of Fig. 3. This is a reasonable question and deserves an answer.

Reference to the tube manual will reveal that, except for the 1.5-volt multi-purpose

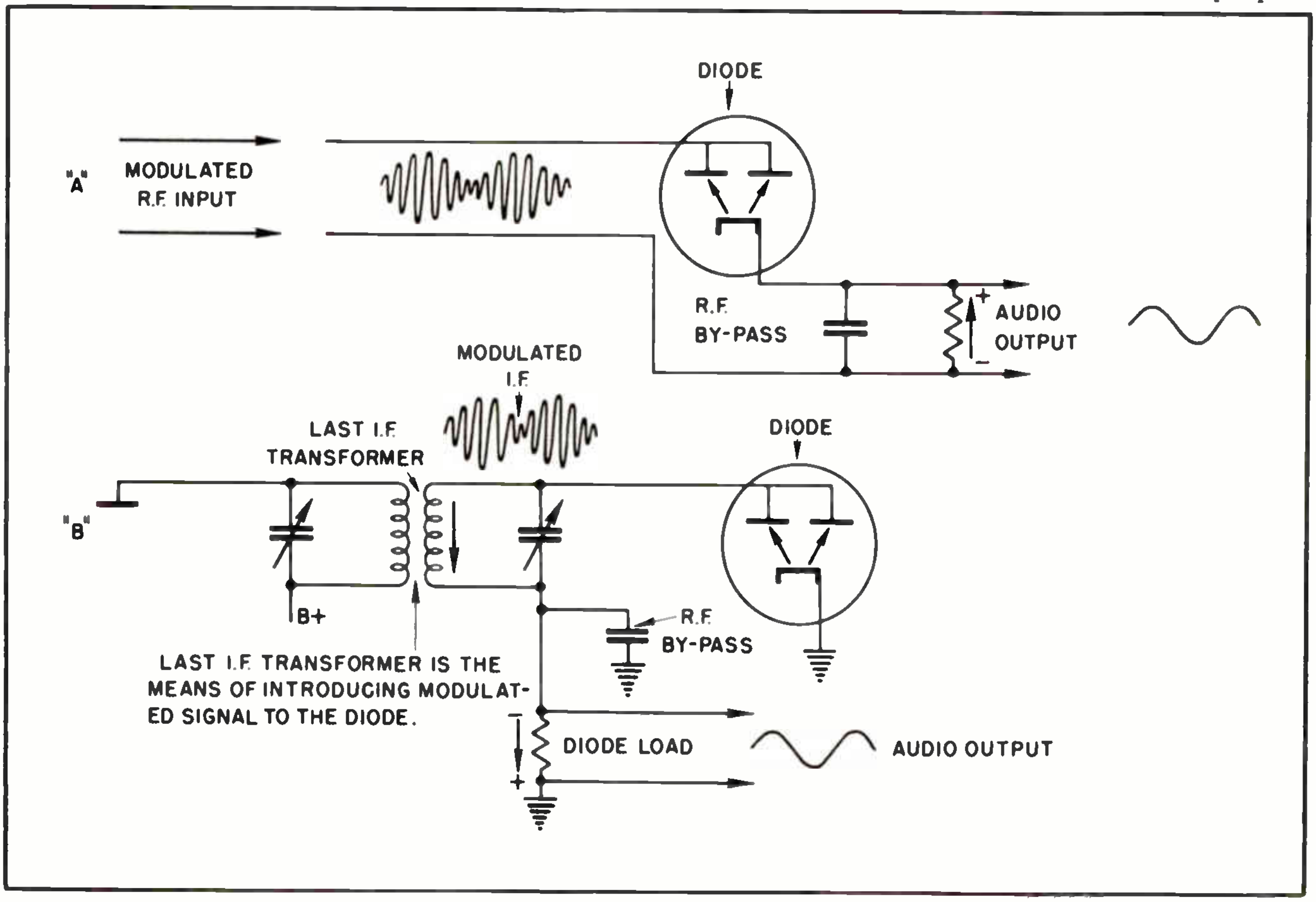

Fig. 4. Application of Signal Voltage to Diode Detector.

tubes, almost all the so-called detector-amplifier tubes are equipped with a pair of diode plates using the same cathode. This is for flexibility in fitting these tubes into various circuits. For instance, one plate of such a duo-diode may be used as the second detector, and the other plate as part of a tuning-eye indicator. Another example would be the combination of one diode as the detector, and the other as an automatic frequency control component. Still another combination may be the detector and automatic volume control. A final example may be in a full-wave detecting circuit, with either plate tied to opposite ends of the last I-F transformer secondary, whose center-tap is grounded.

In Fig. 3, where we were illustrating the action of the diode, it was deemed advisable to show only one plate. In Fig. 4 and those that follow, both diode plates are shown, but they are connected together and act as a single plate with double the surface area and therefore twice the efficiency.

In those special circuits where the two diode plates are not tied together, they will be shown as separate. In most cases, as indicated, the diode plates are tied together as shown in Fig. 4.

In Fig. 4-B modulated I-F voltage, generated in the transformer secondary, (due to primary current), is applied between the two diode plates and ground through the diode load. When the diode plates are positive with respect to ground, electrons will leave ground at the cathode, flow across the diode to the plates, flow through the transformer secondary (which is actually the generator of the system) and be returned to ground once more through the diode load. This, as can be seen, is a series circuit, and current flowing in any part of it must equal that flowing in any other part.

On the opposite half-cycle, when the diode plates are negative, the tube will not conduct, since the plates are more negative than the cathode. This prevents current from flowing in the series circuit on this half-cycle, for if the diode conducts no current, no other component in series with it will conduct current.

We may now look upon the diode load in the following manner: Since it is a part of a series circuit which includes the diode, the diode load will either conduct current in one direction or not at all. In the illustration of Fig. 4-B this conducting direction is downward. Any voltage drop due to current flowing through this load, must therefore, be present in the polarity shown in the diagram, or be absent altogether.

If the RF by-pass condenser were to be omitted, any voltage drop in the diode load would be a rectified form of the voltage applied to the circuit by the generating action of the transformer secondary. We see that this voltage is modulated I-F. The load voltage should therefore be the rectified (clipped-off) form of modulated I-F.

However, we recall that the purpose of the RF by-pass is to shunt the fast-changing component of this voltage to ground, and permit only the audio drop in the load resistor to take place. The effect of the by-pass in this circuit, then, is to send the unwanted I-F to ground, and the average audio voltage across the load. This action typifies the circuit as a true amplitude demodulator, for it has accomplished the recovery of the audio signal by rectification and separation.

Once the audio component is available by itself, the detector has performed its job. We may now feed the resulting audio signal to wherever we deem advisable: to a set of phones, to one or more amplifier stages, to a recording device, or to any other circuit suitable for converting electrical impulses into sound. In most cases, the output of the detector stage is fed to audio amplifiers followed by a loudspeaker.

Section 3. AUXILIARY DIODE CIRCUITS

The basic diode detector circuit of Fig. 4-B may be extended to other functions. This is illustrated in Fig. 5, which shows a skeleton diagram of the superheterodyne receiver, with the detector, the manual volume control, and the automatic volume control (AVC) indicated in detail. The diode detector portion is emphasized in heavy lines, while the auxiliary circuits are drawn in ordinary lines.

Comparison with Fig. 4-B will show that in the detector circuit of that sketch, there is only one resistor indicated as the diode load, while in Fig. 5 two are seen to be in series. The lower of these, R-2, is a potentiometer acting as the manual volume control. The upper, R-1, is employed as an audio filter in conjunction with the .00025 mfd RF by-pass. When placed in series,

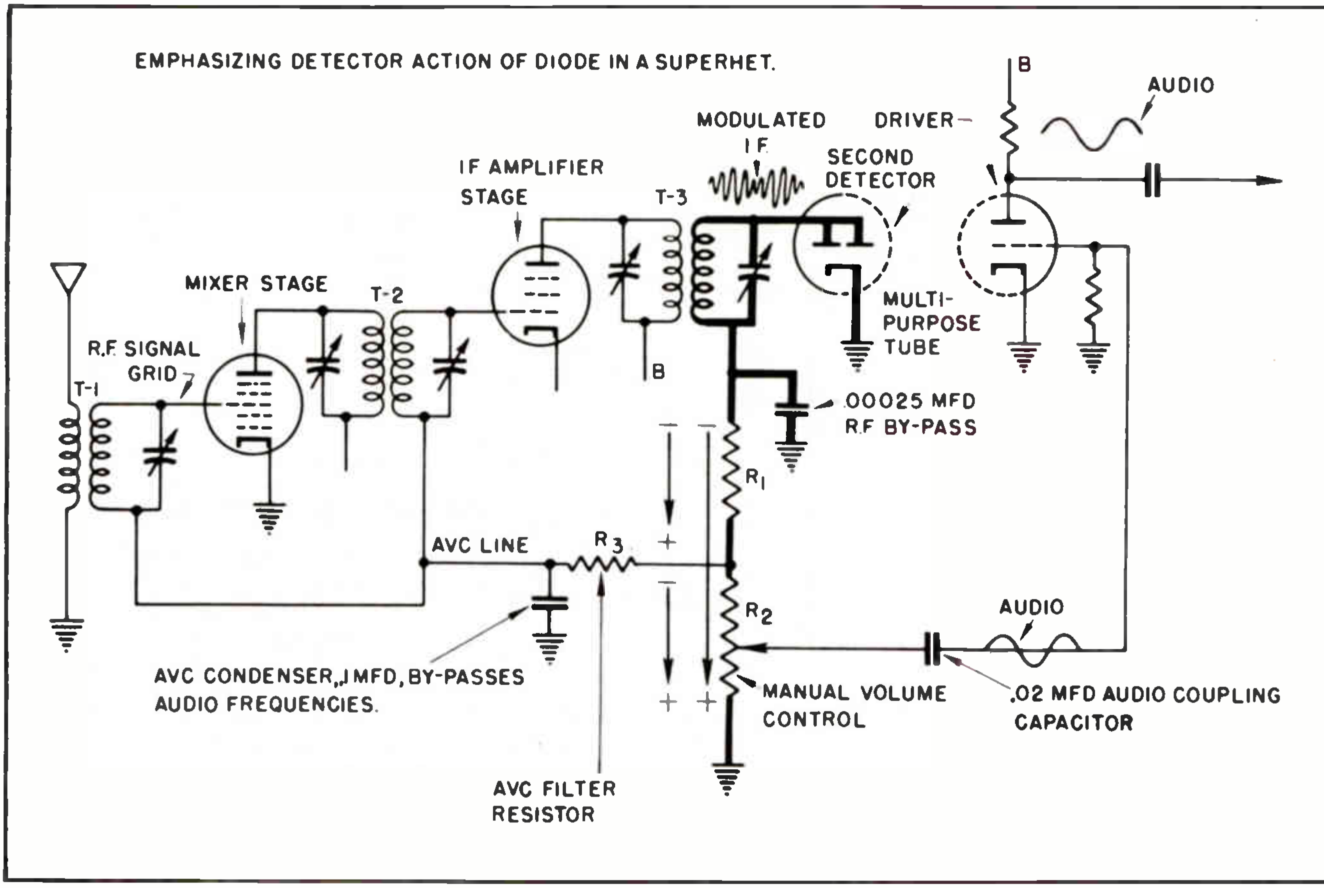

Fig.5. How Diode Detector is Connected to Other Stages.

however, it is evident that if their net resistance is of the right value, they can both act as the diode load and still perform their separate functions. Just how this occurs will soon become evident.

Please note that in Fig. 5, a third resistor, R-3 is also added. Called the AVC filter, or simply the AVC resistor, it has the purpose of filtering the AVC voltage, in association with the AVC condenser, to achieve a slowly-changing voltage on the AVC line. This, too, will be fully explained presently.

Another interesting pair of connections to note at this time is that pair leading to the signal grids of the I-F and the Mixer stages. As the diagram indicates, these leads originate at the AVC line, and are a part of one of the most ingenious control circuits ever devised in radio. Its details will be investigated in connection with the analysis of the automatic volume control action, soon to follow.

The electrical location of the driver stage is likewise shown in Fig. 5, together with the coupling from the manual volume control. Driver stage trouble-shooting is discussed in the lesson on Audio Section.

Justification for associating the manual volume control and the automatic volume control circuits with that of the diode detector is evident when we consider that a superheterodyne receiver needs a manual volume control someplace within its circuits, and when we fully understand the distinct advantages available by the use of automatic volume control, we shall observe that both of these circuits are not only indispensable to a superheterodyne receiver, but also that the diode detector stage is the proper place to include them for discussion.

Section 4. **THE MANUAL VOLUME CONTROL**

Illustrated in heavy lines in the drawing of Fig. 6 is the schematic circuit of the manual volume control. It forms the lower half of the diode load, as previously mentioned, yet its variable characteristic renders it suitable for adjusting the volume level of the receiver. Its action can be

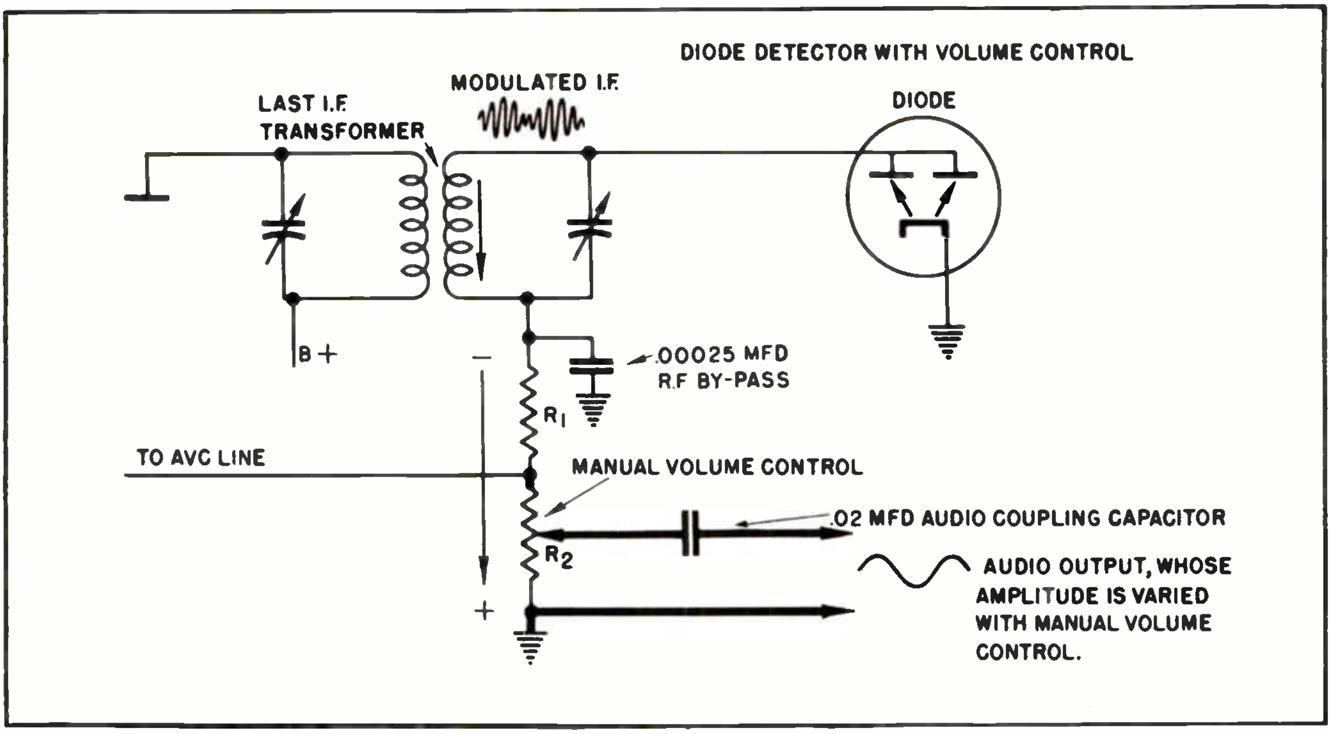

Fig.6. How the Volume Control is Connected to the Detector.

readily understood when we look upon it as an ordinary voltage-divider.

After detection by the diode and by-passing of the RF component by the .00025 capacitor, the signal is applied as a voltage drop at audio frequency across the series resistors R-1 and R-2. If these two resistors are equal, the audio voltage drop will be divided equally between them. Now, by using the sliding tap of the potentiometer, let us further subdivide the audio signal voltage by setting the sliding arm of the potentiometer at its mid-point. Since the drop across the potentiometer portion of the series resistances is always constant for a given value of signal, the sliding arm set at the mid-point will pick up exactly half of the full potentiometer drop. If we desire to lower the volume of the signal at the speaker, we may move the sliding arm somewhat closer to ground. This action allows the sliding tap to pick up less and less of the full potentiometer drop, until ground potential is reached at the lower end. This position, of course, means no signal at all.

If we desire to increase the signal volume at the speaker, we may move the sliding tap up toward the top of the potentiometer. This action allows the sliding tap to pick up more and more of the voltage drop across the full potentiometer until the very top is reached. At this point, maximum signal is fed across the coupling capacitor to the grid of the driver stage and the signal at the speaker is correspondingly strengthened.

R-1 in Fig. 6 has a special function. If we did not incorporate the manual volume control into the diode detector circuit, R-1 would be unnecessary and R-2 would act as a single diode load resistor. However, since manual volume control is an important feature of the receiver, it must be installed in this circuit, R-1 must also be added to aid the .00025 RF by-pass capacitor in filtering off the undesirable RF component of the signal. The electrical sizes of this condenser and R-1 are determined by the time-constant necessary to keep the top of the volume control at zero potential with respect to radio frequencies. Otherwise a distinct "hissing" would be audible in the speaker. The presence of R-1, then, assures effective prevention of this undesirable interference with the audio signal.

Section 5. AUTOMATIC VOLUME CONTROL

One of the most remarkable and useful circuits in modern radio and television is the automatic volume control arrangement shown in Fig. 7. This circuit is popularly known as "AVC", and serves as a most ingenious aid to good radio reception under adverse conditions.

The chief purpose of AVC is to keep the signal at the speaker at a constant level, regardless of the strength of the signal at the receiver antenna. This means that if for any reason the receiver signal becomes weakened before it strikes the antenna, AVC will reinforce it and keep its volume at the speaker constant. This also means that if the antenna signal should for any reason become stronger, AVC will perform the reverse function of cancelling some of the signal and thus keep its volume at the speaker constant. In other words, AVC assists a signal which is too weak, and suppresses one which is too strong.

The AVC circuit does not stop its usefulness at this point. In actual installations, as will soon become clear, AVC does a remarkable job of suppressing both natural and man-made static, and enables the listener to enjoy his programs practically independent of local conditions. But before explaining the exact action that takes place while it accomplishes these things, let us analyze the electrical character of the AVC circuit.

With reference to Fig. 7, we have already learned that any drop across the diode load must assume the polarity shown by the arrows; that is, negative all along the diode load with respect to ground.

If there is no signal whatever passing through the detector stage, the diode would conduct no current, the load would conduct no current, and no voltage drop would take place across the load. If there is no voltage drop across the load, every point on the load resistor must be at ground potential, including the junction of R-1 and R-2 at which the AVC line is tied. If we now refer again to Fig. 5, we notice that the AVC line leads to the signal grids of both the I-F amplifier and the Mixer stage. With no signal in the receiver, these grids must now be at ground potential. This condition represents the highest possible positive (and the lowest possible negative) value that these two grids can attain. In terms of amplification and gain in these stages, we take a low negative bias to indicate high gain, and a high negative bias to indicate low gain. If no signal is passing through the receiver, we now have the greatest possible gain in both the mixer and the I-F amplifier stages, resulting in very high sensitivity of the receiver.

Let us now see what happens when a strong signal strikes the antenna of this receiver.

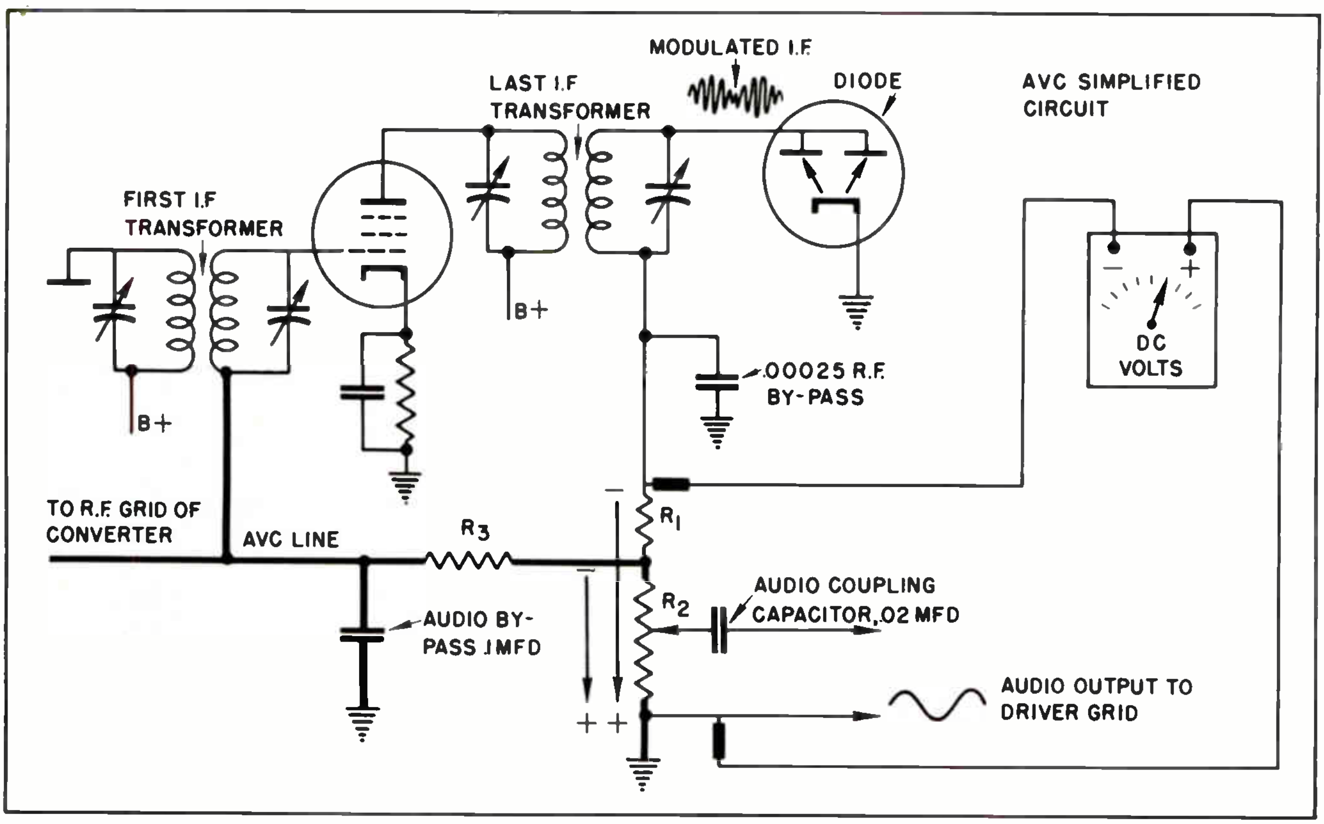

Fig.7. How the AVC Circuit is Connected.

First of all, a strong signal at the antenna means a strong signal in the mixer and the I-F stages. This causes a strong signal in the detector stage, and its diode passes heavy current down through the diode load. A voltage drop occurs which has the polarity indicated in the diagram. So long as signal current is flowing through the load resistance, this polarity of voltage drop will be maintained, and ground will be more positive than the junction of R-1 and R-2. The strong antenna signal results in a comparatively high voltage drop across the diode load. This renders both the I-F and Mixer signal grids rather more negative than ground, thus decreasing the gain of those stages. The decrease in gain means that the receiver is no longer as sensitive as it was, with the resulting overall effect that a strong signal at the antenna tends to cancel out a portion of it.

What is the effect, then of the AVC circuit on general reception in the receiver? A weak signal is reinforced and is made to sound stronger. A strong signal is partially cancelled (or degenerated), and made to sound weaker. The net result of both actions is that the signal volume at the speaker will tend to remain constant, whether the antenna signal strength is high or low.

Resistor R-3 and the 0.1 mfd audio by-pass capacitor associated with it constitute an R-C filter for audio frequencies. Their function is to keep the AVC line at ground potential insofar as audio and RF voltages are concerned. If the AVC voltage were to change in accordance with each audio or RF cycle, a condition of signal degeneration would take place which would result in extremely low sensitivity of the receiver at all times. The RF component of the voltage drop across the diode load is by-passed through the .00025 capacitor. However, the audio by-pass across the AVC line, being of a much greater capacitance (0.1 mfd) will by-pass audio frequencies effectively and with them, of course, will go any RF that somehow squeezes past the .00025 capacitor.

To a great extent, the actual voltage of AVC, measured across the diode load, depends upon the sensitivity of the meter employed to measure this voltage. Theoretically, the voltage, as indicated by a vacuum-tube voltmeter, would be around negative ten volts at the top of R-1 with respect to ground. Incidentally, this is the ideal type of voltmeter to use in circuits such as these, since the vacuum-tube voltmeter reads the existing voltage without loading the circuit to any great extent. Yet, a vacuum-tube voltmeter may not be available. In this case, the ordinary 1000-ohm-per-volt-meter, on the low D-C scale, will indicate an AVC voltage across the diode load of about three volts when a strong local station is being received. The actual reading, in addition to depending upon the type of meter used, also depends upon just how strong the antenna signal is at the time.

An interesting and simple experiment in this connection would be to measure the AVC voltage. This can be done by removing the receiver from the cabinet, locating the diode load, in accordance with Fig. 7, and snapping the meter leads across these two resistances. With the meter leads firmly fastened, apply power to the receiver, and tune in a strong local station. The meter will read the AVC voltage developed at this time. Now, de-tune this strong station, and set the dial to a point between stations, watching the meter while doing this. The AVC voltage will be seen to decrease, and may go all the way to zero. The receiver dial may now be tuned to another local station, and the changes of AVC voltage will correspond to the station changes.

Summarizing the character of the AVC circuit, we may emphasize the following points:

1. The AVC voltage varies directly as the signal strength at the receiving antenna.

2. The gain of the tuned stages, and the sensitivity of the receiver, vary inversely as the signal strength at the antenna.

3. The AVC voltage will change at a comparatively slow rate. It will change only when the signal strength at the antenna changes. (If we are listening to a strong local station during a one-hour period, for instance, the AVC voltage will remain constant for that one hour).

Section 6. PRACTICAL PERFORMANCE OF AVC

It was stated earlier that the AVC circuit was one of the most useful in modern radio. That this is not an exaggeration will be evident when we consider its manifold performance under widely varying conditions.

As a stabilizer of signal strength, the AVC circuit permits reception of weak signals from distant stations. With a weak signal, the AVC voltage is lowered, the receiver becomes more sensitive, and the station is brought in with greater volume.

The AVC circuit prevents "blaring" when the receiver is tuned from a weak station to a strong one. This was an annoying phenomenon in the early days of radio before AVC was developed. If the listener changed stations, the manual volume control, which was set as a certain position suitable to the weak station, would make the strong station "blare" at the listener as soon as it was tuned in. AVC prevents this by suppressing a good portion of the strong station, regardless of the manual volume control setting. Strong stations, with AVC in the receiving circuit, come in without any marked blaring, and they come in smoothly. As the strong station is tuned in, the AVC voltage is increased, the receiver becomes less sensitive, and the signal sounds quieter to the ear.

The signal-stabilizing property of the AVC circuit can be further applied to minimize the "fading" of distant stations. Fading is a phenomenon caused by certain temperature, pressure, and altitude changes in a layer of the earth's upper atmosphere called the Kennelley-Heaviside layer, or ionosphere. Since these changes are often erratic in their nature, and completely beyond the control of human beings, we cannot stop the changes. But we can compensate for them to a great extent by the use of AVC in our radio receivers.

Transmitting stations located at a distance of one or two hundred miles will be received by means of somewhat indirect paths. The signals will be reflected back and forth between the ionosphere and the surface of the earth one or more times before reaching the receiver. Any change in the height, or refracting nature of the ionosphere will result in a different angle of reflection from that layer. The receiver will therefore receive a signal varying in amplitude from the transmitter. To the listener, it will simply seem that the station is fading in and out; the intervals may be anywhere from several minutes to several hours.

To compensate for the fading of the RF signal at the receiver, the AVC voltage decreases when the signal becomes weak; the receiver becomes more sensitive, and the signal is built up to moderate strength. When the signal becomes too strong, the AVC voltage increases, cancelling out a portion of the signal, so the signal strength at the speaker is reduced. It is to be noted that this action is compensation, not correction, of the phenomenon of radio signal fading due to long distances from the transmitter.

In conjunction with its ability to stabilize a signal voltage, the AVC circuit performs a miraculous job of suppressing static of all kinds, natural and man-made. This is especially true of automobile receivers and home receivers that are used in hotels, large buildings, rooming houses, and apartments, where people live and work in close proximity to each other.

Man-made static is the product of electrical equipment, usually devices which contain sparking components. Most electrical machinery and equipment contains sparking components. The automobile is a perfect example. Other examples are toasters, pressing irons, electric shavers, thermostats, fluorescent lights, many popular types of motors, doorbells, elevator switches and controls, and many others too numerous to mention.

Let us consider the automobile first. Its ignition depends upon a jumping spark. Since this type of spark happens to be amplitude-modulated (not on purpose, but by its very nature), it is only natural that an AM receiver will pick up the spark as static. The car radio receiver is no exception, especially in view of the fact that with the small antenna with which most car radio receivers are limited, the sensitivity of the car receiver is designed to be quite high. Many methods of static suppression in the car radio are discussed in another lesson of this series. But no single correction for car static is as effective as the AVC circuit of the car receiver. It can be said without fear or contradiction that auto receivers would be impractical without the AVC circuit.

The operation of AVC in an automobile receiver is simple. While picking up a strong local signal, the AVC voltage increases, decreasing the gain of the RF and I-F stages, resulting in low sensitivity. Since the station signal is stronger than the static, the static is successfully suppressed while the signal comes through to the audio stages. In the average car radio installation, if the tuning dial is slowly rotated to a point between stations, ignition static (if the car motor is running) will

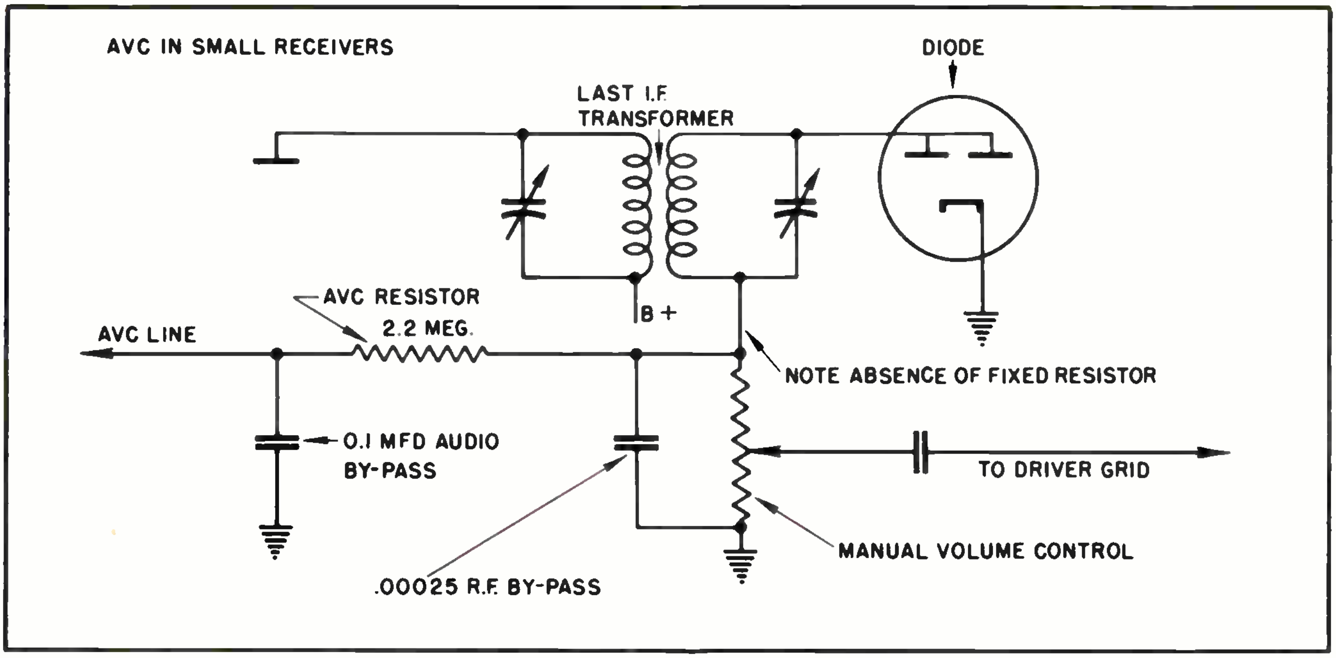

Fig.8. Simplified AVC for Small Receivers.

be heard. This phenomenon is likewise true when the car is driven under a viaduct, under steel structures, or near large buildings. The signal strength, being reduced by absorption by these steel and concrete structures, arrives at the antenna in weaker form. This decreases the AVC voltage, the receiver becomes more sensitive, and in automatically bringing up the station signal, the receiver will bring car static along with it. The signal, however, will tend to remain constant in its strength at the speaker.

This same principle applies equally well to those receivers used in apartments, hotels, big buildings, or wherever electrical equipment is used in quantity. While the local static may be unbearable between strong stations, it generally is effectively reduced, if not suppressed altogether, when a strong station is tuned in. The local static, it may be added, may easily prevent a hotel-dweller from listening to long-distance radio reception without a special outside antenna, but automatic volume control will permit him to receive the majority of local stations with little or no static interference.

Natural static (lightning) is effectively reduced as noisy interference in radio reception by the use of the AVC circuit. In the days before AVC, it was almost impossible to listen to a radio program during a lightning storm, or for an hour or two before and after it. The static was so annoying that in many cases the program itself was unintelligible. The application of AVC to modern receivers, however, made it possible for each lightning bolt to tend to cancel out its own effect in the receiver output by sending a sudden and strong pulse of AVC voltage to the tuned circuit grids almost exactly as soon as the bolt began to strike. Furthermore, if a strong local station is being received, the AVC voltage is already high, rendering the receiver less sensitive, and reducing the strength of all signals at the speaker. The speaker noise due to lightning is thus substantially reduced while a constantly high AVC voltage is present in the receiver due to the reception of a strong local signal.

The small radio receiver, including the AC-DC and the portable types, is built for economy of cost, weight, and space. In the interests of these economies, the small receiver often uses a simplified, yet effective, form of AVC. Fig. 8 is a typical example, in diagrammatic form, showing the omission of the fixed resistor in the diode load, and the placing of the .00025 RF bypass condenser directly across the outside terminals of the manual volume control, which also acts as the diode load. This potentiometer, usually about 1/2 megohm, has the additional function of developing the AVC voltage fed to the signal grids of earlier stages. Receivers of the console type and automobile receivers ordinarily include the fixed resistor, while the AC-DC and portable types generally omit it. The circuit shown in Fig. 8, is very much like that used in the Knight Ranger, an AC-DC 5-tube table-model superheterodyne receiver, and in many other makes and models of this type of receivers.

Section 7. **DELAYED AUTOMATIC VOLUME CONTROL**

Delayed Automatic Volume Control (DAVC) is a more elaborate AVC circuit designed to minimize one of the undesirable effects of ordinary AVC. This undesirable effect is that even a weak signal will develop some AVC voltage and thus degenerate itself to some extent. The DAVC circuit does not permit a weak signal to develop AVC voltage, but a strong signal will succeed in doing so. Fig. 9 illustrates a standard DAVC circuit, such as would be used in receivers designed for high gain during the reception of weak signals. Communications and automobile receivers are of this type.

In Fig. 9 the action of the pure detector principle is conventional, with D-1 current flowing downward through the diode load and developing the audio drop required across the manual volume control. Condensers C-1 are the RF by-passing components, R-2 the manual volume control, and C-3 the audio coupling capacitor to the driver grid. These components have been explained previously and their functions have been outlined. Notice, however, that the two diode plates are not connected together directly, but by capacitor C-5.

It should also be noted that the voltage drop across the diode load now consists of that due to D-1 current only, since C-5 bars the passage of current from D-2 to the diode load.

There is, however, a path for D-2 current. When RF of sufficient strength is applied to the plate of D-2, a portion of this voltage is fed through C-5 to the plate of D-2. This causes D-2 to conduct on the positive half cycles, and cancels out the negative voltage at this plate due to the fixed D-C voltage. D-2 current flows downward through R-3, causing the drop in this resistor, as indicated in the Fig.

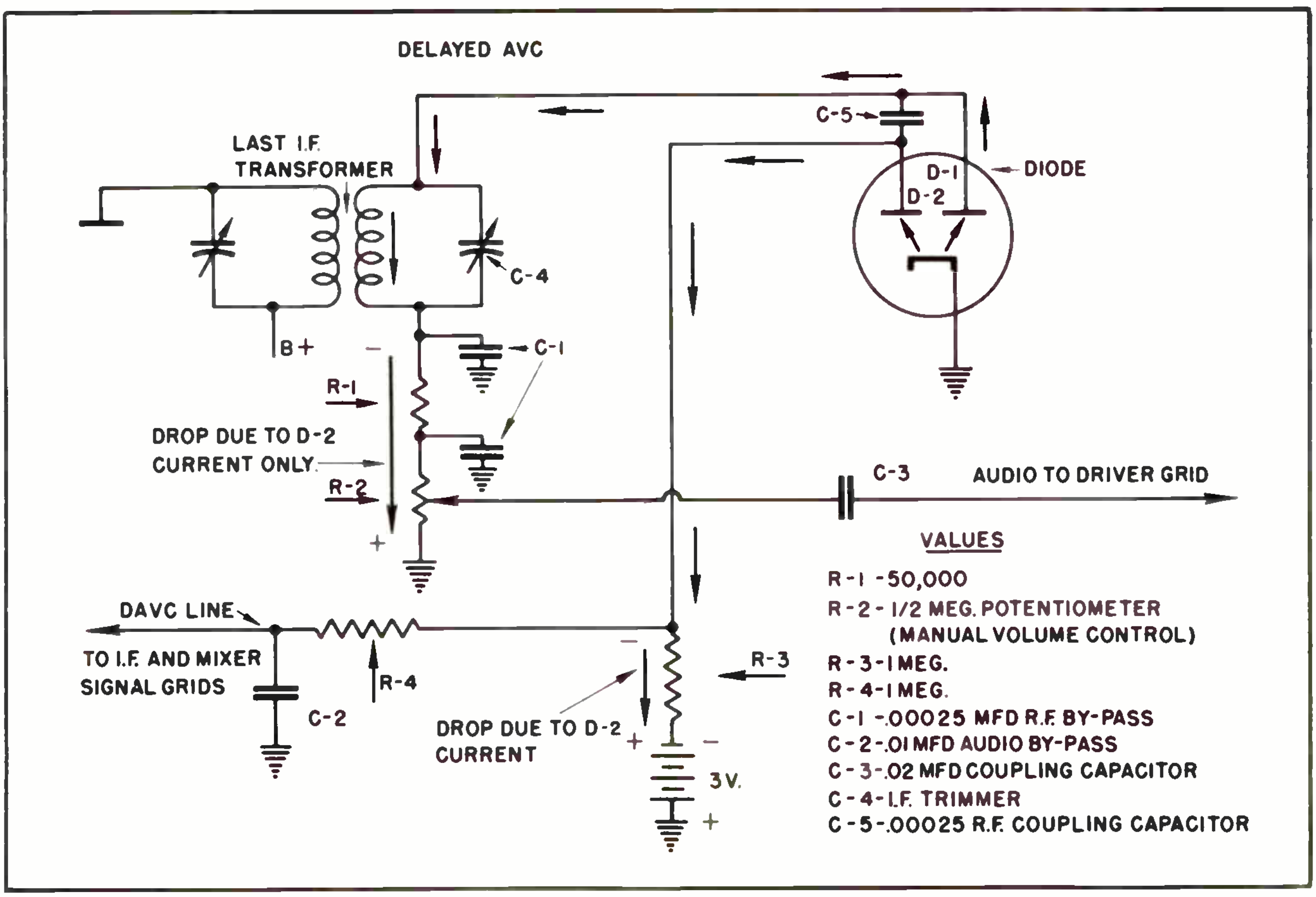

Fig.9. Delayed AVC Circuit.

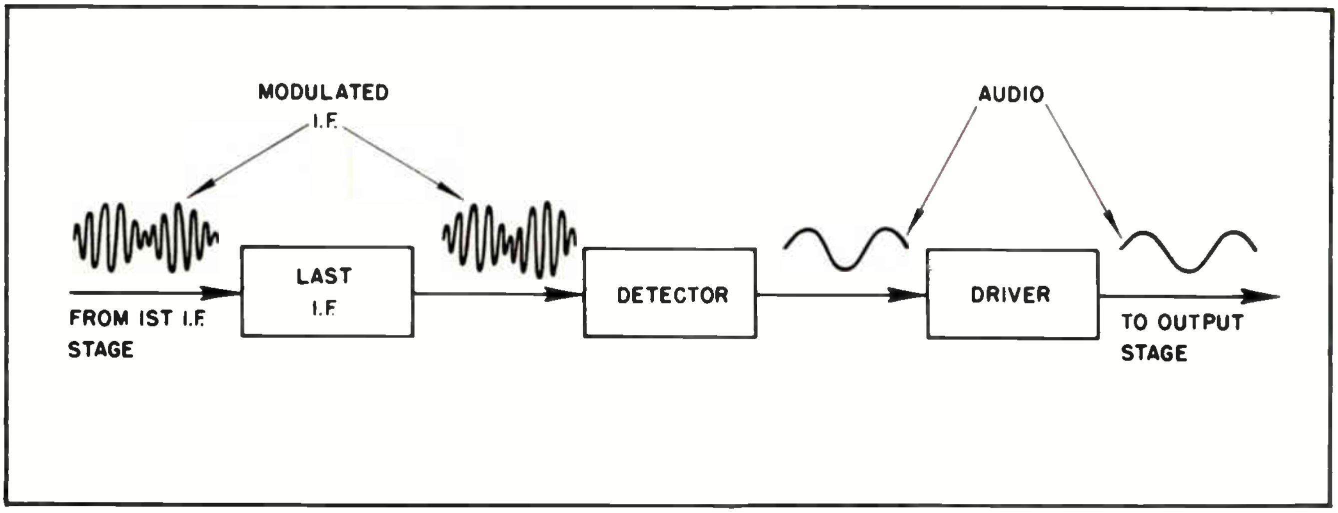

Fig. 10.

We note that there is also a negative voltage at R-3 due to the fixed 3-volt D-C supply. A strong modulated signal at the receiver antenna, therefore, will add its effect to the fixed negative voltage at R-3.

What does this mean as far as weak and strong signals are concerned?

It means that a weak signal cannot increase the AVC voltage, for in order to do so its amplitude must reach a value corresponding to the fixed voltage. 3 volts in this case. In other words, AVC voltage will remain at a minimum of minus-3 volts with respect to ground until an RF signal of 3 peak volts is applied to the diode plates. This is the highest negative bias obtainable by a weak signal.

A strong signal, on the other hand, whose peak amplitude exceeds 3 volts will drive D-2 into conducting current, providing a drop in R-3 which will add to the already existing voltage of 3 fixed volts at R-3. This, as we know, decreases the gain of the I-F and Mixer stages, resulting in stabilization of strong signals at the receiver antenna.

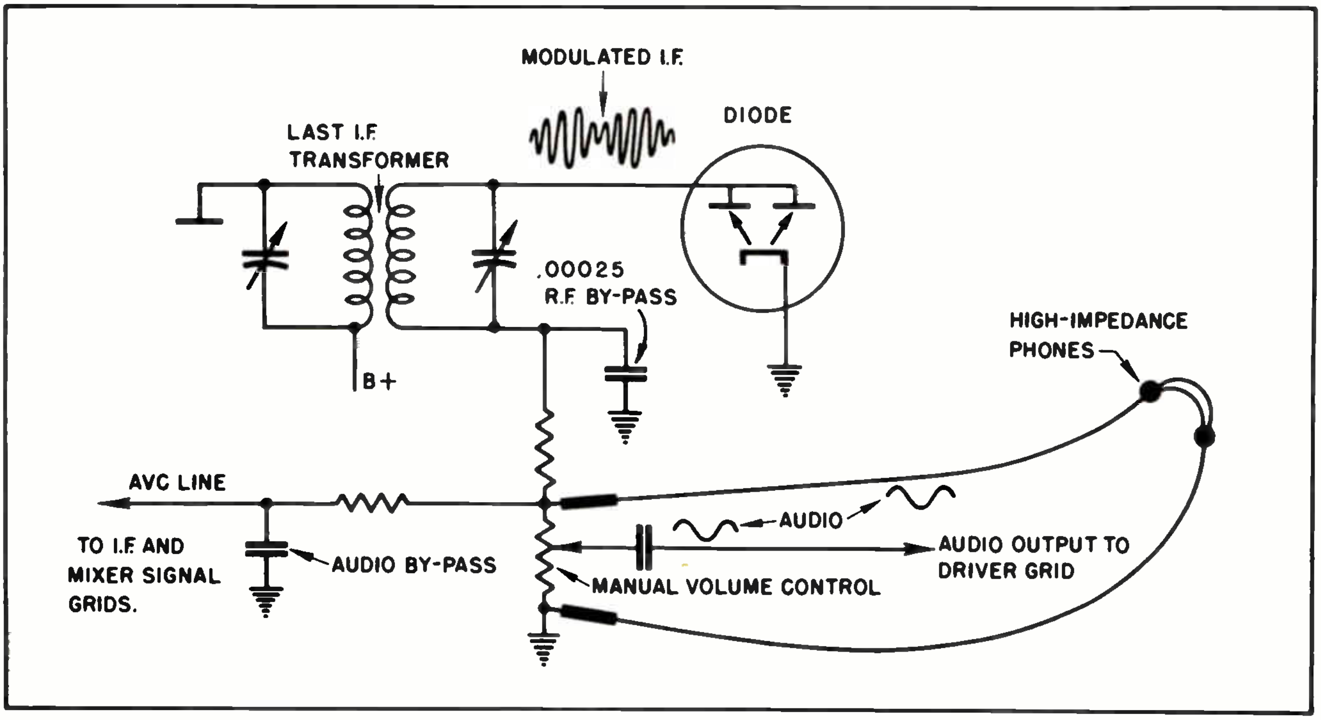

Fig. 11. How Headphones Can be Used to Test Diode Detector.

As in the case of ordinary AVC, C-2 and R-4 (in Fig. 9) form an R-C filter to rid the DAVC line of its audio component, thus avoiding degeneration of the signal at this frequency.

It is interesting to note that Delayed AVC does not involve a time delay, in the usual sense of the word. It can better be understood as a restraining effect, holding the controlled bias voltage constant except when a strong signal is applied to the receiver antenna. This is not so much a matter of chronological time as it is of a varying signal strength from more or less distant radio transmitters.

Section 8. DETECTOR TROUBLES

In view of the function of the detector stage, which is to recover the audio component from the modulated carrier, an operational check of this stage may be described in the following terms: If, when all audio components in the receiver are known to be operating by previous checks, and a modulated RF input does not result in an audio output, the detector stage may be suspected of one or more faults. Fig. 10, a block diagram, indicates these input and output signals.

There are two methods of determining the condition of the detector in accordance with the above rule. The first is to monitor the detector output with a pair of high-impedance earphones, as shown in Fig. 11. The second is to permit the receiver's audio system to accept, amplify, and reproduce the output of this stage. In both cases the results depend upon audible signals.

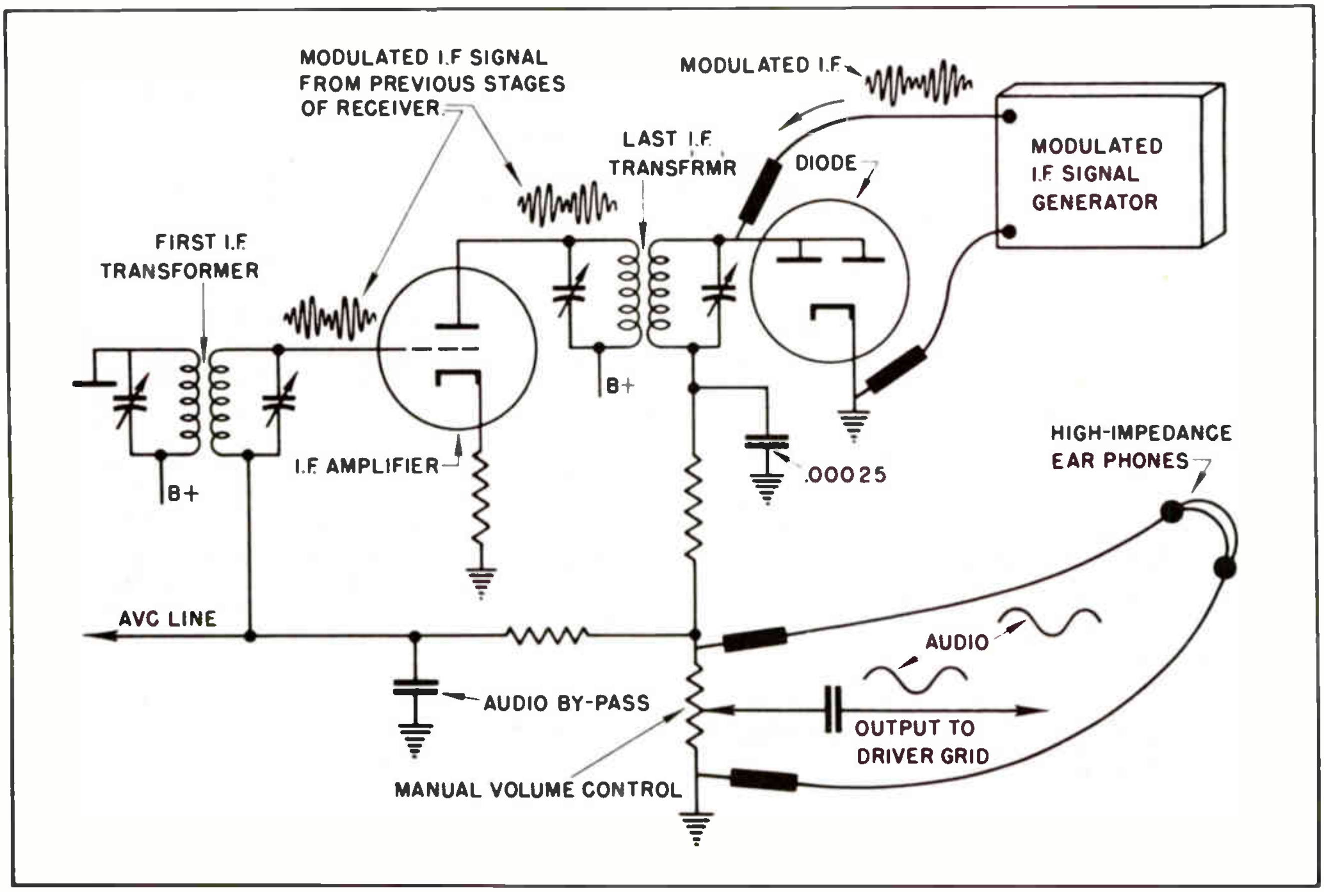

Fig. 12 One Method of Checking the Detector Circuit.

Likewise, there are two general methods of applying a modulated carrier to the detector input. The first is to provide the modulated carrier with the use of a signal generator. The second is to apply power to the receiver and tune in a strong local station which will supply a natural signal to the input of this stage. (See Fig. 12.)

It is evident that either type of input signal may be checked by either type of output check, and proper interpretation of the results obtained will tell us if the

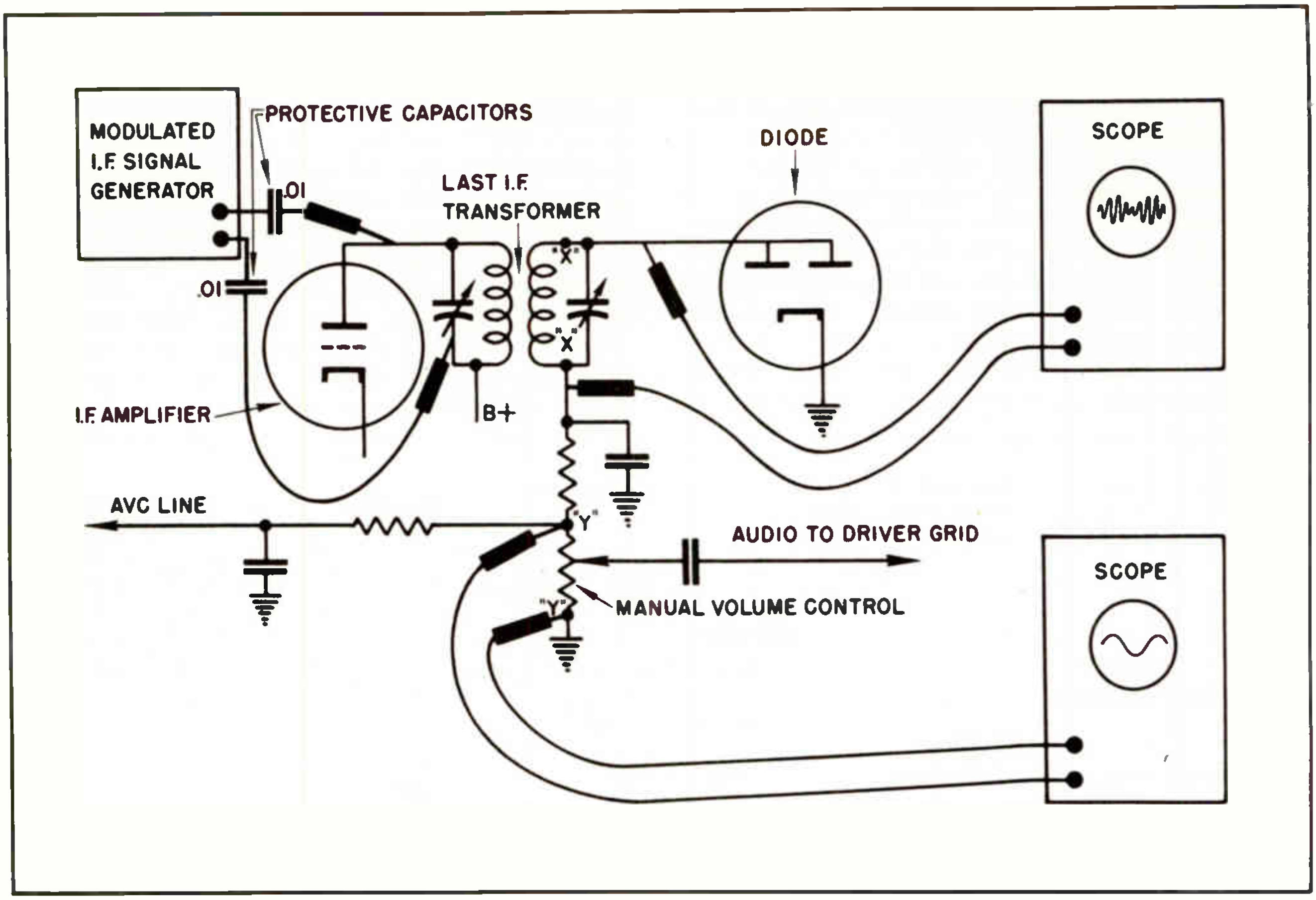

Fig.13. Checking Detector With a 'Scope.

trouble lies in the detector stage, a previous stage, or a following stage.

1. If a natural signal from the transmitter is applied to the receiver, and a pair of earphones at the detector output does not reproduce an audio signal, the trouble lies either in the detector or a previous stage.

2. If an artificially-generated modulated I-F carrier is introduced at the detector input, and the speaker of the receiver does not reproduce the audio component, the trouble lies in either the detector or a stage following.

3. If an artificially-generated modulated I-F is introduced at the detector input and a pair of earphones monitoring the detector output does not reproduce the audio component, then the detector stage is at fault.

Besides these results, there is other important information at hand. We recall that the step-by-step procedure for locating trouble in a receiver requires that we check the last stages first. Before even suspecting detector trouble, therefore, we should know:

That the tubes are all good.

That the speaker is good.

That the output stage is good.

That the driver stage is good.

We may now apply test (3) to the detector stage. If this procedure results in the expected signal, we can at once assume that the trouble lies in a previous stage, and can move forward to the previous stage in our analysis. If this procedure does not produce the expected results, we can direct our detailed attention to the detector stage.

Section 9. CHECKING THE DETECTOR WITH A 'SCOPE

A cathode-ray oscilloscope, as described in the lesson titled "Using the Oscilloscope" may be used to monitor the input and output signals of the detector. Fig. 13 indicates the connections required, and the type of pattern to be expected from a detector stage working properly. The test leads of the 'scope are first applied across the secondary of the last I-F transformer, marked X-X in the illustration, which indicates the input wave-forms. The 'scope test leads are then moved over to the manual volume control marked Y-Y, to indicate the detector output wave-forms. Significant information may be obtained from this procedure:

If the detector input is correct and the output is not as expected, the detector stage is at fault.

If the detector input and output are both correct, with the receiver tuned to a strong local station, the sought-for trouble is in a stage following the detector.

If neither the input nor output wave-forms are correct, the trouble lies in a stage preceding the detector.

As you will quickly recognize, the preceding tests need not all be made; they are complementary methods of answering the same analytical question, which is: In which stage does the trouble lie?

If this data points to the detector, you must direct your detailed attention to this stage, locating the exact component responsible for the receiver failure with the use of the ohmmeter, the voltmeter, or both.

It should also be mentioned that the symptoms of a defective detector will contribute valuable information toward locating trouble in this stage. In many cases, if the symptoms are duly noted and properly interpreted, the operational test with additional equipment may be unnecessary, or may simply serve as a confirming test.

To localize the trouble in the detector stage by means of the audible symptoms turn the receiver power on. Allow the receiver to warm up for at least thirty seconds, then try to tune in a strong local station. If this receiver contains a defective detector, but all other stages are properly operating, the following facts will be noted:

No signal will be audible, but the speaker will hum with a residual 60-cycle ripple; this ripple hum is normal. It will be noticeably controllable by the manual volume control. From this data we conclude that the audio section of the receiver is in good order. With the volume control advanced to maximum clockwise position, there will be a complete absence of background static. Background static is normal in any receiver, especially when the volume control is advanced. We usually do not notice this background static because if the signal is present, it drowns out this harmless degree of static. Besides, if a strong signal is present in the detector stage, we know that the AVC will be placed into operation by this signal and will de-sensitize the receiver below the static level.

The complete absence of background static (which sounds like a light rushing or hissing), is a significant observation, for it tells us that a certain minimum amount of unavoidable static cannot get through the detector. Since the detector under normal conditions passes this type of interference at the same time a signal is detected, we can infer that the reason for the arresting of the signal and the static must be detector trouble.

(It might be interesting to learn that wherever commercial power is used in a radio or television receiver, such power, being part of a vast system of distribution, will contain the spark voltages and transient voltages originating in many parts of the power system. This includes the vast number of motors, switches, and general electrical equipment in operation within many miles radius of the radio receiver.)

While there may be many causes for the lack of background static in a defective radio receiver, there is only one defective stage which will account for this symptom as well as the presence, at the same time, of the normal residual ripple-hum adjustable by the manual volume control. This stage is the detector. It can be shown by theory and experiment that if the trouble is in a stage previous to the detector some static would be heard, and that if the trouble is in a stage following the detector, the residual hum would not be adjustable by the manual volume control.

Once the detector is identified as the defective stage, we may proceed to analyze this stage in detail. We recall that in the modern receiver the detector stage is associated with two other important auxiliary circuits: The manual volume control and the AVC circuit. Since these two functions are closely bound up with the diode detector, trouble-shooting this stage involves both

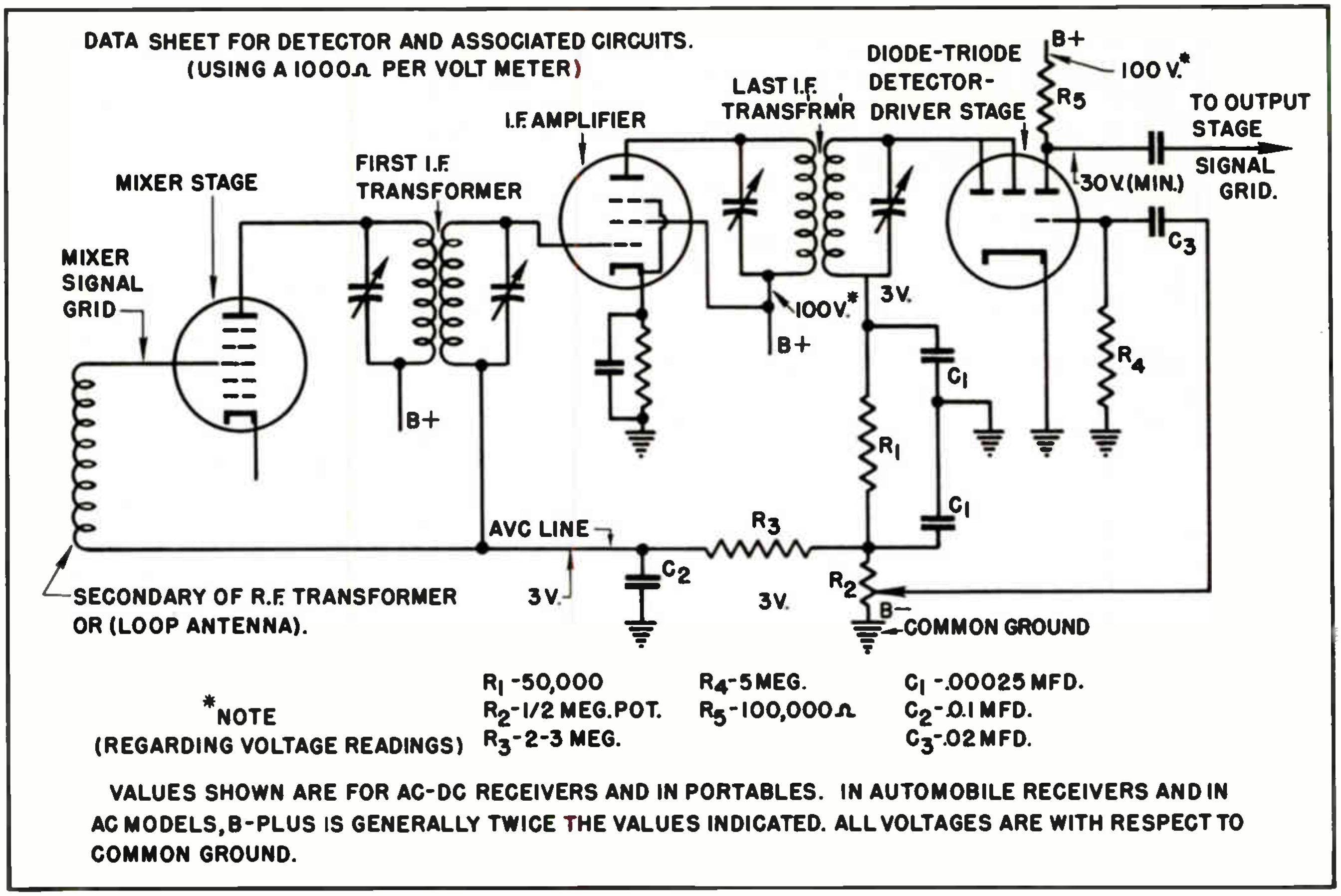

Fig. 14. Voltages Associated with Diode Detector.

of these auxiliary circuits. Trouble-shooting the manual volume control is discussed in the lesson on the Audio Section, but additional remarks will be inserted here regarding this important component.

Fig. 14 may be used as a data sheet for the standard diode detector stage and its associated circuit. Normal voltages and resistor values are supplied, for comparing the voltmeter and ohmmeter findings in a defective detector with standard conditions.

Failures in detector component parts are easily identified by the audible symptoms and as easily verified by test equipment. We are now ready to show the symptoms resulting from these components, and to indicate verifying tests in each case.

Section 10. **THE DIODE TUBE**

If the heater is open neither the detector nor the AVC action of this stage will take place. There will be no signal in the speaker, but normal residual hum will be heard. Feel the tube for heat, and check it carefully on the tube-checker for shorts and emission. In an AC-DC receiver, if this heater is open, none of the tubes, nor the pilot lamp, will light, and there will be no sound of any kind in the speaker. In portable receivers, although this tube may be perfectly good, it will not feel warm nor appear to be lighted.

The last I-F transformer secondary winding. Residual hum will be present but no signal in the speaker whether this winding is open, or if it is short-circuited by the trimming capacitor with which it is in parallel. To check for open winding, measure with an ohmmeter across the winding. Resistance should read about 10-35 ohms. If this resistance is zero, examine the trimming condenser for shorts.

RF by-pass condenser C-1. Two of these capacitors are shown. If open, they will result in a "hissing" sound in the speaker, accompanying the signal. If shorted, there will be no signal, but the speaker will contain its normal hum. Check for opens in these condensers by shunting them with an equivalent. Check for short-circuits with an ohmmeter, which should read no less than 1/2 megohm, the potentiometer resistance.

R-1, the RF filter resistor. If open, no signal will be heard, but residual hum will be present. There is practically no likelihood of a short circuit in this component. Verify for an open condition by shunting with your meter leads, with the meter set on the 300-volt D-C scale. If this procedure brings in the signal, replace R-1.

R-2, the manual volume control. If open, R-2 will prevent control of signal volume in the following manner: While rotating this potentiometer, the signal will be loud until the open break is crossed, at which time the signal will drop to a very low value. The signal will thus be either too loud or barely audible. If the manual volume control is short-circuited by the lower of the two RF by-pass capacitors, signal will be lost, and the residual hum will not be adjustable by the volume control.

With regard to the AVC voltage, an open volume control potentiometer will act to increase this voltage by preventing grid current from the I-F and Mixer stages leaking off to ground. While this increase in negative potential may not result in blocking these two stages, it may introduce motor-boating. To verify this condition, place the leads of the 1000-ohm-per-volt D-C meter across the potentiometer and notice if the signal clears up. If so, and the volume control shows other signs of defect, replace it with an equivalent unit.

AVC filter resistor, R-3. We may rule out any likelihood of a short circuit across this component, but if open, it will cause a drop in signal volume and the presence of motor-boating. This motor-boating may take one of several forms: It may sound like the "putt-putt-putt" of a motorboat, or it may be so fast as to sound like a screech, or, when a signal is tuned in, it may sound like a 60 cycle hum modulating the signal. Verification of an open in this resistor may be quickly made by placing the leads of a 1000-ohm-per-volt D-C meter, on the 300-volt scale across it, and noting if the signal clears up. If so, replace this resistor with one of equivalent ohmage.

AVC audio by-pass capacitor, C-2. This capacitor, which may be of a value between .05 and 0.1 mfd, is meant to keep the AVC line at ground potential with respect to the audio component of the signal. If open, this purpose will not be accomplished, with the result that the audio signal will be degenerated, or weakened, by the lack of capacitance in this circuit. Degenerating the audio frequencies is equivalent to lowering the signal volume, and the receiver will appear to have a weak signal. To verify this suspicion, shunt an equivalent condenser across the existing by-pass, noting if the signal is brought up to normal volume by this procedure.

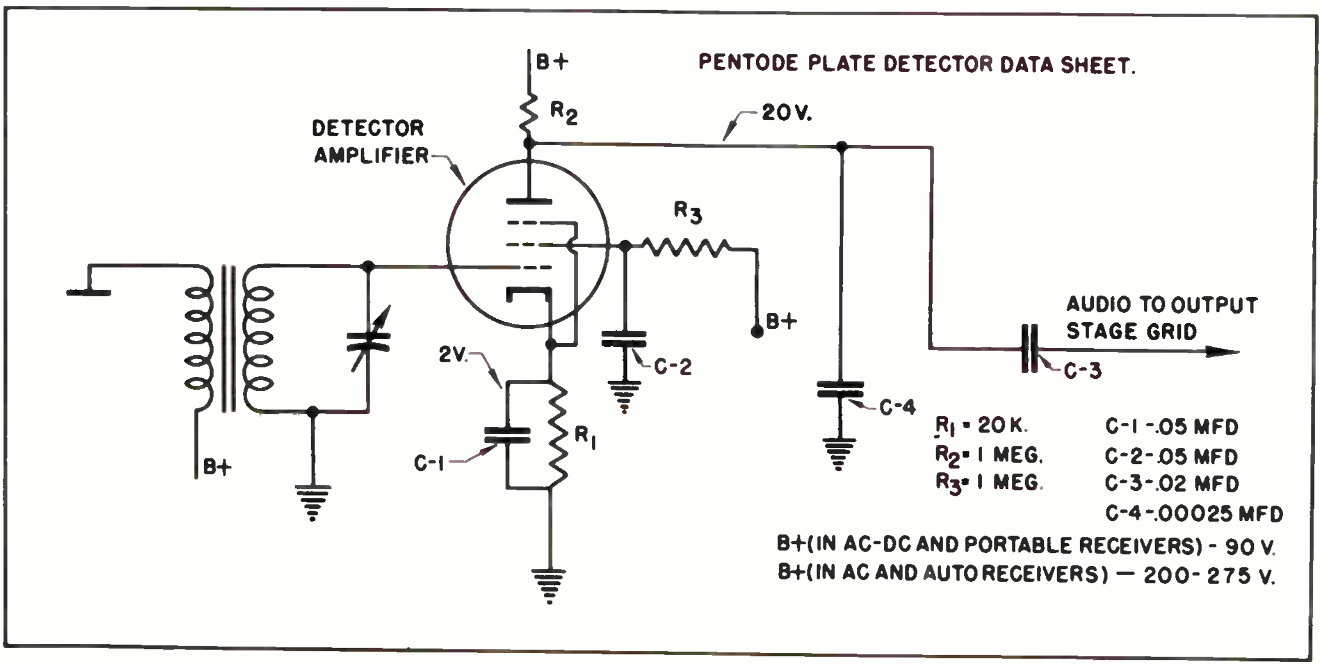

Fig. 15. Voltages to be Found at the Pentode Detector.

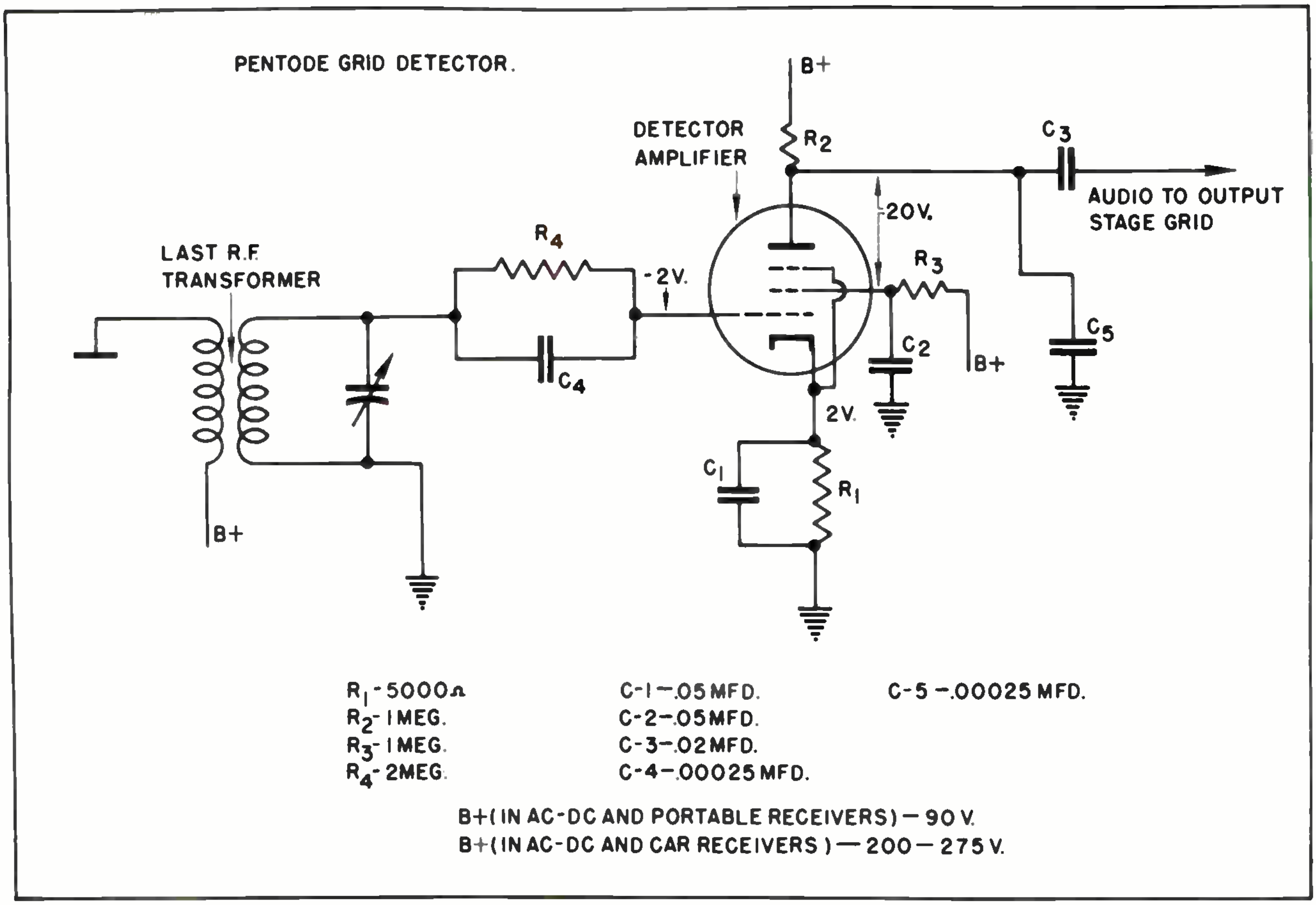

Fig. 16.

A short-circuit in the AVC audio by-pass capacitor will have peculiar effects, mostly noticed by the presence of static on, and between, all stations. Such a short-circuit will place the AVC line at ground potential with respect to both A-C and D-C. Since ground is as positive as the AVC line may go (in the complete absence of a signal in a normally operating receiver), it is evident that the I-F and Mixer signal grids will have the least possible bias. This will increase the gain of these stages to maximum, and local stations, as well as static, will be brought in with excessive strength. An ohmmeter, on the lowest scale, will readily indicate a short in this capacitor. It is to be noted that shorts and opens in both the AVC resistor and its associated capacitor do not result in the loss of the signal -- they simply deform it.

Section 11. **PENTODE DETECTOR TROUBLES**

Triode and pentode detector stages may be grouped together insofar as trouble-shooting is concerned. Since the potentials on the screen and suppressor grids of the pentode type detector are constant, their effect is simply to increase the audio gain of the stage without altering the detecting action they perform. Fig. 15 represents a pentode detector, showing standard values of resistance and expected voltage readings. This, as we know, may either be the square-law or the linear plate detector. If the receiver under analysis uses a triode instead of a pentode in this stage, as would be true only in the older models, the data in Fig. 15 regarding the screen and suppressor grids may be ignored.

If R-1 is open, the stage will not conduct and the signal will consequently be completely lost. Test for excessively high cathode voltage and verify by an ohmmeter check (on the high scale) on this resistor.

If C-1 is open, the audio as well as the radio frequencies will be degenerated. This means a weak signal, considerably below normal volume. Confirm the suspicion of an open in this condenser by shunting it with an equivalent. If C-1 is shorted, the bias of the stage is lost, the signal is also lost for the most part. Verify by an ohmmeter check (on the low scale) across this capacitor.

C-2 is the screen by-pass capacitor required wherever the screen of a stage is operated at a voltage below that of B-plus. If C-2 is shorted, the gain of the stage would be reduced, thereby losing all or part of the signal. If C-2 is open, a high degree of audio degeneration will occur, with the added possibility of distinct motor-boating. Make a check for a short across C-2 by an ohmmeter set to the low scale. An open in this condenser may be confirmed by shunting the existing one with its equivalent, and noting whether or not the signal returns to normal volume, and the motor-boating (if present) disappears.

R-2, the plate load resistor, may open or increase its value. If so, the signal will be lost, or at least become very distorted and quiet. Plate voltage lower than normal would be one indication of this condition. This can be further verified by an ohmmeter check across this resistor on the high scale of the meter.

R-3, the screen dropping resistor, may either be open, or shorted out by its associated capacitor C-2. If open, the signal will drop to below normal, a symptom which will also be present if C-2 is short-circuited. To distinguish between these two possibilities, use the voltmeter first for screen voltage, and follow up with an ohmmeter test, on the low scale, between the screen grid and B-minus.

C-3 is the audio coupling condenser which is the common property of both the detector stage and the output stage following. If C-3 is short-circuited, the following stage will be driven to saturation, and signal distortion will result. This may be verified by a voltmeter check on the output stage grid, which should not be positive to any degree. If C-3 is open, signal volume will drop almost, but not quite, completely. Verify the suspicion of an open in this component by shunting it with an equivalent condenser, while the receiver is turned on.

Section 12. GRID LEAK DETECTOR TROUBLES

Fig. 16 represents a typical pentode grid-leak detector, with standard values of resistances and voltages indicated. For most of the components of this type of detector, except for R-4 and C-4, the same method of analysis may be used as in the case of the plate detectors discussed above. Failure of components will result in the same audible symptoms and the same discrepancies in voltage readings. The additional bias in the grid detector, however, involves the use of the grid leak resistor, R-4, shunted by capacitor C-4. To check the continuity of the 2-megohm resistor is difficult on most meters. However a voltage may be indicated when the stage is operating, and thus if resistor is open, the voltage read by the 1000-ohm-per-volt meter will be excessively high. However, even if the voltage is too high as read by the meter across this open resistor, the meter itself will act as a leakage path for grid electrons, and the signal may be brought in at the time this test is being made. If these conditions are true during this test, the grid resistor, R-4, may be considered open and should be replaced by a new one.

Capacitor C-4 may open. If so, the grid bias developed across R-4 will contain its RF and audio components, the latter of which will tend to degenerate the audible signal. Verify by shunting with an equivalent capacitor. A short-circuit in C-4 will make itself known by the loss of the grid-leak bias in this stage, by the drop in signal output, and, lastly, by an ohmmeter check directly across this capacitor. If either open or shorted, C-4 should of course be replaced.

Section 13. CONNECTING A PHONOGRAPH TO A RECEIVER

Radio-phonograph combinations, whether of the console or the table-model type, involve a switching system that will permit the audio stages of the receiver to accept either a radio or a phonograph signal. There is no better place to introduce the phonograph signal than at the manual volume control. This potentiometer, as we know, is associated in superheterodyne receivers with the diode detector stage. Fig. 17 shows the electrical connections to accomplish the desired results.

A single-pole-double-throw selector switch is employed to connect the high side of the volume control to either the radio or phonograph circuits. This arrangement permits the listener to select either the radio signal or the phonograph signal, and also permits him to use the receiver volume control for either of these audio signals. If the receiver is equipped with a tone control, it, too, can be used on both radio and phonograph operation. A scratch filter, shown here in its simplest form, is a capacitor circuit which opposes the record-scratch commonly heard in radio-phonographs without this shunting capacitor. There are many fancy designs for scratch filters, but a capacitor, around .005 mfd placed directly across the phonograph signal output leads, will effectively reduce the record scratch. Where the receiver is provided with a tone control, no scratch filter is needed, so long as the listener knows how to use the tone control (making it more bass) while he is listening to phonograph records.

Section 14. TROUBLE-SHOOTING THE RADIO-PHONOGRAPH COMBINATION

Testing the crystal pickup. Fig. 18 shows the photograph of a crystal pickup unit used to reproduce music from records. The crystal pickup, generally made of quartz or Rochelle Salts, can be readily tested by the use of a pair of high-impedance earphones, connected as shown in Fig. 19. It is usually necessary to remove the crystal unit from the pickup arm while making this test. Turn the record player on, and holding the crystal unit as level as possible, permit the needle to follow the record grooves as it would during normal operation. The phones should pick up a clear but not too loud reproduction of the music on the record. This test should be made in a quiet room, and the desired results showing a good crystal are the characteristics of clarity rather than of high volume. If this test results in a distorted signal, or in no signal at all, the crystal can be assumed defective, and should be replaced.

Common troubles in phonograph-associated receivers are easily located if one considers the nature of the electrical connections between the two components.

If the radio plays satisfactorily, the phonograph turntable operates, but the phonograph music does not come through, look for a defective crystal or an open ungrounded lead from the crystal to the audio circuits of the receiver. If a loud hum is heard and the other conditions are the same as described above, look for an open ground connection from the crystal to the receiver.

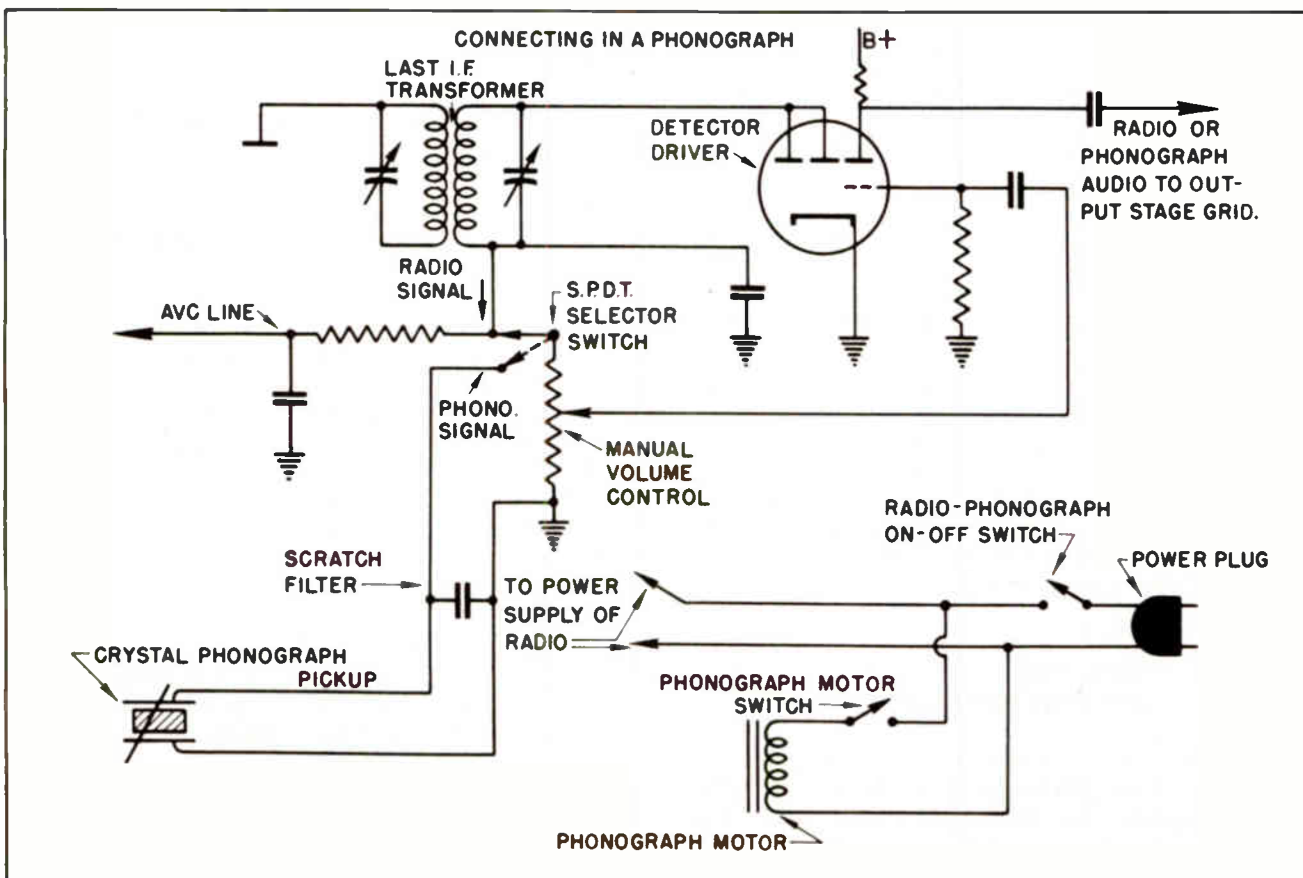

Fig. 17. How to Connect Phonograph to a Radio Receiver at the Detector Stage.

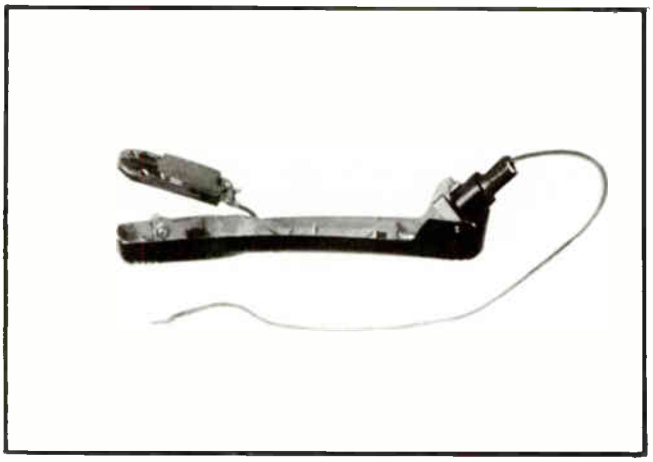

Fig.18. Crystal Pickup Cartridge.

If the phonograph plays, but no radio signal is heard, look for a defective selector switch, or for a defective oscillator, RF, or I-F stage in the receiver. Check all tubes up to, and including, the detector stage.

If the radio plays, but the phonograph signal contains a hum or moan only when the pickup arm is placed upon the record to be played, check the rubber or spring bushings designed to shock-mount the turntable assembly. The rubber bushings become hard, and the metal springs lose their elasticity, and the result in either case is acoustical feedback from the loudspeaker to the crystal pickup. If this occurs in a system where the phonograph pickup is a separate unit from the receiver, it will be found that the pickup is generally mounted upon the receiver. This type of annoying feedback can be corrected by placing the phonograph at some distance from the receiver, or by placing it on a sponge-rubber mat to absorb vibrations.

If neither the radio nor the phonograph play properly, and if the phonograph motor turns, look for a defective power rectifier, driver, or output stage. Check the rectifier tube and all tubes following and including the detector driver stage. If the phonograph motor does not turn and the rest of the conditions described are present, check the power source, the power plug and cord, and the on-off switch.

If the receiver operates properly but the phonograph motor does not turn, look for an open power connection to the motor.

If a loud hum is heard when someone handles the phonograph pickup arm, reverse the power leads to the phonograph motor. This is an important step in installing a phonograph unit, or in replacing a crystal pickup. It is quite easy to make the wrong connections, with respect to chassis polarity. Excessive hum will indicate that either the phonograph motor leads should be reversed, or the crystal signal leads should be reversed. Do not reverse both sets of leads, for this will bring back the excessive hum. It is only necessary to reverse one of the pairs of leads.

Where the radio plays clearly, but the phonograph plays with distortion, check the phonograph needle, the crystal, and the record being played. (The "permanent needle" is not always permanent, and an old or defective record may be the cause of signal distortion.)

The foregoing outline of troubles in radio phonograph combinations is by no means meant to be complete. It is a list of the most common troubles with which the combination of a radio and phonograph is involved. The radio receiver may contain these troubles, plus all those to which the receiver is subject; the phonograph may have these troubles, plus all those to which the phonograph is subject.

It may be added that this is one case where the complexity of the radio-phonograph has clarified and helped to locate the probable troubles in the receiver itself, a process which would be more difficult (although by no means impossible) without the associated phonograph equipment.

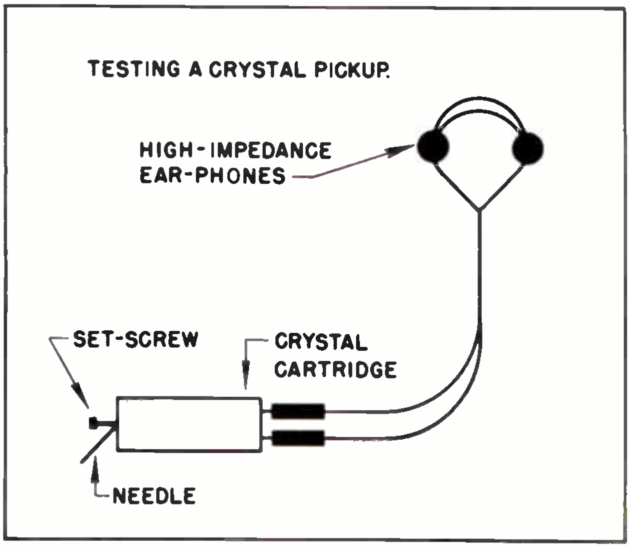

Fig. 19. One Method of Testing Crystal Pickup Cartridge.

NOTES FOR REFERENCE

The diode detector is the most important demodulating device used in radio and television circuits. It will be found in almost all modern radio and television receivers.

The diode detector is almost always associated with the manual volume control of a receiver, and the AVC circuit. Most diode detectors are a part of a multi-purpose tube, the other part being either a triode or a pentode voltage amplifier.

Automatic Volume Control (AVC) is designed to stabilize the signal strength at the speaker under varying conditions of signal strength at the antenna. When strong signals strike the antenna and are tuned by the receiver, they act to increase the AVC voltage to a more negative value. This decreases the gain of the I-F and Mixer stages, thereby reducing the strength of the signal at the speaker. When a weak signal strikes the antenna and is tuned by the receiver, the opposite action takes place. The weak signal acts to lower the AVC voltage, the Mixer and I-F stages become more sensitive, and the weak signal is reinforced.

The detector should be checked for operation after the tubes, the speaker, the output stage, and the driver stage have been tested and found to be in good order.

NOTES

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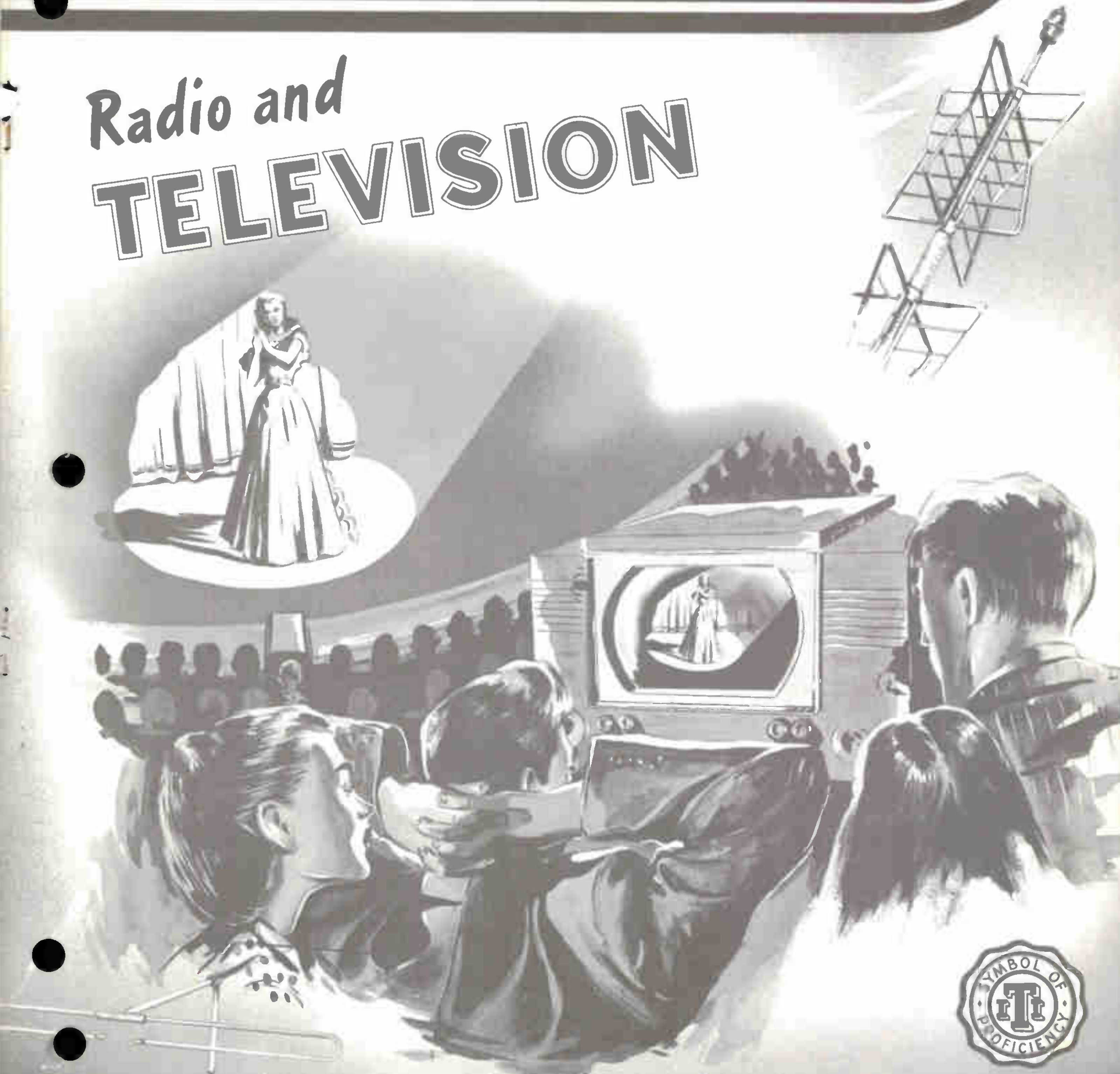

INDUSTRIAL TRAINING INSTITUTE

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Revised 1954

RADIO TELEVISION

THE INTERMEDIATE FREQUENCY STAGE

Contents: Introduction - Need for an I-F Stage - The I-F Stage Components - Operational Tests for the I-F Stage - General Symptoms of I-F Stage Troubles - Troubles in the Transformers - Other I-F Troubles - RMA Color Code for I-F Transformers - Shorts Between the Coils of I-F Transformer - I-F Troubles Peculiar to A-C and Automobile Receivers - The Permeability-Tuned I-F Stage - Alignment of the I-F Tuned Circuits - The "Q" of a Tuned Circuit - I-F Band Width and the Audio Component - Aligning the I-F by Ear - Aligning the I-F by Signal Generator - Staggering the I-F Tuned Circuits - Notes for Reference.

Section 1. INTRODUCTION

The purpose of the intermediate frequency (I-F) stage in a superheterodyne receiver is to accept, tune, and strengthen the modulated signal fed to it by the mixer stage which precedes it. Thus strengthened, the signal is then fed to the second detector for extraction of the audio component. The audio is then further amplified and converted into sound energy by the audio section of the receiver in the manner which has been discussed in other lessons.

Fig. 1 shows the electrical location of the I-F stage in relation to the rest of the receiver, and indicates the shape of the wave forms as they pass through each stage.

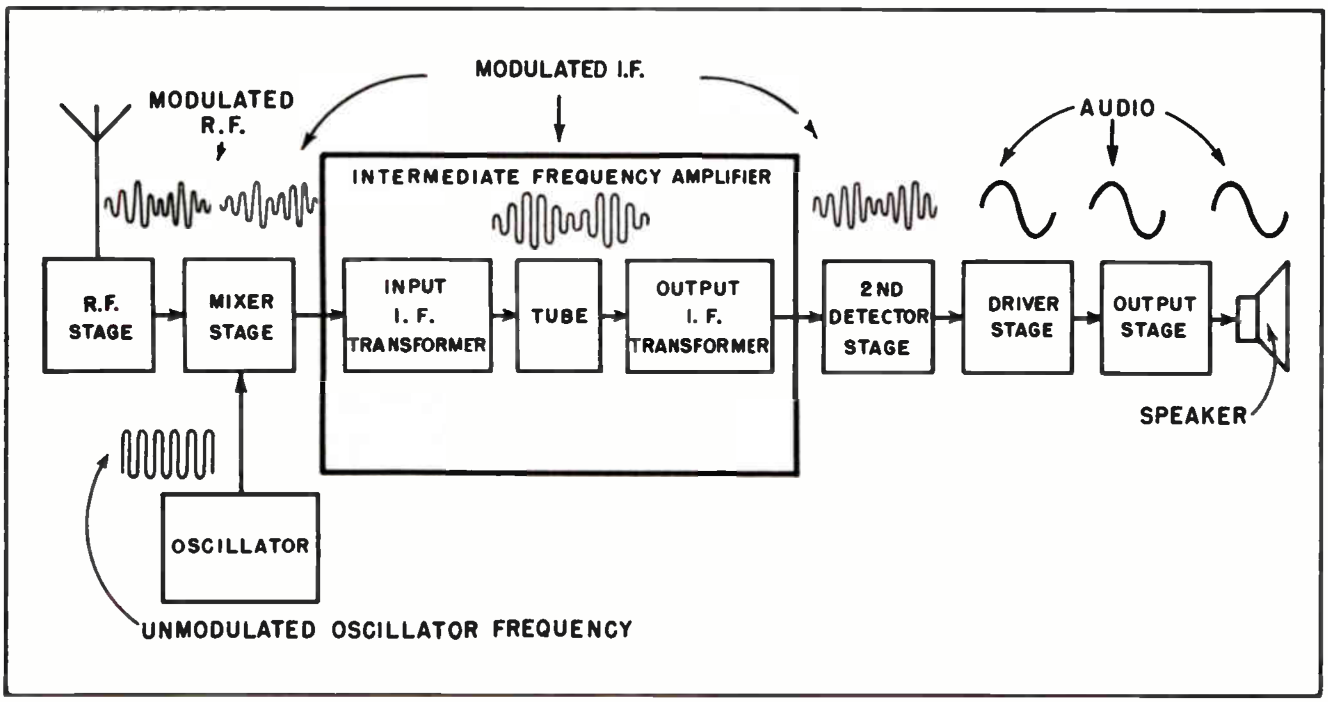

Fig. 1. Location of the I-F Stage in a Superheterodyne Receiver.

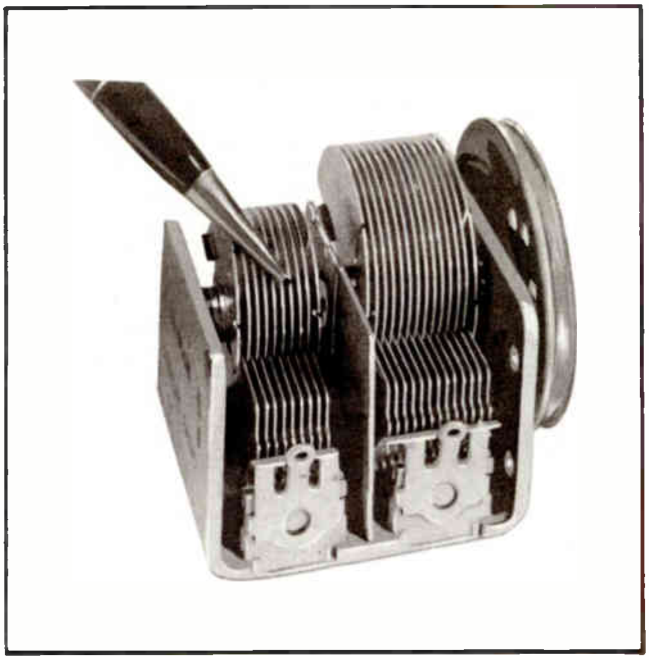

Fig.2. A Two-Gang Variable Condenser Such as is Commonly Used in a Small Superheterodyne.

Section 2. **NEED FOR AN I-F STAGE**

Why does the superheterodyne receiver need an I-F stage? This question may be answered in general terms in a simple way. The superheterodyne receiver needs an I-F stage to provide high gain at a *fixed frequency* in order to insure the high degree of selectivity and sensitivity required by modern receivers. It may be added that the I-F stage of a superheterodyne receiver is useful not only for the reasons given; other highly desirable abilities of the I-F stage actually justify the existence of the superheterodyne receiver circuit. Let us review the fundamental superheterodyne principle, in order to better understand the analysis and trouble-shooting of the I-F stage.

In contrast to the Tuned Radio Frequency (TRF) receiver, which amplifies an incoming modulated signal at the same frequency at which it is received, the superheterodyne receiver runs the received signal through a conversion process before attempting to amplify it. Because the TRF receiver is designed to accept the many different frequencies to be found in the broadcast band, it must amplify and tune all these different frequencies. The superhet receiver is also made to accept many different frequencies, but the conversion process, plus the I-F amplifier stage, enables the superhet to *amplify* all signals at the same frequency, the fixed intermediate frequency. The ability to amplify all signals at one fixed frequency, regardless of the frequency at which the signal is transmitted and received, results in the desirable characteristics of excellent gain and sharp selectivity. The gain of a receiver is its ability to take a weak signal and build it up to considerable strength. Selectivity is the ability to separate one received signal from all others, and to thus avoid receiving more than one signal at a time.

In other lessons the conversion process is described in detail. There we see how an incoming signal, regardless of its transmitted frequency, is "heterodyned" against the signal of a local oscillator in the receiver and a third frequency equal to the difference between them is fed to a fixed tuned circuit. This tuned circuit, which is both the converter stage plate load and the source of signal to the I-F amplifier, is a fixed resonant circuit tuned to the difference between the incoming signal frequency and the local oscillator frequency.

Because any change in the circuit which is resonant to the incoming signal automatically effects an equal change in the local oscillator frequency, it is evident that the difference between the incoming and oscillator frequencies will be constant. The I-F tuned circuits, of which there are at least four, are all tuned to this difference frequency. These circuits will all be discussed in detail.

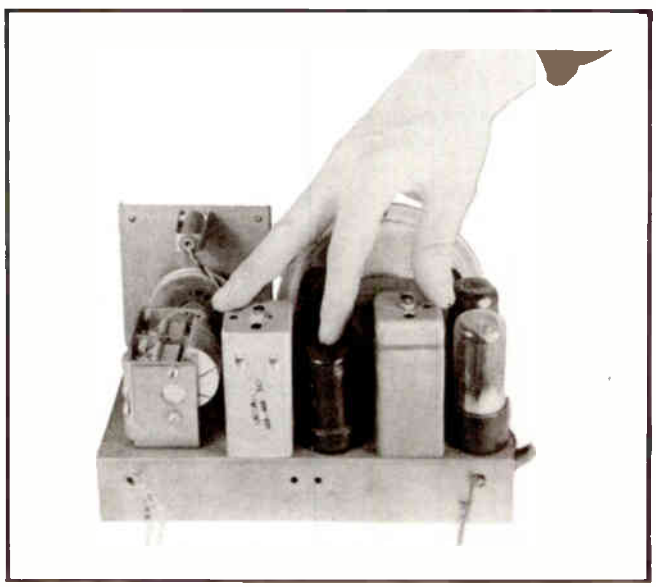

Fig.3. Components of the I-F Stage Which are Peculiar to Superheterodyne Receivers.

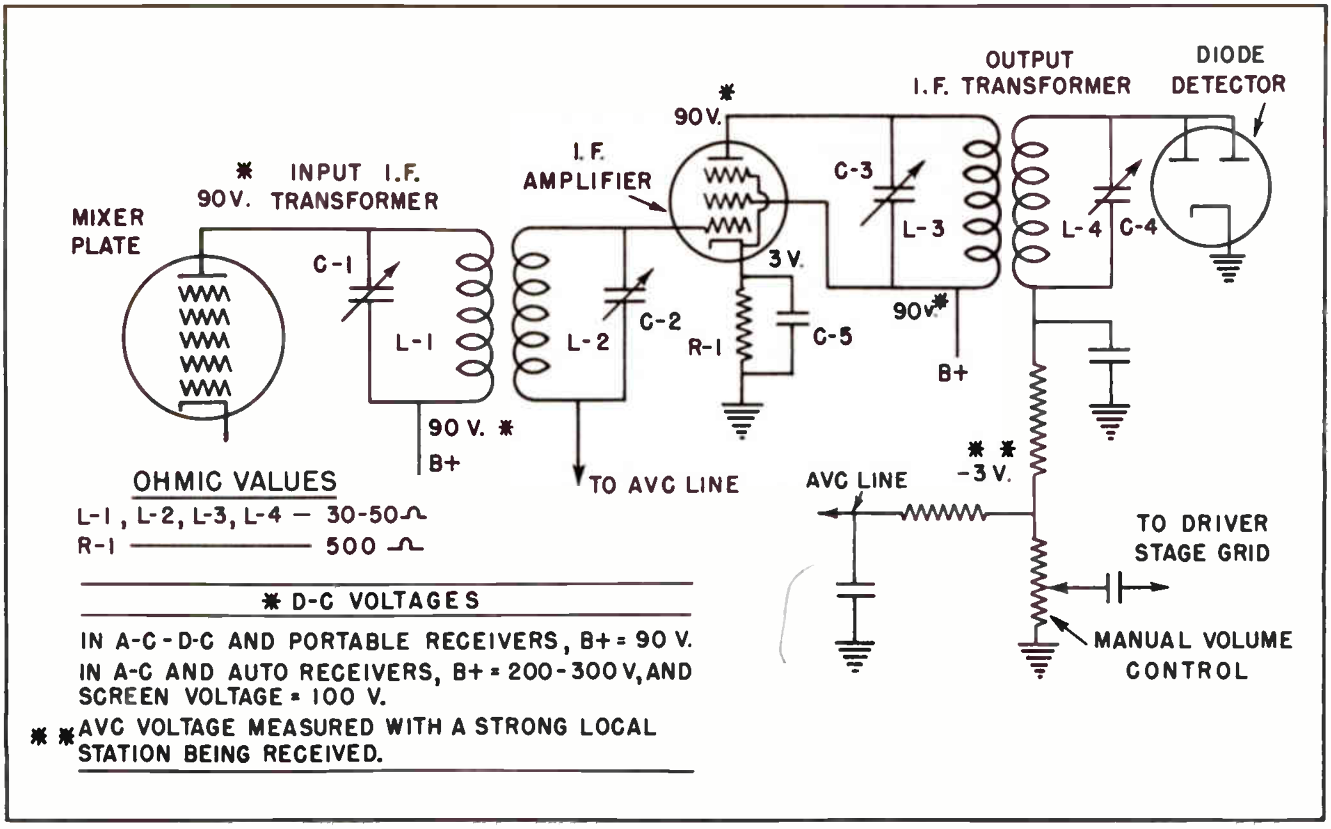

Fig. 4. Principle Components in the I-F Stage of a Small Superheterodyne.

Suppose a radio receiver in the city of Chicago is tuned to receive a signal from transmitting station WCFL, whose frequency (a nice round number) is exactly 1,000,000 cycles per second. To receive this signal we must manually rotate the tuning condenser located at the front of the receiver, an act which resonates the RF tuned circuit to 1,000,000 cycles per second, or 1,000 kilocycles. Since the oscillator variable condenser is mechanically coupled to the same shaft as the RF tuning condenser (see Fig. 2) it will rotate also. The oscillator tuned circuit will then resonate at 1456 kilocycles. The difference between the transmitted signal from WCFL (1,000 kilocycles) and the oscillator (1456 kilocycles) is 456 kilocycles. This is the I-F frequency, and all the I-F tuned circuits in this receiver are adjusted to resonate at 456 kilocycles. In Fig. 2 the pencil is pointing to the oscillator section of the ganged capacitors. The smaller section has less capacity — thus a higher frequency.

With respect to the I-F amplifier system, this is an important characteristic, for the I-F amplifier can be built to amplify only one frequency, the I-F frequency. Such an amplifier can be specially designed to operate with maximum efficiency, since its components may be assembled with the I-F frequency -- and only the I-F frequency -- in mind.

Illustrated in Fig. 3 are the main components of the I-F amplifier stage, showing the input I-F transformer, the amplifier tube, usually a pentode, and the output I-F transformer. The hand covers the input I-F transformer, the I-F amplifier tube and the output I-F transformer.

The schematic diagram of a standard I-F amplifier stage is represented by Fig. 4, and indicates the preceding, as well as the succeeding, stages. The I-F signal, originating in the plate winding (the primary) of the input I-F transformer, is fed through the I-F stage, there amplified and tuned, and sent on its way to the second detector for recovery of its audio component.

Section 3. **THE I-F STAGE COMPONENTS**

Input I-F transformer primary, L-1 in Fig. 4. In this winding the I-F frequency is born, even though it was conceived in the mixer tube. This winding, tuned to I-F resonance by C-1, with which it is in parallel, provides a selective load for the mixer tube plate. It will reject any frequency deviating in any great degree from its resonant frequency and will thus effectively block from passage any other frequency. Being a transformer primary endows it with another function. It will create a magnetic field around its windings which will vary in accordance with its current changes; that is, in accordance with its resonant frequency. This changing magnetic field, of course, will affect the secondary of the transformer.

Input I-F transformer secondary, L-2. The purpose of this winding is to respond to changes of primary current by producing and delivering a voltage, at I-F frequency, to the grid of the I-F amplifier tube. The I-F resonates in this winding, also, due to the coils parallel connections with C-2. Tuning both the primary and secondary windings of this transformer narrows down, or sharpens, their combined selectivity.

Output I-F transformer primary, L-3. Its function is identical with the purpose of L-1, except that the I-F frequency, having been already born, need not be re-born. The primary winding of this transformer is also tuned by the parallel capacitor C-3. It is tuned to the same frequency as the input I-F transformer. Current in the plate circuit of the I-F amplifier tube, flowing in the windings of L-3, causes magnetic field changes corresponding to the I-F signal frequency. These field changes are meant to affect the secondary of this transformer, L-4.

Output I-F transformer secondary, L-4. This component, also tuned by its associated condenser C-4, produces a voltage at I-F frequency under the influence of magnetic field changes due to primary current in this transformer. It delivers the voltage to the detector stage diode, and acts as the generator whose energy activates not only the second detector, but the AVC circuit and the manual volume control as well.

Condensers C-1, C-2, C-3, and C-4. Within a narrow range, these condensers are usually adjustable. They have the common function of resonating the coils with which they are connected to achieve a series of selective circuits which will grant passage to only one frequency, the I-F frequency. Their arrangement in this series is such as to make their aggregate selectivity considerably sharper than the selectivity of any one of the tuned circuits by itself. In some I-F transformers the value of the condensers are fixed, but the inductance of the coils is adjustable to a limited degree.

Cathode Resistor, R-1. Its function, like that of all cathode resistors in amplifying stages, is to establish the cathode bias of the stage. Note that the grid of this stage is also biased by the AVC voltage. The presence of additional cathode bias, due to R-1 permits a certain amount of minimum bias for the stage, whether a strong signal is activating the AVC circuit or not. In effect, this means that if no signal were being received, or if only a weak signal is being received, this stage will not lose its bias to the point of saturation as it would without the minimum cathode bias supplied by R-1.

Cathode By-Pass Capacitor, C-5. This is the R-F by-pass around the cathode bias resistor R-1. DC bias developed across R-1 is not affected by C-5; nor does it affect the AVC voltage developed in the second detector.

The I-F amplifier tube. The purpose of this tube is to amplify the incoming I-F signal, building it up from a relatively weak signal at the grid to a comparatively strong signal at the plate. This tube is usually a pentode amplifier of the "remote-cut-off" type (sometimes called a "super-control" tube) whose characteristics permit effective response to a very slight change of AVC bias voltage when the gain of this stage is to be changed in accordance with the strength of a signal at the receiver's antenna. The action of the "super-control" tube is described in another lesson.

Section 4. **OPERATIONAL TESTS FOR THE I-F STAGE**

In a normally-operating I-F stage, modulated I-F signal, originating in a signal generator as in Fig. 5, will be accepted, tuned, and amplified. If the stages following the I-F amplifier have been tested and known to be operating, the audio modulation from the signal generator will be heard in considerable volume at the speaker. This procedure may constitute a test for normal operation of the I-F stage.

An equivalent test for the I-F stage may be done with a signal tracer, the connections for which are shown in Fig. 6. If either an artificially generated radio signal, or one

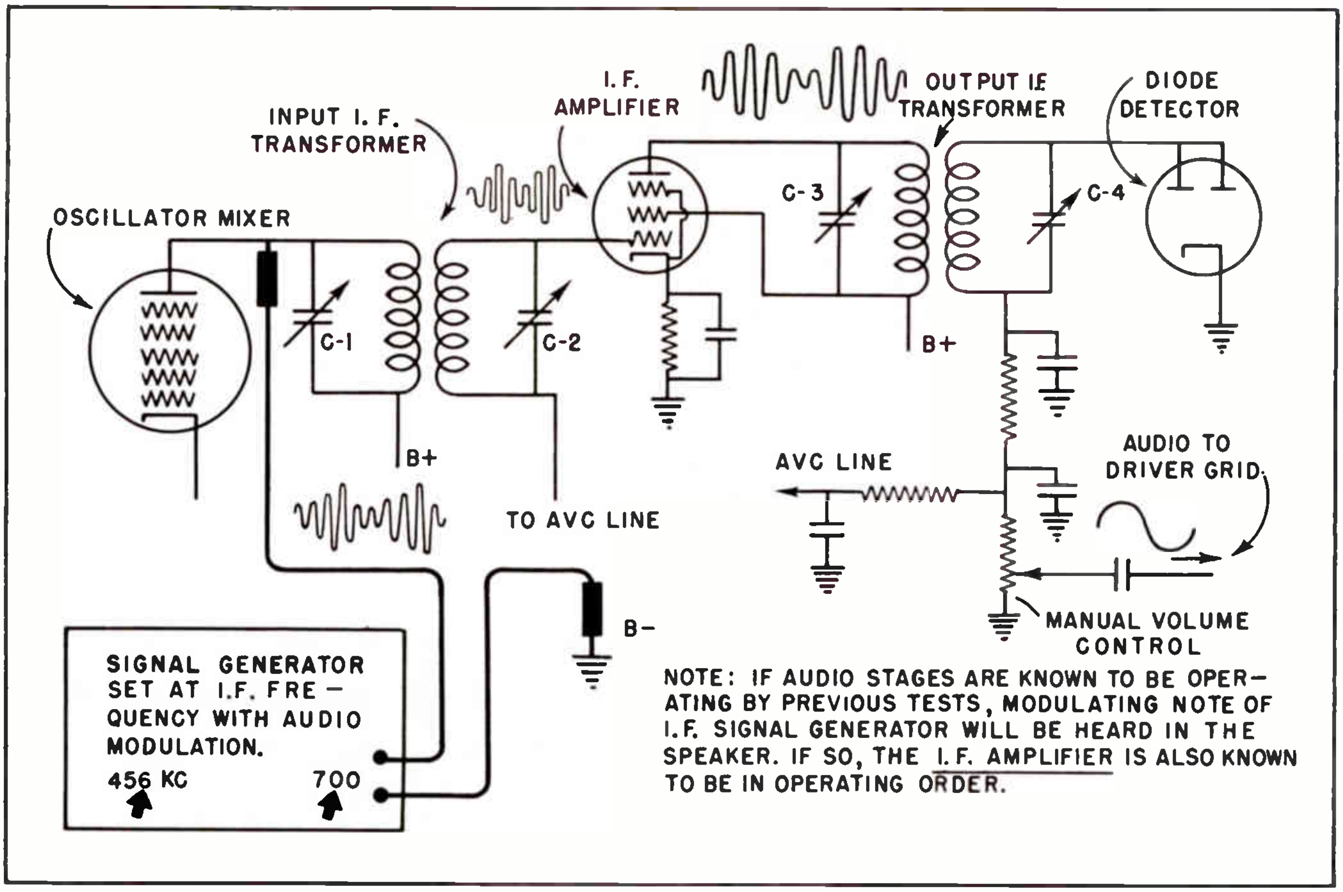

Fig.5. Using a Signal Generator to Localize the Trouble in the I-F Stage.

brought in naturally from a nearby transmitter, are heard in the speaker of the signal tracer, then the I-F stage may be assumed in good order. This assumption is more certain if there is a noticeable loss in signal strength as the signal tracer prod is moved progressively from "A" to "B" to "C" in Fig. 6. This is because there is less and less of the amplification of the receiver as we move from the output I-F secondary toward the antenna of the receiver.

It is to be remembered that the tests of Figs. 5 and 6 are essentially equivalent to each other. The technician can always select whichever test meets his convenience. They are designed only to indicate the stage in which a trouble lies. The exact defective part of the stage is located by subsequent ohmmeter or voltmeter tests. For the sake of simplicity, however, let us analyze these equivalent tests separately.

The operational test outlined in Fig. 5, using the signal generator only, assumes that the succeeding stages have been previously tested and found operative. Suppose, then, that the test fails; that is, that an I-F modulated signal from the signal generator, introduced at the mixer plate, does not result in an audible modulation note at the speaker. This will indicate, as is evident on consideration, that the I-F amplifier system is not performing its function. The trouble must lie somewhere between the mixer plate, where the signal is introduced, and the detector plates, where it should appear as audio. Between these limits lie the components of the I-F amplifier system, including the mixer tube plate circuit and the diode plate circuit. The next step is to take critical voltmeter readings, comparing them with a standard set of I-F data, and noting any discrepancies.

If the above test, however, results in an audio signal at the speaker, we assume the I-F stage to be operating and may further investigate the trouble by advancing to another suspected stage.

The interpretation of the test in Fig. 6, is similar, but slightly more inclusive. As indicated, a radio transmitter signal may be used in place of the signal generator, if more convenient (and it usually is more convenient). This signal is then monitored at various key points along the signal path, starting with the secondary of the output I-F transformer. The signal tracer, as the name indicates, is built to accept a radio or I-F frequency signal, modulated by an audio component, and it then effects the detection process within itself. The two frequencies are separated, as in the receiver detector stage, and the audio is amplified through the speaker located in the signal tracer.

It is to be noted that this technique does not presuppose a normally-operating audio section, although the procedure will, if properly interpreted, tell us if the audio section is at fault. This enables us to conclude that the best time to use this method is when the audio section has been tested and found good, and yet the receiver does not operate properly. For by moving the signal tracer test prod from "A" to "B" to "C" there may be a point where the signal tracer will pick up the signal, but the receiver audio section fails to respond to it.

This test is somewhat more complete than that of Fig. 5 because it enables us to more quickly locate the defective stage. Keep in mind that we are moving the signal tracer prod, and not the point of introduction of the test signal, which is fixed at the receiver antenna.

Suppose, for example, that we fail to pick up a signal at "A" but succeed in getting it at "B". Instead of suspecting all the previous circuits, our trouble is narrowed down to a point lying between the secondary of the input I-F transformer and the secondary of the output I-F transformer. While this still includes a number of components to be individually tested, this procedure immediately rules out all circuits previous to the point marked "B". Voltmeter and ohmmeter readings, therefore, between points

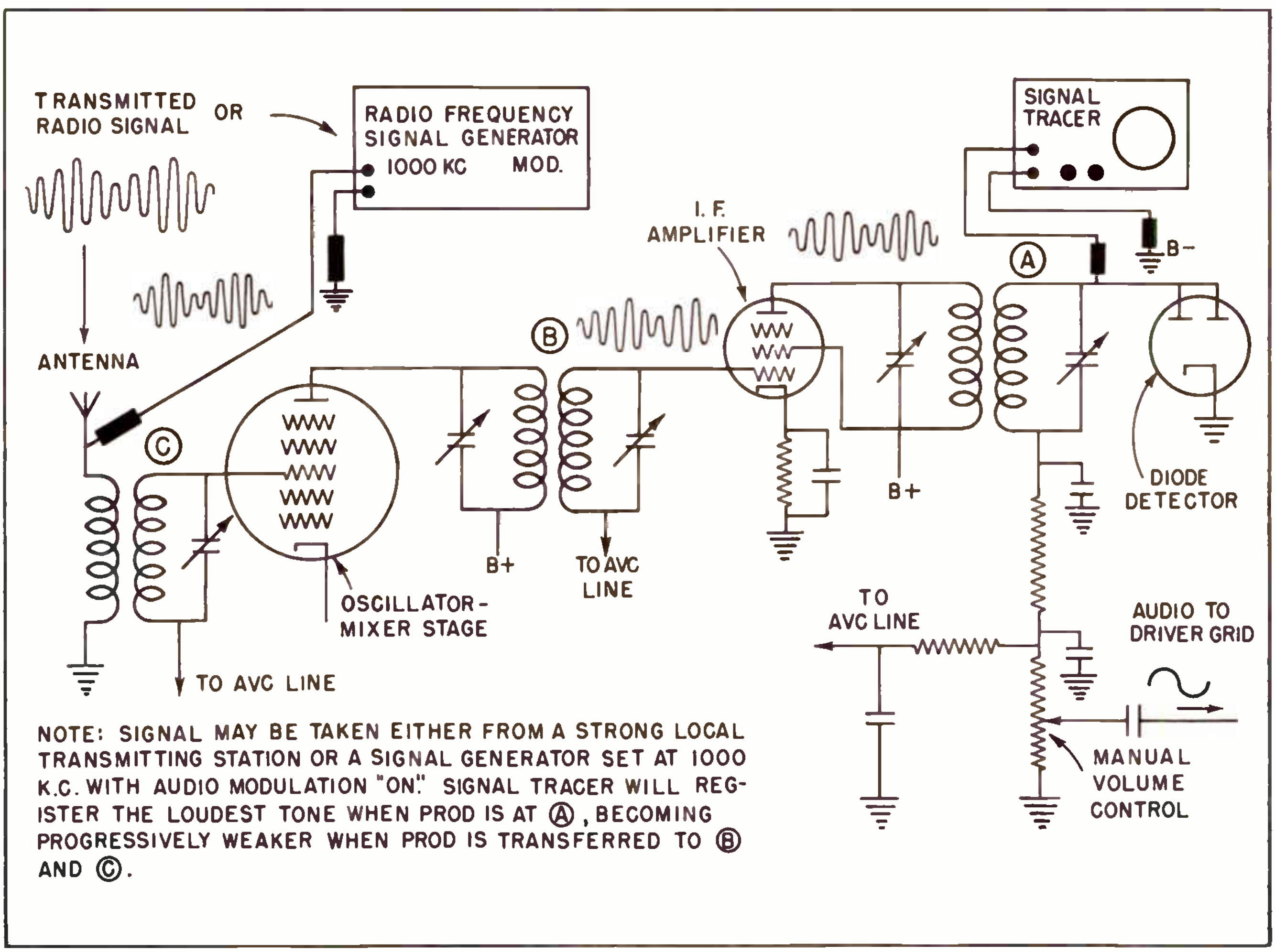

Fig.6. Using a Signal Tracer to Isolate Trouble Into the I-F.

"A" and "B" will soon yield the exact component responsible for the receiver's failure.

Notice how this test infers the proper operation of the audio section of the receiver. This is done by a process of logical thought. If the signal tracer does not pick up a response at "A" then we can hardly expect the receiver audio section to pick up a signal at this point. If a signal were present at this point, the signal tracer would pick it up. The fact that the signal tracer fails to respond does not in itself prove that the detector and audio section are in order. But, in the face of the known facts, if we suspect these stages of trouble, we find ourselves suspecting a stage only because there is no signal being fed to it. A little thought will show that this does not constitute grounds for suspicion. And we should not suspect a stage in a receiver of being defective without sufficient evidence.

If, in the test of Fig. 6, a signal is picked up at "A" we may reasonably assume the trouble lies in a succeeding stage, and that any previous tests for these stages should be repeated with extreme care.

Section 5. GENERAL SYMPTOMS OF I-F STAGE TROUBLES

The detailed behavior of a defective radio receiver with trouble in the I-F section will serve as a guide in locating the exact faulty component. Such trouble may be suspected on the basis of the following facts:

1. All the tubes have been tested carefully for shorts, leakage, and emission.

2. The second detector and the audio sections have been tested and found to be in good operating order.

3. B-plus at the cathode of the rectifier tube is normal.

4. The speaker contains the normal residual hum, in addition to a rush of background static only when the volume control is advanced to maximum.

5. The signal may be altogether absent, it may be weak, or it may be accompanied by whistling, howling, or cross-talk.

6. The signal, if present in any form, can be tuned by the station selector.

Let us now examine these six facts and show that their combination (that is, their simultaneous presence) in a defective receiver virtually isolates the exact trouble to the I-F stage.

1. If, after testing the tubes and replacing any which are bad, the trouble is still present in the receiver, we can eliminate the suspicion of tube trouble. This rules out the tubes from the trouble-shooting procedure.

2. Previous tests have eliminated the detector and audio sections. If the tests have been made carefully, we need no longer consider that the trouble lies in these portions of the receiver.

3. Normal B-plus at the rectifier cathode eliminates any power supply trouble, except that of a high filter hum level. This can be immediately checked by turning the manual volume control to minimum; the hum and static level should both drop down to a bare minimum, indicating the filtering is proper.

4. When the manual volume control is advanced to maximum the residual hum will increase, and the static level will increase as well. This tells us that the trouble does not lie in the second detector stage, for if it did, the hum level would increase, but there would be no background static of any kind.

5. If the signal is altogether absent, or weak, or is accompanied by whistling, howling, and cross-talk, this is a distinct deviation from normal conditions and points almost conclusively to trouble in the I-F amplifier system.

6. The ability to tune the signal, even if the signal is weak or bothered by whistling and cross-talk, tells us that the trouble does not lie in the oscillator-mixer (converter) stage. If it did the signal would not be tunable by the station selector.

There is a wealth of information in the facts mentioned above, especially when taken together. They have told us that the trouble does not lie in the audio section, the detector stage, the oscillator-mixer, or the power supply. In addition, they have succeeded in casting strong suspicion upon the only remaining stage, in most receivers, the I-F stage. And this isn't all. The peculiar nature of many I-F stage defects causes whistling, howling, cross-talk, weak signal, or no signal at all. Thus it can be logically deduced on the basis of electronic analysis that trouble exists in certain specific I-F circuit components.

When the I-F stage has been identified as defective, the next step is to seek the exact trouble with voltage and resistance readings as specified in Fig. 4.

With an ohmmeter measure the resistances of all the I-F transformer windings. Measure the D-C voltages on the plate and screen of the I-F amplifier tube, as well as its cathode voltage and resistance to ground. Compare these readings with standard values, either from the data in Fig. 4 or from the manufacturer's wiring diagram of the receiver under analysis.

If any wide discrepancy is noticed between the manufacturer's ratings and the readings as taken by voltmeter and ohmmeter, the circuit involved should be checked in detail to reveal the reason for this difference. In most cases this method will clearly disclose the trouble.

Let us now see in what manner the components of the I-F stage may be defective, study the symptoms resulting from such defects.

Section 6. TROUBLES IN THE TRANSFORMERS

Primary winding of the input I-F transformer. If this winding is open, no signal of any kind will be heard at the speaker. However, a noticeable level of static will be heard when the manual volume control is advanced. B-plus voltage will be present throughout the receiver except at the plate of the mixer tube. The ohmic resistance of this winding, if open, will be infinite.

If this winding is short-circuited, the trimmer capacitor with which it is in parallel is probably responsible. For if a short occurs across the condenser, it would show up as a short across the coil as well. Resistance reading of the parallel circuit, including the shorted condenser, will be around zero. B-plus will be normal both in the rest of the receiver and on the plate of the mixer tube. Verify by disconnecting the condenser from its terminals within the transformer shield and measuring both the condenser and the coil for short circuits.

A short across these components will cause the signal to drop out completely, while background static will be evident at the speaker.

The audible symptoms of a short across this winding are therefore the same as in the case of an open winding, the differentiating data are the voltage and resistance measurements.

Primary winding of the output I-F transformer. Its troubles are identical to those of the primary of the input transformer, except that the high side of this winding leads to the plate of the I-F amplifier instead of to the plate of the mixer tube. Otherwise the voltage and resistance readings are the same, and should compare with each other. An open or short in this winding would be indicated, as verified with meter readings, by the signal dropping out completely.

Secondary winding of the input I-F transformer. If open, this winding would be unable to pick up the signal voltage from its primary, with the consequence that the signal would be completely, or almost completely lost. In addition, since the grid of the I-F amplifier no longer has a discharge path to ground (normally through the secondary winding to the AVC circuit) there is a chance that instead of blocking this stage, such an open would encourage "motor-boating". Motor-boating may take several different appearances. If it is slow motor-boating, it will have the "putt-putt-putt" sound to it. However, if the motor-boating takes place at a fast rate, it may sound like a 60-cycle hum. In extreme cases, motor-boating may assume the sound of a rough squeal. Whether this disturbance sounds like pure motor-boating, howling, squealing, or whether the signal is altogether absent will be determined by just where in the coil the open has occurred, and by certain other circuit constants.

We should pause here to mention another important trouble in the I-F stage which also may cause motor-boating, howling or whistling. If the tuned circuits are too sharply aligned, which means that they are all set almost exactly at the same I-F frequency, a good opportunity may be present for *regenerative* motor-boating. This possibility can be readily checked by a trim-up of the variable capacitors with a screwdriver, a simple process in which the trimming adjustments of the I-F condensers are made by turning each of them only a small fraction of a turn. If the motor-boating is overcome by this adjustment, we need look no farther for its cause. If, however, trimming these condensers does not succeed in removing the motor-boating, howling, or whistling, then secondary windings in either of the I-F transformers may be suspected of being open (an open output filter condenser may also cause these symptoms).

If the secondary winding of the input I-F transformer is short-circuited, the signal will be completely lost and there will be no motor-boating, howling, or whistling. There will, however, be a certain amount of static in the speaker when the volume control is advanced. As in the case of a short across the primary winding, a short across the secondary will most likely be caused by a short in the trimmer condenser with which it is associated. Verification of this suspicion can be made by disconnecting the condenser from the coil within the shield and measuring the separate components isolated from each other.

Secondary winding of the output I-F transformer. While this is not a grid winding, it does complete the circuit through the diode plate circuit, the manual volume control, and the AVC circuit. Therefore, if this winding is open, the signal will be completely lost, and AVC voltage, as measured with a meter, will drop to zero at all times. Background static, even when the manual volume control is advanced, will drop to a minimum, but the residual power supply hum will be unmistakably present. These same symptoms will be evident if this winding is short-circuited, either due to the capacitor which is associated with it, or to any other short in the diode circuit. Here again our meter readings will assist in isolating the exact fault. The ohmic resistance of this winding, if open, will be infinite; and if it is short-circuited, will be zero.

In all cases of defective I-F transformer troubles, whether they are opens or shorts, it is wise to replace rather than attempt to repair the unit. Standard replacements are available. These are easier to secure and install than actually unwinding the coils to look for the defect. In such case, it is wise for you to take or send the defective unit to the supply house for an exact duplicate in both electrical and physical characteristics.

Section 7. OTHER I-F TROUBLES

The I-F amplifier tube. If this tube is defective due to internal short circuits or weak emission, the signal will be lost completely in most cases, but residual hum and some static will be evident at the speaker. In an AC-DC receiver, and in portable receivers where the amplifier tube heaters are wired in series, an open heater in this tube will eliminate all speaker sound, including the hum and any static. This type of tube defect, as well as those due to shorts and low emission in the tubes, can be readily checked on a tube-checker. This should be done as a routine initial step.

Cathode resistor of the I-F amplifier tube. If open, the cathode-to-ground voltage should rise to about 25 D-C volts, and the signal should drop out completely. Verification can be made by an ohmmeter reading between this cathode and ground, with the resistance, in a normally operating stage, being around 500 ohms. If shorted, this resistor will read zero ohms. Since there is little chance of the resistor shorting out by itself, we may reasonably look at the by-pass condenser (in parallel with the resistor) as the source of the short-circuit.

While this condenser does not often short out if the cathode-to-ground voltage and resistance are both zero, and the receiver lacks normal gain, we can readily suspect a short in the by-pass condenser. This suspicion may be verified by cutting one end of it loose from its soldered connections and measuring its resistance by itself.

Short circuits between B-plus and ground in the I-F stage are quite common, and may happen in a variety of ways. The leads connecting the primary windings of the I-F transformers to B-plus are often quite extended. Sometimes they are drawn rather tightly (in order to make them as short as possible) and such tightening may, when the rubber-insulated lead is pressed against a sharp edge of the chassis, cause a short circuit by cutting through the insulation.

Since B-plus is thus touching the grounded chassis, the I-F stage, as well as others utilizing B-plus, will become inoperative. These leads should be checked for such shorts when B-plus is present in almost normal value at the rectifier tube cathode, but is either low or absent from one or more amplifier tube plates.

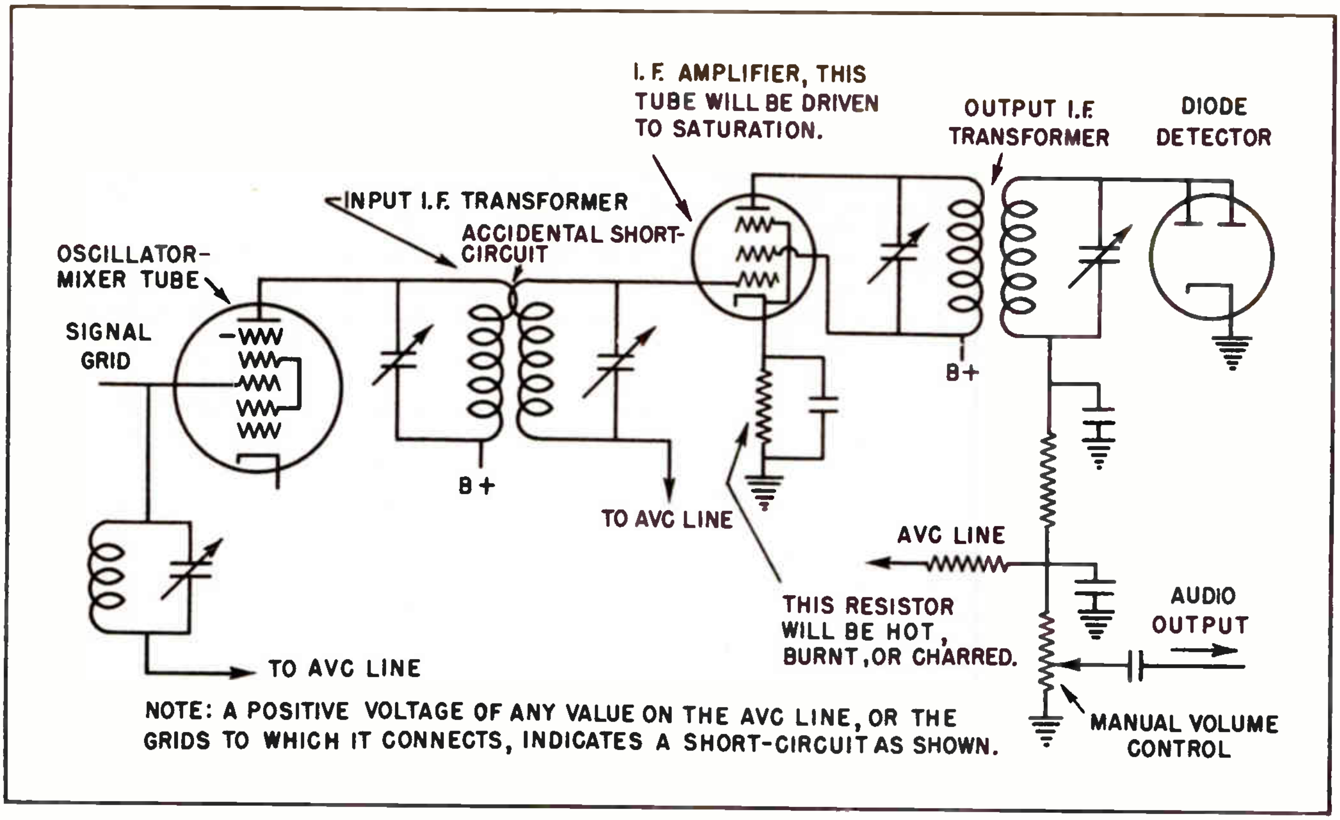

Fig.7. Showing the Effects of a Short Circuit Between Windings in an I-F Transformer.

Section 8. **RMA COLOR CODE FOR I-F TRANSFORMERS**

The Radio Manufacturer's Association color code (R.M.A.) for the I-F transformer leads is:

THE INPUT I-F TRANSFORMER:

Blue -- plate lead;
Red -- B-plus lead;
Green — grid lead;
Black — grid return to the AVC line.

THE OUTPUT I-F TRANSFORMER:

Blue — plate lead;
Red -- B-plus lead;
Green — to diode plates of detector;
Black — to AVC circuit and manual volume control.

From the above color coding of the leads, it is evident that shorts between B-plus and ground can only occur in either the blue or red leads of the I-F transformer stage. In an AC-DC receiver, such a short will probably damage the rectifier tube, which will light up but not produce B-plus. In A-C and automobile receivers the rectifier tube may not become damaged but its plates will become red hot within a short time. This may eventually damage the power transformer if power is applied to the set in this condition.

Section 9. **SHORTS BETWEEN THE COILS OF I-F TRANSFORMER**

Still another type of short circuit can occur in the I-F transformer. This may result in considerable trouble which is often difficult to analyze. Sometimes the original trouble itself is difficult to isolate.

Illustrated in Fig. 7 is a schematic diagram showing how this trouble can occur. The initial or original, trouble may be a short in the windings of the input I-F transformer; that is, B-plus from the primary winding may be shorted to the secondary. Since the secondary winding is connected to the grid of the amplifier tube that grid is immediately driven to a state of saturation, and the signal lost in this stage.

At the same time, since the signal grid of the oscillator-mixer stage is also connected to the AVC line, this tube, too, is driven toward a state of saturation, and the signal would be lost there as well. In addition, since the I-F tube is saturated, it draws more current than its cathode resistor is built to carry, and results in the burning up of that resistor. If the resistor is allowed to heat for an extended period of time, it will burn itself open, and there will be still another reason for losing the signal in this stage.

All this, of course, complicates the analysis. However, we may start with the burned or charred, cathode resistor. This would become evident simply by inspection and the characteristic pungent odor of a burned resistor. First of all, replace the burned resistor. Then, with the power turned on, measure the grid to ground voltage of the I-F amplifier stage grid. It should never read positive to any degree. If a positive voltage is measured at this grid, turn the power off, and measure the D-C resistance between the secondary and primary windings of this transformer. If this resistance is less than 100,000 ohms, a primary-to-secondary short can be suspected. Usually such a short will give an ohmmeter reading of less than 100 ohms. Opening up the transformer will quite often reveal the short. If, however, the short is not revealed by inspecting the windings, or if the winding shows signs of being burned or charred, the entire transformer should be replaced rather than repaired.

Section 10. I-F TROUBLES PECULIAR TO A-C AND AUTOMOBILE RECEIVERS

There is an important variation in the I-F stage of A-C and automobile receivers which deserves consideration, for this variation may account for certain troubles which other types of receiver (the AC-DC and portable) will not suffer. Fig. 8 illustrates this variation. Notice, first, that there are three I-F transformers, rather than two, and that the screen grid leads of the two I-F amplifier tubes are not connected directly to B-plus, but to a reduced value of B-plus. This voltage difference is brought about by the fact that in order to attain the amplification desired, in the larger receivers, the value of B-plus is derived from a stepped-up voltage. The automobile receiver, and the large home console receiver operating on A-C only, are of this type, with B-plus often reaching 250 volts, sometimes even higher.

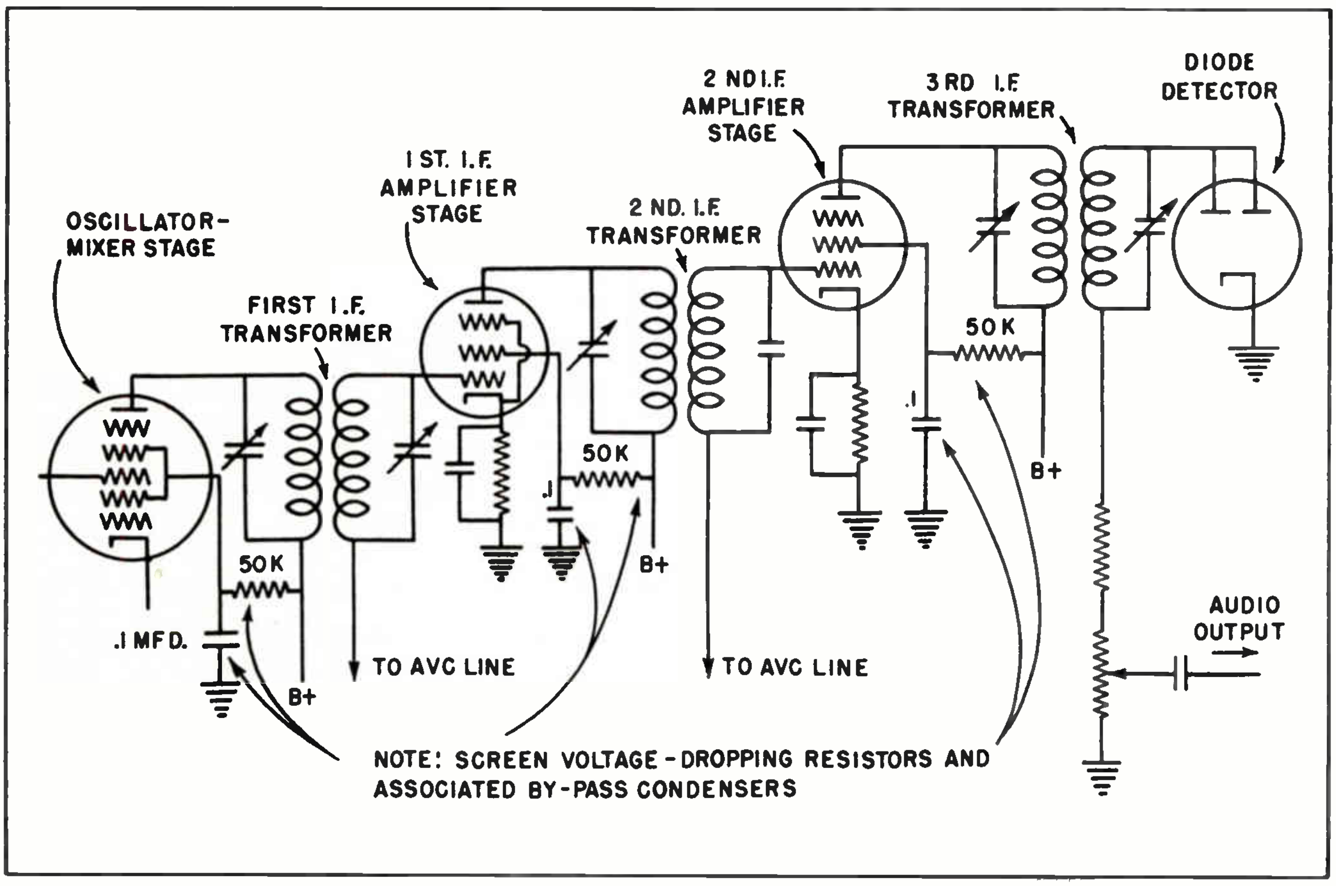

Fig.8. Locations of Screen Dropping Resistors.

The tube manual will tell us that when an amplifier tube in the I-F system of a radio receiver uses high B-plus on the plate, it should not have such high voltage applied to the screen grid. The screen voltage should seldom exceed 100 volts D-C, regardless of what the value is at the plate of the tube. Consequently when a single power supply is used for the entire receiver it becomes necessary to drop some of the B-plus voltage through either a voltage divider or a dropping resistor before applying it to the screen of the I-F tube.

This set of conditions requires another important component, shown in Fig. 8. Since for proper operation of the I-F amplifier stage the screen should be at ground potential insofar as the signal is concerned, a screen by-pass condenser must be installed as shown. During the time that the receiver is in use, of course, this condenser withstands the strain of the applied voltage. Sooner or later, after a long enough time, this condenser may short out. This will bring the screen to zero D-C voltage with respect to ground, and the signal will be lost. At the same time, other effects will be noticeable. The screen resistor will become very hot, and the plates of the rectifier tube will become cherry-red. The value of B-plus will decrease considerably throughout the receiver, and the rectifier cathode will also decrease in its voltage, but not to as great a degree as the rest of the receiver.

If the shorted by-pass condenser at the screen of the I-F tube can be found and corrected in a short time, the trouble can be quickly remedied. But, if either the owner of the set, or the technician, permits the set to operate long enough in this condition, the screen resistor will burn itself open. Notice that the result of both a shorted screen by-pass condenser and an open screen dropping resistor will eliminate B-plus from the screen of the stage involved.

If the resistor is open, replacing the screen by-pass condenser will be only part of the correction, for if the receiver is put back into operation the resistor at this screen will not become hot (since it is open), but the receiver will either bring in no signal at all, or a very quiet one. This is the time to check the resistor, and this may be done by reading the screen voltage. If the screen voltage is absent after the condenser has been replaced, this is sufficient evidence to suspect the resistor of being open. An ohmmeter check will quickly verify this suspicion. Screen dropping resistors are normally between 50,000 and 100,000 ohms in value.

In the A-C and automobile receivers, as indicated in Fig. 8, the extra I-F transformer and tube are to provide additional gain for the receiver, and to enable the I-F stages to be adjusted more accurately for the exact band width for superior tone reception of musical signals. There will be more discussion of this point later.

Section 11. THE PERMEABILITY-TUNED I-F STAGE

In the previous discussion of the typical I-F stage, we have shown the I-F transformers to be capacitively tuned. This means that in varying the resonant frequency of these tuned circuits, we adjust the variable "trimmer" condensers which parallel all of the windings in the input and output transformers of this stage. Fig.9-A shows a capacitively-tuned I-F transformer. The small circular openings, at the top of each transformer shield are for the insertion of the adjusting tool. Usually this is a small screw-driver, well insulated.

Fig. 9-B shows another type of I-F transformer, known as the "permeability-tuned" type. While electrically the same as the capacitively-tuned type, the appearance and construction is different in certain respects.

As the name indicates, the permeability-tuned I-F stage is one in which adjustment of its resonant frequency is made by changing the inductance, rather than the capacitance, of its tuned circuits. That this is electrically sound is exemplified by the formula for resonance in a tuned circuit:

$$f_r = \frac{1}{2\pi\sqrt{LC}} ,$$

where f_r is the resonant frequency, L the inductance in henrys, C the capacity in farads, and π equals 3.1416. This useful formula was derived for you in the lesson on Resonant Circuits.

From an examination of the formula, it can be seen that the resonant frequency of a tuned circuit may be increased by decreasing either the inductance or the capacity. And, in like manner, the frequency of resonance may be decreased by an increase in either the inductance or capacity.

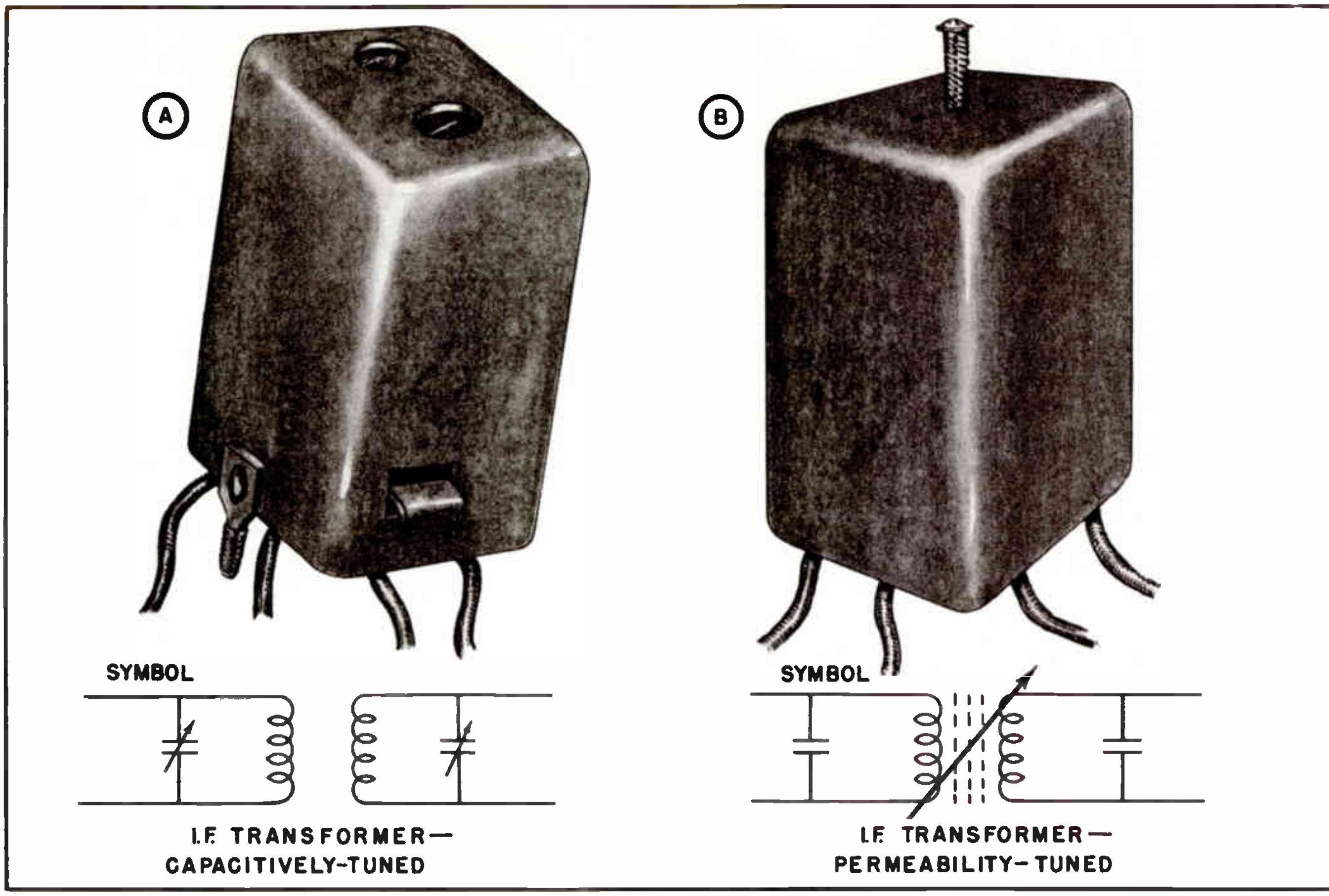

Fig.9. Capacitively-Tuned I-F Transformer and an Inductively-Tuned One.

In capacitively-tuned circuits, the capacity of the trimming condenser is varied. In permeability-tuned circuits, the inductance is varied.

The inductance of a coil can be changed either by varying the number of turns or by varying the nature of the core. Varying the number of turns in the I-F coil is impractical, for the reason that the coil is wound of very thin wire and is completely enclosed in a shield.

Varying the nature of the core, however, is a relatively easy matter. This can be done by turning a threaded tuning slug (made of either powdered iron or brass), into or out of the coil form. If powdered iron is used, (since iron has a permeability greater than air), turning the slug into the coil adds inductance and decreases the frequency. If brass is used (since brass has a permeability less than air), turning the slug into the coil will decrease the inductance and increases the resonant frequency. The opposite effects will be created when the threaded slug is turned out of the coil.

In this way, by small adjustments made with an insulated screw-driver, the resonant frequency of an I-F winding can be brought to a very accurate setting; the pitch of the threaded slug is small enough to produce extremely small increments on a smooth scale in I-F resonant frequency.

While the capacitively-tuned I-F transformers are very popular, radio receiver circuits are tending toward the permeability-tuned types in new equipment. This is especially true of modern FM radio and television receivers.

The use of powdered iron slugs increases inductance by using less wire. Less wire means less resistance. Less resistance means higher "Q". Higher "Q" means better quality and more gain. Television receivers need all the gain possible. Needless to say, when an I-F stage is tuned by permeability tuning, the condensers paralleling the windings are fixed at the proper capacity to provide the necessary range in I-F tuning. In the capacitively-tuned I-F stages the inductance is fixed and the condensers are varied.

Section 12. ALIGNMENT OF THE I-F TUNED CIRCUITS

Misaligned I-F tuned circuits are a very common source of trouble in the superheterodyne receiver. Misalignment ordinarily results from a slow "drift" in I-F resonant frequency due to the trimming capacitors changing their value with time, temperature, or humidity. A drift in the resonant frequency of an I-F tuned circuit will defeat the main purpose of the I-F stage in a receiver. We recall that its purpose is to enable the receiver to supply both a high gain and a high selectivity to the signal. If either of these characteristics is impaired, the receiver will not operate in its best manner.

Misaligned I-F tuned circuits may become evident in a number of ways. Where the misalignment is due to the tuned circuit drifting away from the resonant frequency, the signal will become weak, and the weaker stations in a given locality may not be received at all. Background static, with station reception, will be increased, and the tone quality of the received signal may suffer. Audio distortion, a rare phenomenon due to I-F troubles, may develop.

The drift may also take place in the other direction, that is toward a too-sharply tuned I-F frequency. In this case the signal becomes tinny and high-pitched, and it may be difficult to set the manual station selector exactly on the desired station, especially at the high end of the tuning dial. Howling, whistling and motorboating may also develop.

In both instances of drift, however, the components responsible are with extremely rare exception the I-F trimming condensers which parallel the primary and secondary windings of the I-F transformers.

The problem of misaligned I-F tuned circuits may be approached in several ways, some of which are quite simple, others more elaborate. To save time without sacrificing satisfactory and accurate results, the technician's rule should be to re-align the I-F stages, if they need re-alignment, with the simplest possible procedure.

Before outlining the alignment procedures, however, let us examine a typical normally-operating I-F stage from the point of view of the tuned circuits it contains. Although I-F frequencies of 455, 456, and 465 kilocycles are those commonly used in radio receivers, much higher frequencies are used in television. But for the sake of convenience let us take 456 k.c. as our example.

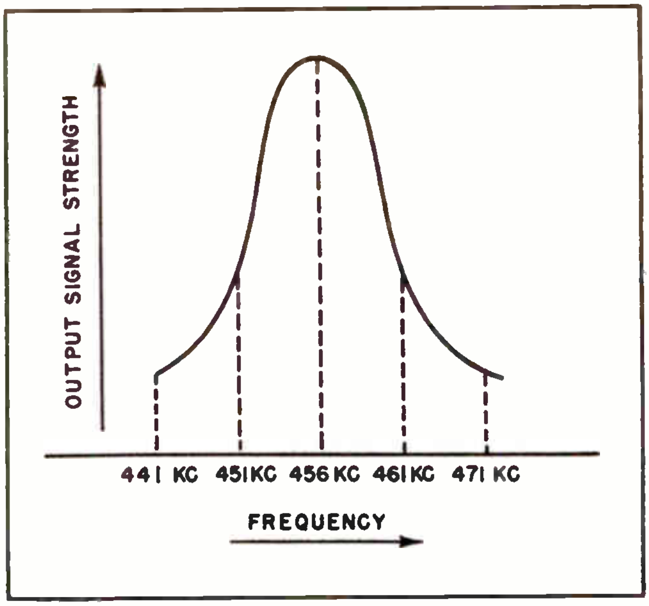

Fig.10. Frequency Response Curve for a Typical I-F Amplifier in an AM Circuit.

Fig. 10 shows the frequency response of a typical I-F amplifier system using a standard I-F frequency of 456 k.c. Here the frequencies below, at, and above the I-F value of 456 k.c. are shown in the relative strength with which they are sent through the I-F amplifier system. Notice that the maximum response is at 456 k.c. and that the strengths at 451 and 461 k.c. are considerably lower. Notice also the general shape of the curve. It is obvious from this figure that there is a decided discrimination against those frequencies which deviate from the 456 k.c. value. But let us be quick to point out that such discrimination at the frequencies near 456 k.c. are not completely blocked out. In fact, even at 5 kilocycles either below or above 456 k.c., an appreciable signal strength is obtained. This is a desirable characteristic, and results from an inherent quality of a tuned circuit employing a coil and condenser.

Section 13. THE "Q" OF A TUNED CIRCUIT

There is a manner of rating a tuned circuit with respect to its efficiency, this rating being indicated by the value of the "Q" of the circuit. As mentioned in an earlier lesson on Resonant Circuits, the "Q" of such a circuit is a figure of merit. It tells us how sharply the circuit will tune to its

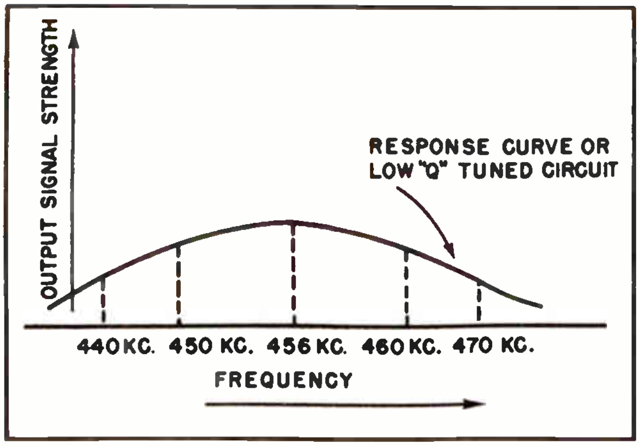

Fig.11. Response Curve of an I-F Amplifier with a Low "Q".

resonant frequency. In numerical value, the "Q" of the tuned circuit is equal to its reactance divided by its resistance, or

$$Q = \frac{X}{R},$$

and since most of the resistance of a tuned circuit is represented by the ohmic resistance of the windings of the coil, we may write:

$$Q = \frac{X_L}{R}$$

In practice, we may interpret this data in the following way: If the Q of a tuned circuit is high, it will tune sharply to its resonant frequency. If the Q is low, it will be resonant, but will not be *sharply* resonant. Fig. 11 shows the response curve of a tuned circuit with a comparatively low Q. While Fig. 12 shows the response curve of a circuit tuned to the same frequency, but possessing a very high Q.

The Q of a tuned circuit, or the sharpness with which it tunes its resonant frequency, is determined primarily by the amount of resistance in the coil winding. If the coil can be wound with comparatively few turns, its ohmic resistance will be low and its Q will increase. But the resonant frequency, as we know, is determined by the number of turns on the coil, and there is a point beyond which we may not go in reducing the number of turns for a given frequency. This problem is partially answered by a special type of wire called "Litz" wire, consisting of perhaps a dozen strands of separately insulated wires twisted together to act as one lead in a high-frequency circuit. The advantage of Litz wire is that at high frequencies its resistance due to the phenomenon of "skin effect" is reduced below that of a single wire lead carrying the same frequency. This resistance, being reduced, raises the Q of the circuit considerably and increases the sharpness with which it tunes a desired frequency, in this case the I-F frequency.

In its selective characteristics, the Litz-wound coil would correspond to the response curve of Fig. 12, while the single-wire coil would offer a response curve such as shown in Fig. 11. It is desirable, of course, to limit the response of a tuned I-F circuit to the I-F frequency. Yet, as we shall soon see, we do not want to sharpen the response too much, for this would result in an impairment of the successful operation of the I-F system of a superheterodyne receiver. As previously mentioned, the introduction of a powdered iron slug within the coil also raises the inductance without increasing the resistance.

The effect of successive stages, all tuned to the same frequency, serves as an aid to selectivity. Fig. 13 shows the frequency response curve of a single I-F transformer containing two tuned circuits (primary and secondary). Fig. 14 shows how another transformer, with both its primary and secondary windings tuned to the same frequency as the first transformer,

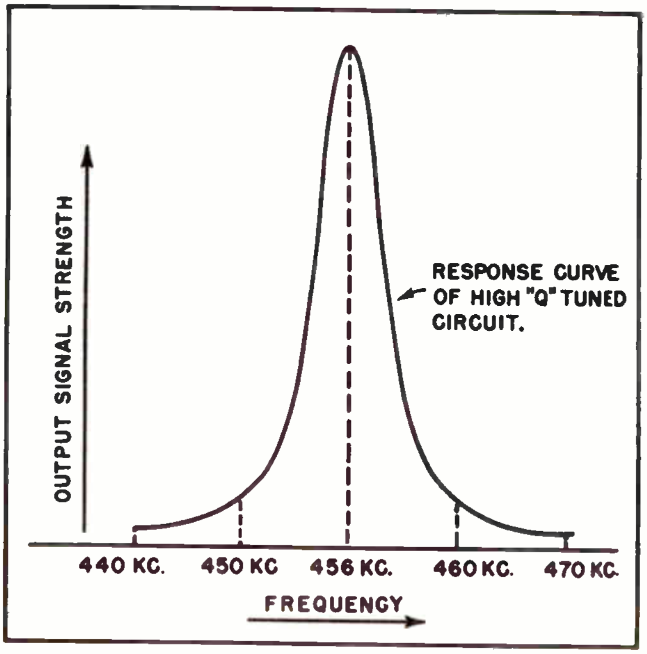

Fig.12. Response Curve of an I-F Amplifier with Very High "Q".

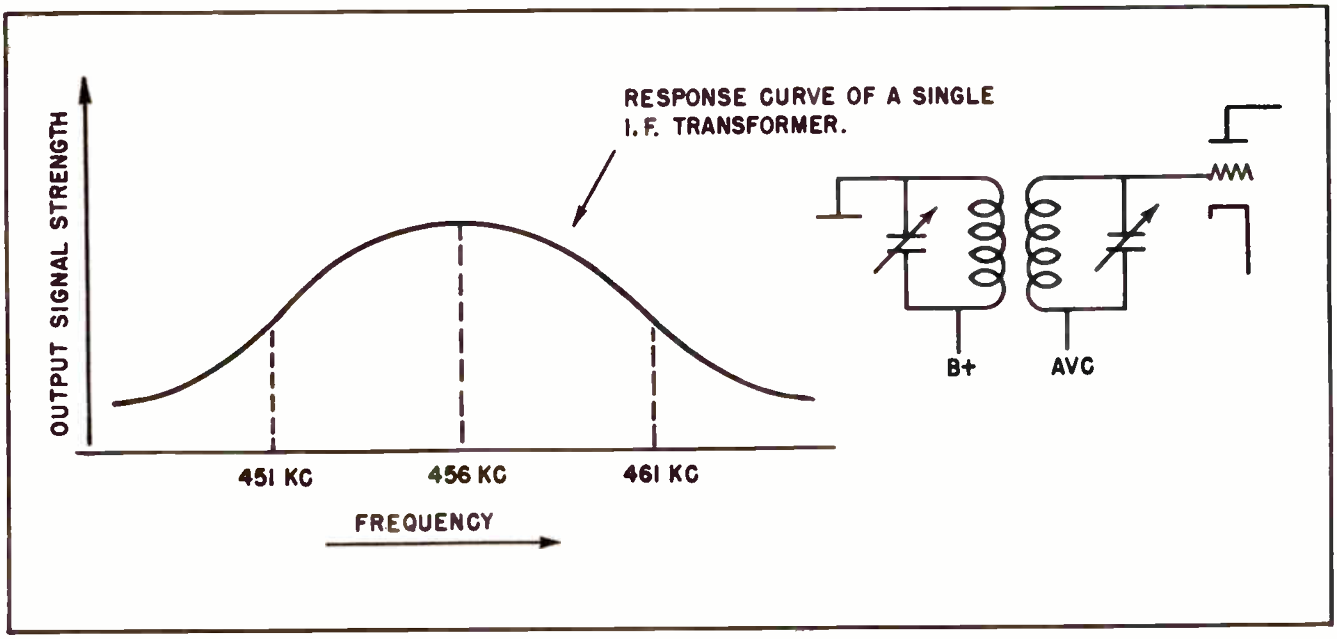

Fig. 13. Response Curve of One Stage of Amplification in an AM Receiver.

will act to narrow down the combined frequency response of both stages. Note that the output of the second I-F transformer (the output I-F) delivers a signal voltage which the diode plates of the second detector can accept in its ideal form -- narrow enough to bar all unwanted frequencies, but wide enough to contain the major part of the audio component.

We may conclude this brief discussion of the "Q" of a tuned circuit by the following summary: Where selectivity is required, the use of Litz-wound I-F coils is desirable. This characteristic narrows down the frequency response of the system sufficiently to bar all undesired frequencies and permit only that band of frequencies at or near the I-F frequency to pass through. The addition of powdered iron slugs also will improve the "Q" of a circuit.

Section 14. I-F BAND WIDTH AND THE AUDIO COMPONENT

In commercially made superheterodyne radio receivers and the audio section of TV receivers the final objective is to effect a faithful reproduction of an audio signal. In order to accomplish this aim, the series of receiver stages must permit all, or most of, the original modulating signal to pass through its circuits without perceptible discrimination. We have already learned that once the signal is converted into pure audio form, as it is in the second detector stage, the problem is simply to amplify it with linear amplifier stages and deliver it to the speaker. But how is faithfulness of reproduction effected in a stage where the audio signal is still a part of the RF or I-F impulses? The following example will serve to illustrate the answer to this important question.

Suppose that at a given instant a radio station is broadcasting its signal with a 1000 cycle note audio modulation. It may be a violin note at this audio frequency. At the same instant, let us suppose our superheterodyne receiver is tuned to this station and is picking up this 1000 cycle audio note. Disregarding for a moment the action which takes place in the RF, oscillator-mixer, and audio stages let us direct our attention to the I-F stage and examine the manner in which the 1000 cycle violin note is being carried through the tuned circuits of this stage.

If the I-F frequency of our receiver is 456 k.c., a 1000 cycle modulation will produce two new frequencies: One consisting of the I-F plus the modulating note (456,000 plus 1000, or 457,000), and the other consisting of the I-F minus the modulating note (456,000 minus 1000, or 455,000). The higher of the two is called the upper side band, and the lower is called the lower side band.

(This condition is brought about by the very nature of amplitude modulation, and a like process takes place in the RF section of the receiver, as well as in the wave transmitted from the broadcasting station). In other words, we may state the rule that in amplitude modulation the frequency of the carrier -- including an I-F carrier -- will deviate by a swing equal to twice that of the modulating signal. In the previous example, the total swing from maximum (457 k.c.) to minimum (455 k.c.) is 2000 cycles, or twice the 1000 cycle modulating note.

You will now understand why the I-F stage of a superheterodyne receiver should not have too sharp a response. For in order to permit the complete audio signal to pass through its tuned circuits, both the upper and lower side bands must be admitted and passed. If either, or both, should be clipped off by a too sharply tuned I-F system, the audio signal, when finally recovered in the second detector stage, will not be complete, but will lack precisely those components which the I-F tuned circuits have rejected.

Such rejection of a portion of the side-band components is not desirable. Two things can cause this situation. The first is too many I-F circuits tuned to exactly the same frequency; the second is too high a "Q" in each of the tuned circuits.

Fortunately, I-F alignment will correct the condition of excessive selectivity. Several alignment "kinks" will be described.

While we have emphasized that the I-F stage of a receiver should be selective, in order to avoid listening to more than one station program at the same time, we are now ready to limit the selectivity so the station being received may be heard with a reasonable amount of faithfulness, or fidelity, so that full enjoyment can be derived from the program. The band width of a superheterodyne I-F circuit is the determining factor. The band width can be defined as the degree of deviation from the median I-F frequency that the I-F system will permit to pass without exorbitant discrimination.

In more simple terms, if the I-F band width is too narrow, the gain and selectivity will be high, but the *tonal* quality of the audio signal will suffer. On the other end of the scale, we may say that if the band width is too broad, the tone of the signal will be excellent, but both the gain and selectivity will suffer. We must obviously strike a happy medium between these extremes. The process of striking this happy medium constitutes the I-F alignment of the receiver.

Section 15. **ALIGNING THE I-F BY EAR**

This is by far the simplest method of correcting for I-F misalignment and can generally be done accurately in a few minutes. This method is suitable for troubles caused by a natural drift of the I-F trimming

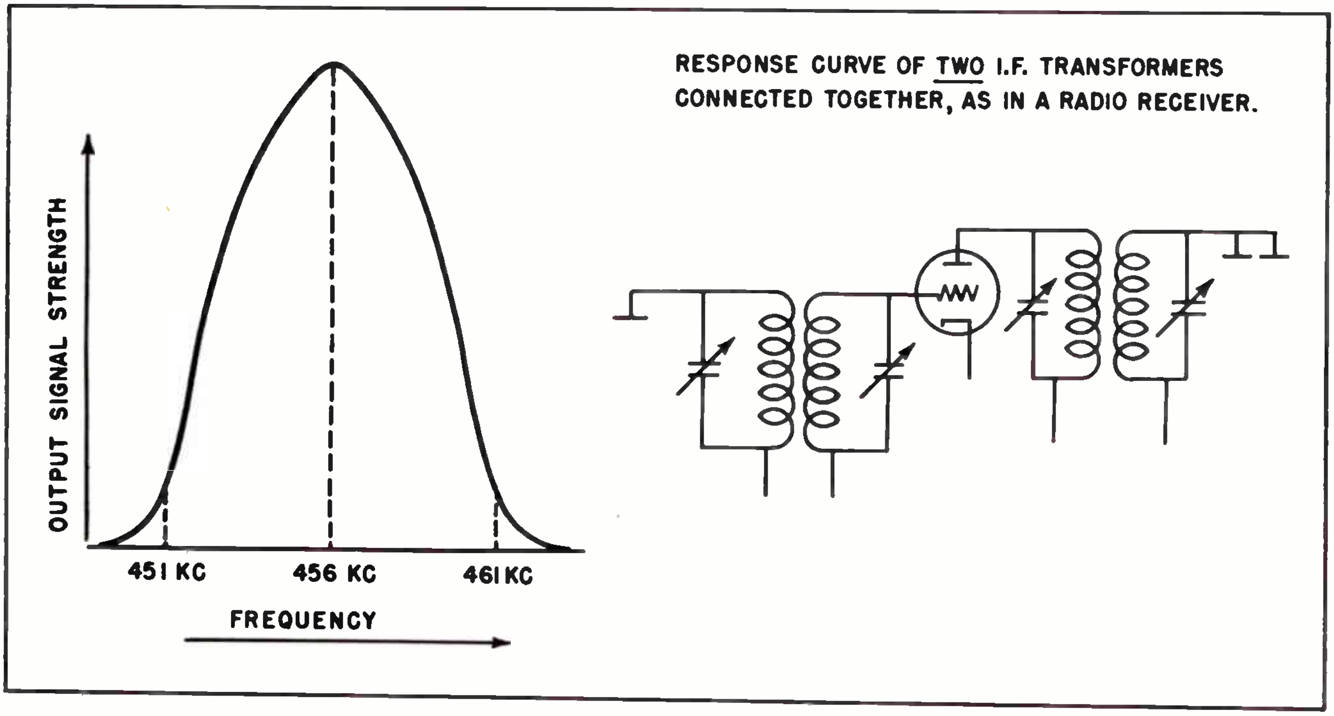

Fig. 14. Response Curve of Two I-F Amplifiers.

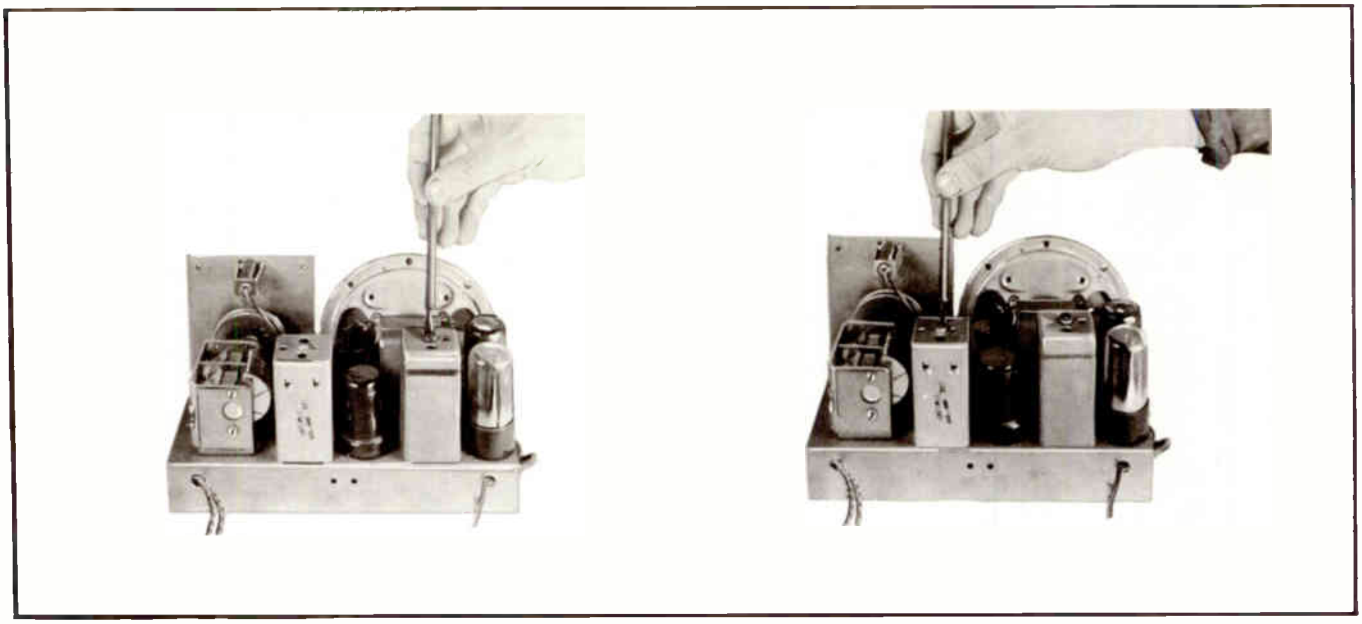

Fig.15. Adjusting, or "Phasing" the I-F. (A) Adjusting the Output; (B) Adjusting the Input.

condensers, but will not be suitable for gross misalignment due to tampering by some well-meaning novice. (See Fig. 15)

Set the receiver tuning dial to a strong local station and apply power with the on-off switch. Advance the manual volume control to a position that will bring the signal through in moderate volume. With a screw-driver (preferably insulated) turn the I-F trimming condensers about an eighth of a turn in both directions, noticing whether the signal becomes louder or more quiet. Starting with the trimmer of the secondary winding of the output transformer, repeat this procedure with the trimmer of the output transformer primary winding. Move the screw-driver to the input transformer, adjusting its secondary trimmer first, and finally adjust the trimmer across the primary of the input I-F transformer. In each case, turn the screw-driver no more than an eighth of a turn, in the direction that will make the signal louder. Now repeat this entire series of four adjustments, again trimming only a small amount, and listening for the loudest signal.

The next step is to re-adjust the manual tuning knob to make sure that the station being received is coming in at its most accurate setting. This is called "rocking".

Notice that these adjustments have been made using the human ear as a standard. If the procedure has been properly done, the I-F stages will be tuned to very nearly the same I-F frequency.

The next step is to adjust the same tuned circuits, but instead of listening for the loudest signal, we shall now listen for the best signal. By "best" signal we mean that which sounds best to the human ear; that is, one with a pleasing degree of tone quality. The tool used is the same -- a screw-driver which is preferably insulated. And we may begin by adjusting the same trimming condensers, and in the same order, as in the previous procedure. In making these adjustments, notice how the tone of the signal changes with only a small degree of adjustment. It may become treble, or bass, or halfway between the two extremes. Do not be afraid to sacrifice loudness for tone quality, although there is no reason to reduce the signal volume unnecessarily by this adjustment. In small receivers, there will be a surprisingly narrow limit where improvement in tone can be made without signal volume dropping too much. In larger receivers, especially those containing three I-F transformers, tone can be changed considerably before an appreciable volume drop takes place. Your judgment is your best ally in making I-F adjustments by ear.

Section 16. ALIGNING THE I-F BY SIGNAL GENERATOR

Alignment of the I-F amplifier may be accomplished in another way, utilizing an audio-modulated signal generator and an output meter. (The output meter is a special A-C voltmeter built to accept a wide range of frequencies.) The connections between the receiver circuits, the signal generator, and the output meter are shown in Fig. 16. Note the protective condensers in the signal generator leads. Also note the shorting wire placed across the AVC condenser to reduce the error due to a varying AVC voltage.

The signal generator is adjusted to produce the I-F frequency of the receiver, modulated by an audio tone, and this artificial test signal is introduced first at point "1" in Fig. 16 while condensers C-4 and C-3 (in the order named) are adjusted for maximum deflection on the output meter. (If the meter is driven off scale, reduce the signal generator output.) Next move the "hot" signal generator lead to point "2" and adjust C-2 and C-1 (in the order named) again for maximum deflection on the output meter. As a final trim-up, with the "hot" signal generator lead still at point "2", repeat the four adjustments in the same order as before, again seeking maximum deflection of the output meter. If this procedure is carefully done, the I-F tuned circuits can be assumed to be in alignment.

However, what about the tone response? This procedure does not provide for optimum tone response, since the output meter simply reads the great value of output signal during the process. To adjust for tone response in this case it is common practice to trim by ear, as described above. That is, once the I-F tuned circuits have been peaked at the correct frequency, the technician readjusts the trimming condensers for the best tone as he listens to the signal. The signal generator, the output meter, and the shorting wire across the AVC condenser are disconnected during the tone adjustments, since these are made while the receiver is receiving a natural broadcast signal--preferably a musical program. This is due to the fact that the human ear can detect distortion or imperfection in a musical signal better than it can in an artificially created sine-wave tone.

Section 17. STAGGERING THE I-F TUNED CIRCUITS

Emphasis has been placed upon the ability of the I-F stage of a receiver to amplify one frequency, the I-F frequency, with maximum efficiency in a specially built amplifier designed for this purpose. The ad-

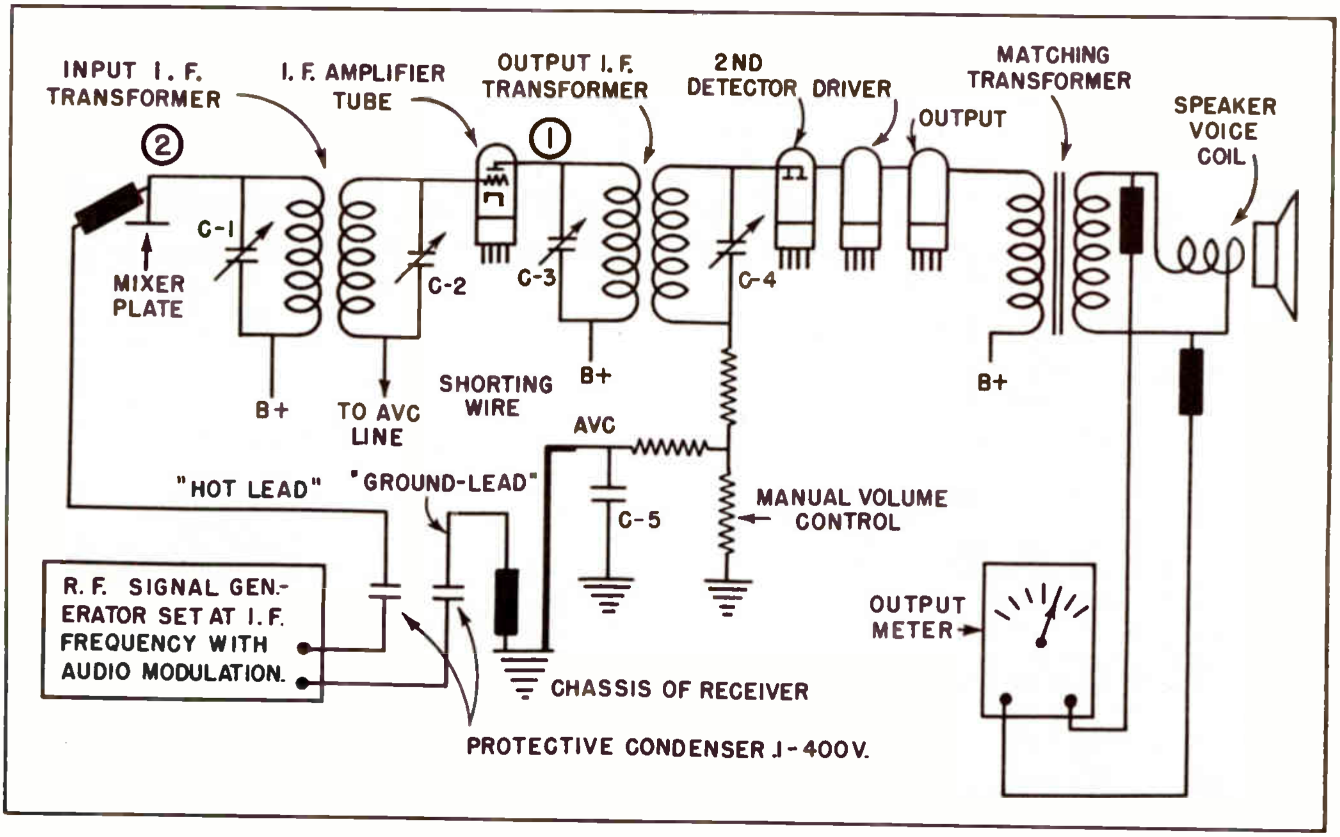

Fig. 16. Using a Signal Generator to Align the I-F of a Superheterodyne.

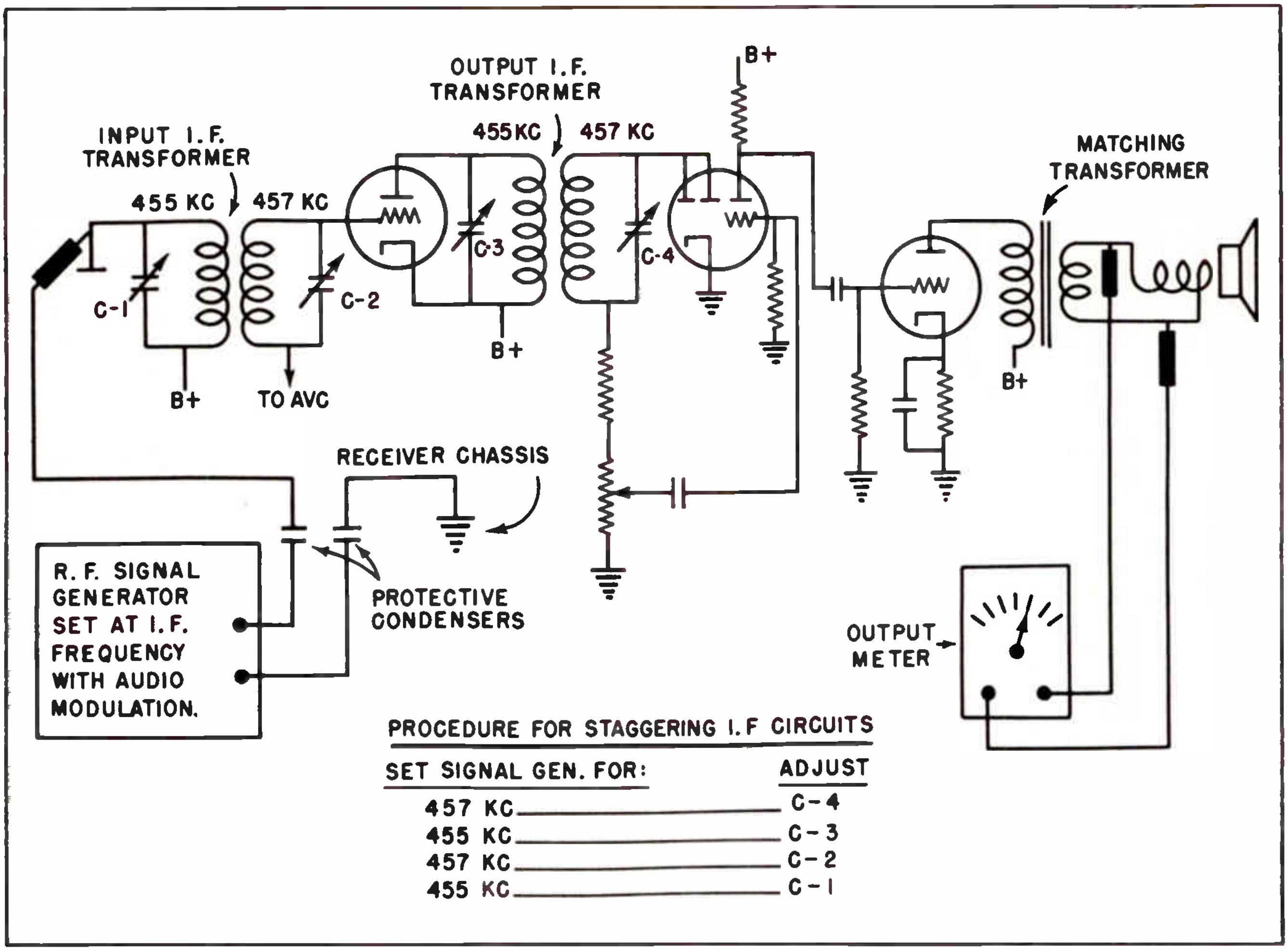

Fig. 17. How a Wider Response Curve can be Attained by Staggering the Resonant Frequencies of the I-F.

vantages to be gained from this ability, as we already know, are sharp selectivity and high signal gain. We have also pointed out that a limitation must be placed upon the sharpness of tuning, since the tone quality of the audio component of the I-F signal depends upon the I-F band width. We have pointed out the use of Litz-wound transformer coils to effect a high "Q" and its consequent sharp tuning, and have hinted that Litz-wound coils are ideal for I-F tuning stages. How, then, can we reconcile the sharp tuning provided by Litz-wound coils with the band width necessary for satisfactory tonal response?

The answer is in the process of "staggering" the resonant I-F tuned circuits in a way which will combine a reasonably high overall sharpness with a reasonably good tone response. "Staggering" the resonant I-F circuits means keeping adjacent circuits slightly detuned from each other. This condition is illustrated in Fig. 17. Note that both the primaries of the I-F transformers are tuned to 455 k.c., and both secondaries to 457 k.c. The response curve of the primaries will be as shown in Fig. 18-A, that of the secondaries as shown in Fig. 18-B, and the overall response of the "staggered" tuned circuits as in Fig. 18-C.

This method of accomplishing staggered I-F tuned circuits uses the signal generator and output meter, and all adjustments are made toward the maximum reading of the latter. This method, therefore, does not depend on the human ear as a judge of quality. However, let us bear in mind that adjusting the I-F circuits for best tone response amounts to the same thing, whether we are using the human ear as a standard or whether we employ the signal generator and output meter to "stagger" the circuits, as just described.

The key to both methods is the same. In the staggering procedure with the signal generator and output meter we purposely widen the I-F band-width and justifiably expect that a wide range of audio frequencies will readily pass through the I-F circuits. In tuning by ear, we adjust for the best tone response, and justifiably expect that the band-width has been widened. We should never lose sight of the important fact that we are aiming at a satisfactory tone response, and extending the band-width is but a means to this end. We do not improve the tone to get a wide band-width -- we are widening the band-width to get a better tone.

An equivalent procedure for aligning the I-F tuned circuits and setting their band-width is given in the lesson on Using the Oscilloscope, a process which you will find highly beneficial if reviewed at this time.

Special alignment procedures, by several methods, are usually included in the manufacturer's data on a given make and model of receiver. When in doubt, you should refer to this information. The most authoritative source of a receiver's I-F frequency is the manufacturer's schematic circuit diagram.

When properly aligned, the I-F band-width should be equal to twice the highest audio frequency desired. If the receiver designer expects his set to pick up audio frequencies at 5,000 cycles, as an example, the I-F band-width of this receiver should be 10,000 cycles; that is, 5,000 cycles either way from the median I-F frequency. There is a legal limit, however, in amplitude-modulated broadcasting, which narrows this width down to lower values. Since, throughout the country, AM transmitters on the regular broadcast band are allotted frequencies differing by 10 kilocycles (10,000 cycles) from each other, their audio components cannot deviate by more than 5000 cycles from their radio frequency, otherwise two stations whose broadcast frequencies are ten k.c. apart may find that the upper side-band of one runs into the lower side band of the other. When picked up by a receiver and converted to I-F frequency, these stations would still interfere with each other, but not to such a great degree in the superheterodyne receiver. This is one of the advantages of the superheterodyne receiver. While our superheterodyne AM receivers often deliver excellent tonal signals, there is a limit to the fidelity of which they are capable.

In F-M, on the other hand, (to be treated in much greater detail later), simply because the transmitting stations are separated from each other by large frequency differences, the F-M receiver can produce a definitely superior tone quality in its signal reproduction. This is especially desirable for musical programs.

When there are three I-F transformers in a large radio receiver, with an additional I-F amplifier tube, the procedures outlined above are simply done in triplicate instead of duplicate. In all cases of I-F alignment, start adjustments at the last I-F tuned circuit, and advance toward the antenna,

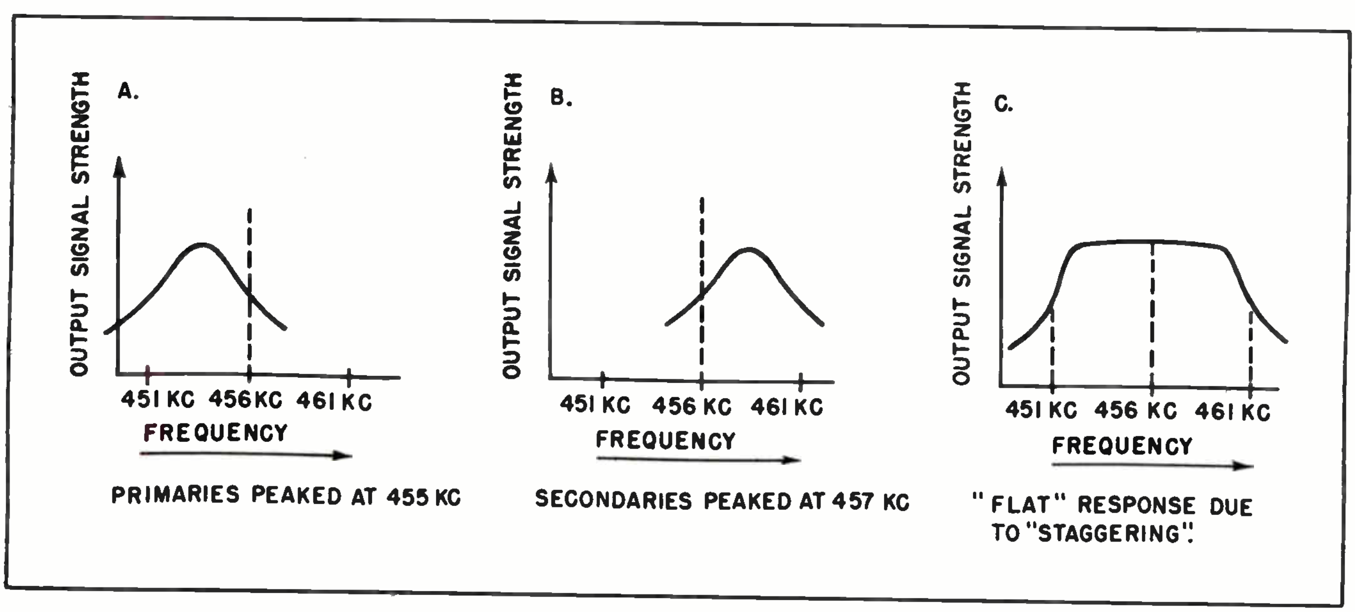

Fig. 18. How Staggered Tuning Creates a Flat Topped Frequency Response Curve.

adjusting each of the tuned I-F circuits on the way. The final I-F adjustment will thus be the primary winding of the input (first) I-F transformer, electrically located in the plate circuit of the oscillator-mixer stage. In this lesson several procedures for I-F alignment have been discussed. It is to be remembered that any I-F alignment is only a part of the general process of aligning the superheterodyne receiver in its entirety, including the oscillator and R-F tuned circuits. Adjusting these stages will be taken up under appropriate separate headings.

NOTES FOR REFERENCE

Shooting trouble in the I-F stage of a receiver pre-supposes that the audio section and the second detector have been tested and found to be in good working order.

Several methods of locating trouble in the I-F stage of a receiver may be used. They include tests with a signal generator, a signal tracer, an output meter.

Once the trouble is localized in the I-F stage, detailed measurements with ohmmeter and voltmeter are applied to locate the exact component responsible for the receiver's failure.

The I-F alignment procedures outlined in this lesson may be applied simply to align, or "phase" the tuned circuits, or they may be used to trouble-shoot the receiver, localizing the trouble in a certain stage.

When the receiver suffers from "motor-boating", trim-up the I-F tuned circuits by ear before engaging in any complicated tests or repairs. If I-F stages are too sharply adjusted, they may cause motor-boating.

Where cross-talk (two stations at the same time) occurs, and is not corrected by adjusting the I-F tuned circuits, look for:

1. Image frequency. Rotate the receiver or its loop antenna to minimize this interfering effect.

2. I-F stages too sharply tuned and picking up a local and a distant station on the same frequency. Correction is to detune the I-F trimmers until the cross-talk disappears. Make only small changes while doing this.

3. Oscillator not properly adjusted.

If the receiver produces no signal, but static is present in some degree when the manual volume control is advanced to maximum, make a detailed check of the I-F circuits.

NOTES

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THE MIXER STAGE

Contents: Introduction - Other Names for the Mixer Stage - The Need for a Mixer Stage - Heterodyning - The Mixing Action - Broadcast Receiver Converters - Type 6SA7 Mixer-Tube - Heptode and Hexode Converters - Trouble-Shooting the Mixer Stage - Functions of the Components - Checking the Oscillator-Mixer Tube - Alignment of the Oscillator-Mixer - The Oscillator Padder - Image Frequencies - What Causes Image Frequencies in the Superhet? - Condenser Calculations - Notes for Reference.

Section 1. INTRODUCTION

The function of the mixer stage in a superheterodyne radio receiver is to convert an audio-modulated radio frequency signal into an audio-modulated intermediate frequency signal. In a sense, the mixer stage can be compared to an old-time relay station where a pony-express messenger changes from an exhausted horse to a fresh one in order to complete his mission. The radio frequency carrier, which brings the audio signal from the transmitter to the receiver with the speed of light, gives up its burden (the audio signal) to a fresh new carrier -- the intermediate frequency. The I-F frequency, now saddled with the audio signal, completes the trip to the second detector stage by a path best suited to its peculiarities -- the I-F stage.

The comparison given above is, of course, somewhat strained. Nevertheless, it offers a graphic illustration of the purpose of the mixer stage in a superheterodyne radio receiver. The tired horse is the R-F carrier; the fresh horse is the I-F carrier; the audio modulation is the rider and his message; the mixer stage is the relay station, where the transfer takes place. It is the purpose of this lesson to discuss the methods employed to accomplish this transfer.

Section 2. OTHER NAMES FOR THE MIXER STAGE

Various names have been used to describe the mixer stage, most of them are reasonably descriptive in that they give a hint as to the function or operation of the stage. The name "converter" indicates that a process of conversion takes place in this stage. The term "first detector" (while not too descriptive) at least tells us that we should also expect to find a second detector in the receiver. The name "oscillator-mixer" suggests that this stage combines two separate functions, mixing and oscillating. The application of all these names (mixer, first detector, converter, and oscillator-mixer) to describe the same stage

Fig.1. Every Superheterodyne Receiver, Whether Radio or Television, Employs A Mixer Stage.

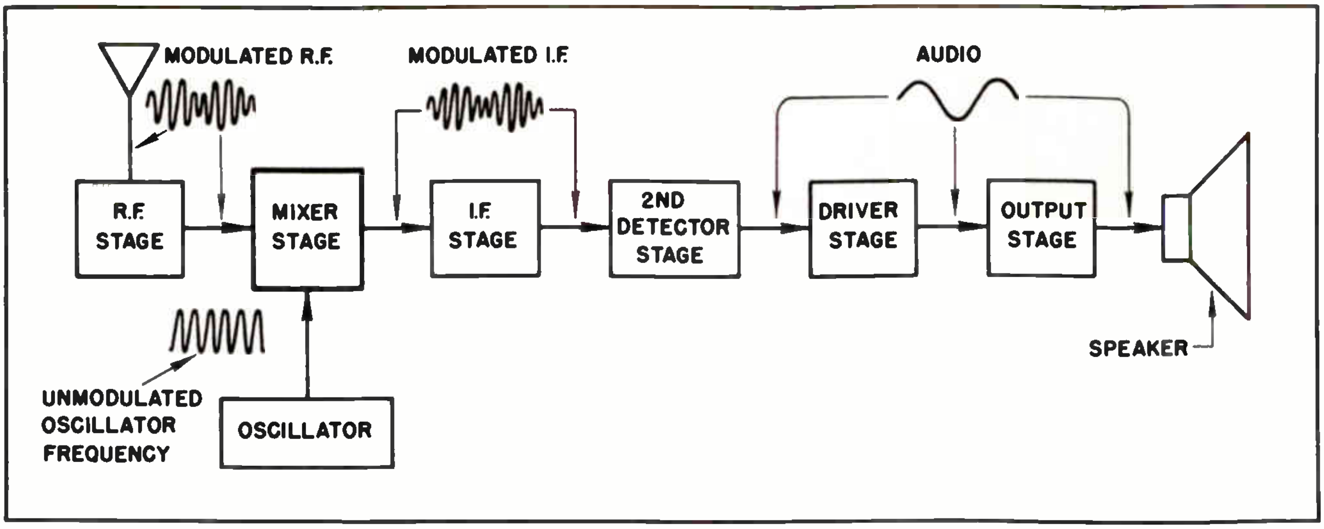


Fig. 2. Block Diagram of a Superheterodyne Receiver for Receiving Only Sound.

in a radio receiver may seem somewhat confusing. The numerous terms have resulted from the interplay of terminology used between radio engineers and designers on the one hand, and by practical radio and television technicians on the other.

For the sake of brevity, we shall use the term mixer here to represent the stage where the R-F carrier is converted into the I-F carrier. As this name suggests, the conversion process is accomplished by mixing two frequencies together and then selecting their difference as the I-F carrier.

Section 3. THE NEED FOR A MIXER STAGE

The need for the mixer stage of a radio receiver springs from the requirements of the I-F stage. As we already have learned, the high gain and selectivity of the components comprising the I-F amplifier system require that it be fed a signal whose frequency does not vary. This signal frequency must remain constant regardless of which transmitting station is tuned in by the receiver. The mixer stage supplies this constant frequency -- the I-F frequency -- and the I-F stage is built especially to accept and amplify this frequency.

Fig. 2 is a block diagram of the modern superheterodyne receiver, emphasizing the mixer stage and showing its relationship to the rest of the receiver. The wave-forms into and out of each stage are indicated.

As the block diagram of Fig. 2 shows, there are four significant frequencies involved in the mixer stage of a radio receiver designed to receive only sound. These four frequencies have been mentioned previously, but for the sake of clarity we will describe them again:

(1) The R-F frequency, carrying the audio signal from the transmitter in the form of amplitude modulation.

(2) The oscillator frequency, an unmodulated locally-generated frequency.

(3) The I-F frequency which is the numerical difference between the R-F and oscillator frequencies; it is also modulated.

(4) The audio frequency, the clear and loud reproduction of which is the ultimate aim of the receiving equipment.

Let us examine these four significant frequencies as they are introduced into the receiver circuits.

First we meet the R-F frequency which arrives at the receiving antenna bearing its audio signal from the transmitting station.

The local oscillator frequency "collides" with the R-F frequency in the mixer stage.

The result of this "collision" is a new product -- the I-F frequency, which has assumed a value equivalent to the difference between the R-F and oscillator frequencies, and has taken on the audio modulation borne through space by the R-F carrier.

After tuning and amplification in the I-F stages, the I-F frequency is fed to the second detector, where its modulation is extracted. The resulting frequency is the audio signal. This is then fed through audio amplifiers to the loud-speaker, where the electrical impulses are transformed into sound energy.

Section 4. HETERODYNING

This radio and television term is derived from Greek roots meaning unlike (hetero), and power (dyne). Thus heterodyning means mixing two powers together which are unlike each other. This is essentially what happens in the mixer stage. The power of one frequency (the R-F) is mixed with the power of a different frequency (the oscillator). Their union in the mixer stage is blessed with an offspring which does not directly inherit its parents' traits, but inherits the difference between the parent frequencies.

Let us take a typical example. When we tune in a station at 1,000 k.c. on the receiver dial, we are introducing a transmitted signal at this frequency into the mixer stage. At the same time, because the local oscillator is tuned by the same control which tunes the R-F, the oscillator frequency will be 1456 k.c. This, too, is directed into the mixer stage. The two frequencies, beating together, produce their difference, 456 k.c. This is the resultant I-F frequency of the receiver.

Let us take another typical example. If we select a radio station at 600 k.c. on the receiver dial, we are introducing a transmitted signal at this frequency into the mixer stage. Because the condenser that tunes the R-F signal is mechanically attached to that which tunes the oscillator, the oscillator will produce a frequency of 1056 k.c. and feed it to the mixer stage. Here again the two frequencies beat together to form their difference, an I-F frequency of 456 k.c.

Taking a final example at the high end of the tuning dial, if we tune in a transmitting station at 1500 k.c., we automatically set the oscillator to produce a frequency of 1956 k.c. Again these two frequencies meet in the mixer stage, beating together to produce the 456 k.c. I-F difference.

It is evident that wherever we set the R-F tuning condenser, the oscillator tuning condenser will resonate the oscillator tuning circuit at a frequency 456 k.c. above that of the received signal. Their difference is constant at this value. Thus an arrangement of this type fulfills the first requisite of the I-F amplifier system -- it will favor a 456 k.c. I-F signal with high gain and sharp selectivity, and will reject all other frequencies.

As has been previously mentioned, the value of 456 k.c. for the I-F is one of several possible frequencies. Values of 455 k.c., 465 k.c., and 456 k.c. are all about equally popular. In many of the older automobile receivers, a value of 175 k.c. was used as the I-F. Actually, the exact choice of the I-F value is the option of the manufacturer. He designs his equipment with low cost, high quality, and maximum efficiency in mind.

In any case, the value of the I-F frequency in a given radio or television receiver will determine by how much the R-F and oscillator frequencies will differ, for this difference must equal the resonant frequency of the I-F amplifier system.

In our discussion of the mixer stage we will use a radio receiver as an example of the operation of this stage. Essentially there is no material difference between the operation of the mixer stage in a radio sound receiver and that in a television receiver. The reason we choose to describe the operation of the sound receiver is that it operates at much lower frequencies than the television receiver. Since we are working with lower frequencies it is much easier to understand and comprehend the operation of a sound receiver than a television receiver. Once the operation of the sound receiver is thoroughly understood, it becomes a simple matter to apply the same principles of operation to the higher television frequencies.

Fig. 3 is a block diagram showing the layout of the various parts in a television receiver. Note that the video portion of the received signal is separated from the sound portion of the signal at the output of the mixer stage. This is a common practice in many television receivers.

You might also note there is an I-F stage and a detector stage in the video channel. These stages are identical in every respect to those you have been studying, with the single exception that they are designed to pass higher frequencies. The video channel of television is amplitude modulated.

Now notice the audio channel in Fig. 3. Here you will see a new stage which we

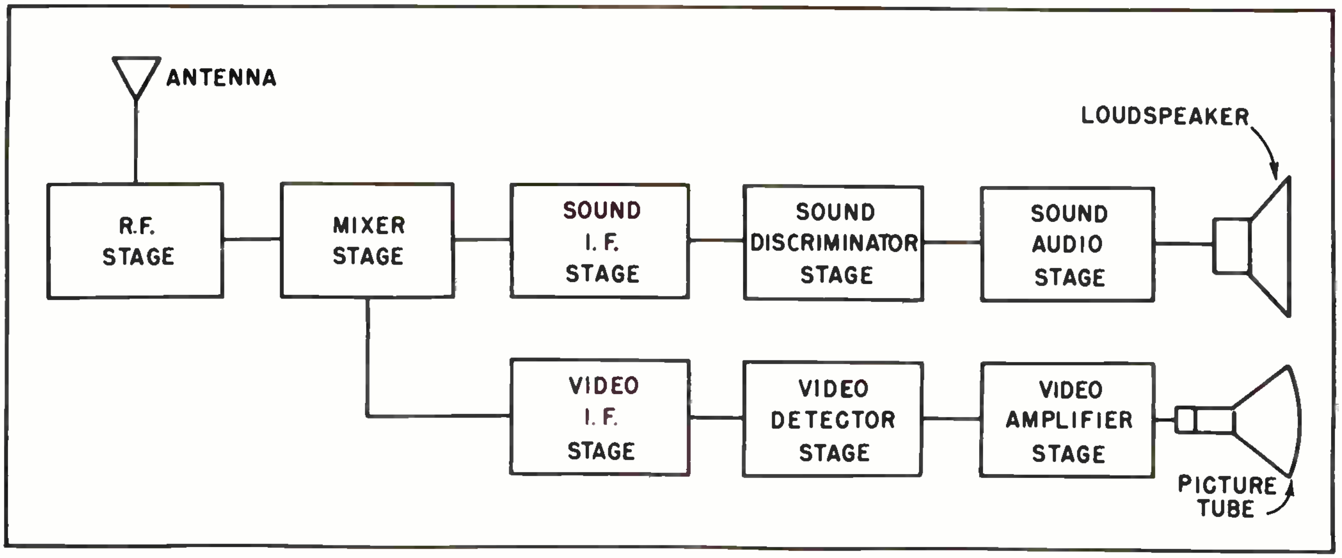


Fig.3. Block Diagram of a Television Receiver.

have not yet studied. That is the discriminator stage.

The sound portion of a television signal is *frequency modulated* instead of being amplitude modulated. We have not yet had a chance to study frequency modulation, but we can tell you at this time that the discriminator stage in a frequency modulated receiver performs a similar function to that of the detector in an amplitude modulated receiver.

While the block diagram of Fig. 3 is representative of many television receivers it is not representative of all such receivers. You will note that in Fig. 3 there is a separate I-F channel for the sound and another for the video. Since the intermediate frequency is quite high, it is necessary to have more stages of amplification than when the intermediate frequency is low. This means that when we use two distinct I-F channels for the video and the sound, we must use from eight to ten I-F transformers, four or more for each channel.

It is possible to use the same I-F stages to amplify both the video and the sound. Where this system is used, there are fewer I-F transformers. Then instead of the video and the audio being separated at the mixer stage, the two signals are separated at the final I-F stage as is indicated in the block diagram of Fig. 4.

Not all television receivers use video amplifiers after the detector stage. Each

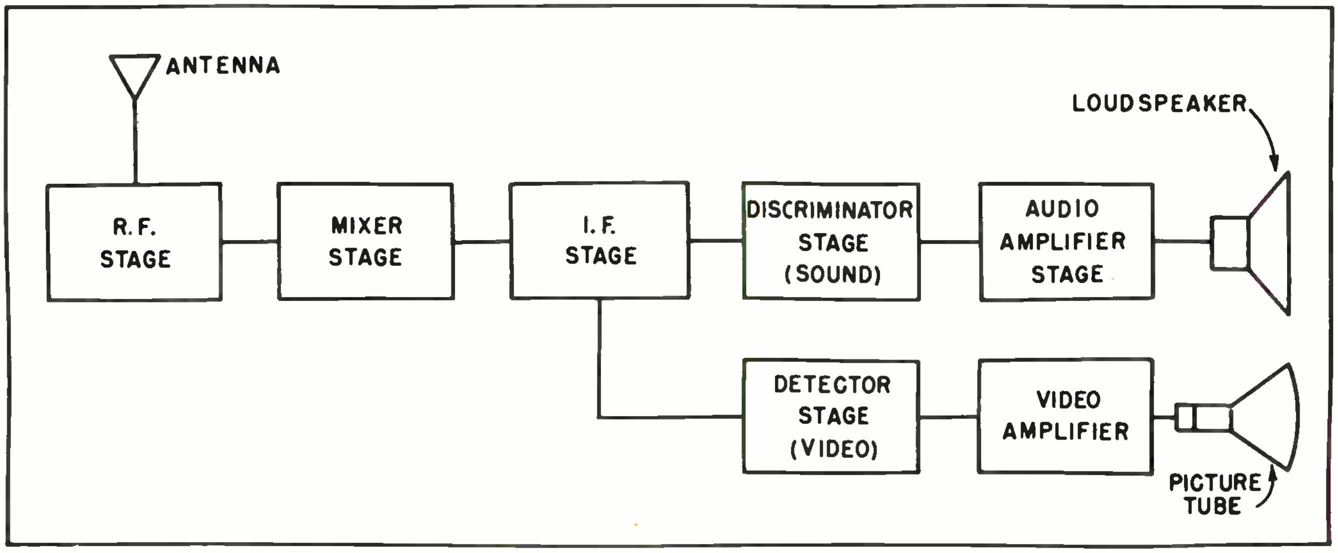


Fig.4. Block Diagram of a Television Receiver Using a Single I-F Channel.

designer and each manufacturer has his own ideas regarding the exact details of operation.

Section 5. THE MIXING ACTION

Fig. 5 is a schematic diagram of a mixer stage and a separate oscillator in a radio receiver. It will serve to illustrate the fundamental electrical method of heterodyning two frequencies in this stage to produce their difference frequency.

The mixer tube is a 6L7 and is known as a pentagrid tube (five grids). The oscillator

The R-F signal brought in by the antenna, is fed through the primary winding *(L-1)* of the antenna transformer which is magnetically coupled to the secondary, *L-2*, and there resonated by condenser *C-2*. This circuit acts to separate the desired R-F signal from all other signals which are striking the antenna.

The selected frequency appears as a voltage across the R-F tuned circuit, between the first grid of the 6L7 and its cathode. (In the pentagrid tube, grids are numbered in the order of their proximity to the cathode.) This introduces the R-F

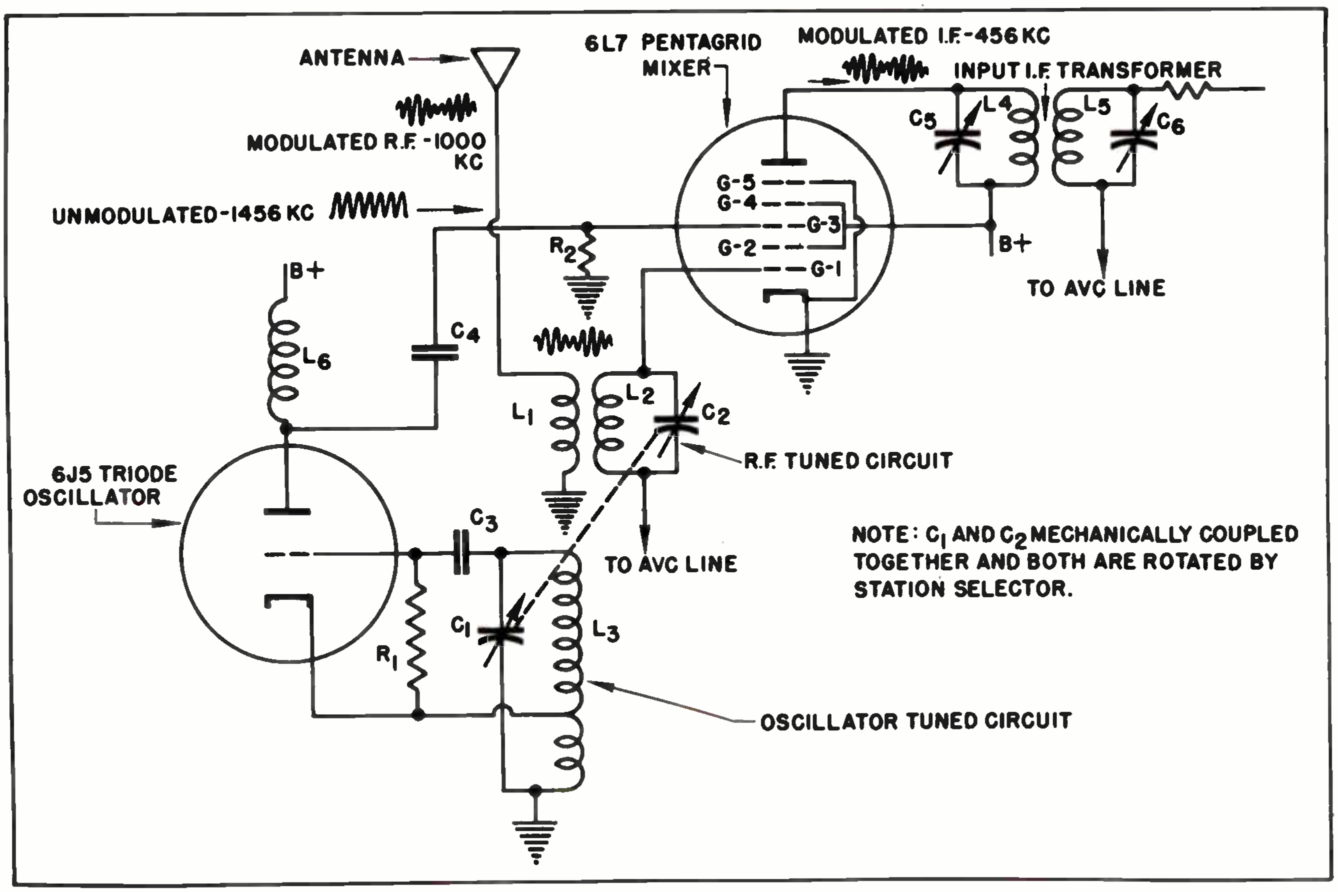


Fig. 5. A Pentagrid Mixer Stage Using a Separate Oscillator Tube.

is a separate tube, a triode employing a Hartley series resonant circuit. The frequencies indicated in Fig. 5 are those for a typical setting of the radio receiver tuning dial at 1000 k.c.

Notice that the variable tuning condenser of the R-F resonant circuit is mechanically coupled to that of the oscillator resonant circuit, so that any amount of rotation of one condenser will automatically effect an equal change in the other.

signal with its audio modulation, into the mixer stage.

At the same time, the Hartley series oscillator, the 6J5 tube and its associated circuit, is producing an output signal frequency which is unmodulated, but whose frequency is determined by the setting of variable condenser *C-1*. We already know that the position of *C-1* is in turn determined by the position of *C-2*, with which it is mechanically coupled. The oscillator output is coupled through capacitor *C-4* to the third grid of the 6L7 mixer. This introduces the unmodulated oscillator frequency into the mixer tube.

Let us now examine each of the five grids of the mixer stage and see what conditions prevail, so that we may more readily understand the action which must follow.

FIRST GRID. R-F signal, modulated by audio component. Biased by the AVC line. Tube has remote cut-off characteristics.

SECOND GRID. No signal voltage, but a steady B-plus potential. Its purpose is to screen *G-3* from *G-1*.

THIRD GRID. Unmodulated oscillator voltage. Bias is achieved across resistor *R-2* and has sharp cut-off characteristics.

FOURTH GRID. Connected directly to *G-2*, contains no signal voltage, but a steady B-plus potential. Its purpose is to screen *G-3* from the mixer plate.

FIFTH GRID. Internally connected to the cathode. Acts as the suppressor grid to minimize secondary anode emission.

Let us now follow the electron stream as it leaves the cathode and flows to the plate. The first influence it meets is the R-F signal at the first grid. The electron stream will now flow and cease to flow (that is, it will pulse) at a rate equal to the radio frequency on this grid.

Grid *2* possesses a constant B-plus potential and since this grid is a wire mesh consisting mostly of empty space, it will serve to accelerate the flow of current in accordance with the R-F pulses.

Grid *3* contains a potential which changes in accordance with the oscillator frequency. By itself, grid *3* would cause the current to pulse at the oscillator frequency rate. However, we know that the current has already been made to pulse at an R-F rate by grid *1*. Grid *3*, then, influences the electron stream with pulses at the oscillator frequency only after grid *1* has influenced it with pulses at the radio frequency.

Neither grid *4* or grid *5* (neither of which possess any changing voltage) affect the frequency of the tube current pulses, but simply act to increase the total amount of plate current flowing through the stage.

The interlacing of the pulses caused by grids *1* and *3* bring about some interesting results. The most important is brought about by the fact that the mixer stage is *non-linear* and is biased as a Class-B amplifier. (Its operating bias is near the lower, non-linear, knee of the tubes characteristic curve.)

The current pulses through the mixer stage, and therefore through the primary of the input I-F transformer, could assume several different values. One value is that of the R-F itself. Another is the oscillator frequency. A third is the sum of the R-F and the oscillator frequencies. The fourth is the difference between the R-F and oscillator values. Inside of the tube, within the electron stream, all four of these frequencies are conceived. However, since the plate load of the mixer stage is a resonant circuit, tuned to the I-F frequency, only the difference between the R-F and oscillator values can actually pass successfully through this tuned circuit toward B-plus. In other words, while all four of these frequencies are conceived and are potentially present in the mixer tube, only the difference frequency is ever taken into account in the functioning of the stage.

It is interesting to note that if we desired, we could tune the mixer plate load to the sum frequency. The sum frequency would then pass successfully to the following I-F stage, and all the others would be suppressed. However, there is an advantage to the selection of the difference frequency to act as the I-F. This will later be explained in connection with image frequencies.

In the meantime, what has happened to the audio modulation riding on the R-F carrier? The audio modulation is now found to be riding on the I-F carrier.

Even though the I-F carrier frequency is equal to the difference between the oscillator frequency and the R-F frequency, it still continues to carry the audio modulation of the latter. Understanding this point is of prime importance.

Section 6. BROADCAST RECEIVER CONVERTERS

Mixer stages found in communications receivers and other types of multi-band equipment, due to their need to handle signals at frequencies considerably higher than the ordinary broadcast band, are usually

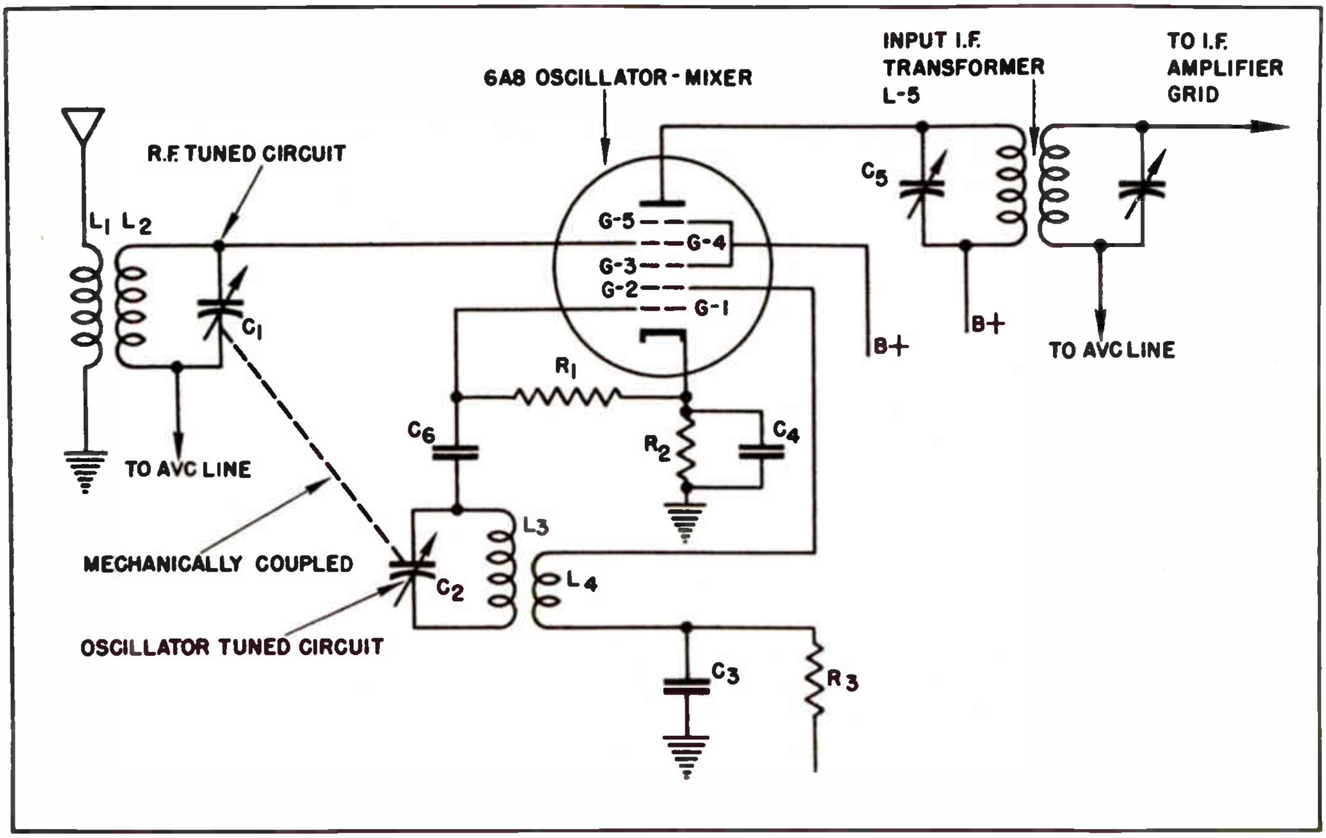


Fig. 6. Mixing and Oscillator Functions Combined Within a Single Tube. -- The 6A8.

of the type explained above and illustrated in Fig. 5. In ordinary broadcast receivers, including those with only one or two short-wave channels, a more compact type of mixer is used. This is known as the oscillator-mixer, or converter, stage.

Here a pentagrid (five-grid) tube is employed. But in addition to acting as the mixer stage, it combines the function of an oscillator tube as well. A fundamental schematic diagram is shown in Fig. 6 representing a typical modern oscillator-mixer stage. The tube used is a double-ended 6A8 (with the signal grid at the top cap) designed to work into an R-F tuning circuit and an Armstrong oscillator. Because the heterodyning process takes place within the electron stream of this tube, the system is also known as an electron-coupled oscillator-mixer. In everyday use by radio and television men, this term is conveniently shortened to "E.C.O."

The oscillator section of the stage consists of the cathode and the first two grids, *G-1* being the oscillator signal grid and *G-2* the oscillator anode. Notice that the latter is connected to a high positive potential. If we were to remove these three elements and place them in a circuit by themselves, they would still operate as an oscillator. However, their location is such that any electrons arriving at the plate of the tube must first pass through the oscillator elements. In fact, we may look upon these three elements as a composite, or virtual, cathode whose emission is interrupted at the oscillator frequency. Regardless of what else may occur to the current in its drive toward the plate, it will be pulsing at the oscillator rate.

What else can happen to this current before it reaches the plate? Grids *3* and *5* hold a positive and unvarying voltage. They will serve simply to accelerate the flow of electrons through the tube without affecting their frequency. Grid *4*, however, is carrying a voltage which changes in accordance with the R-F signal led down from the receiving antenna. The electron stream, already pulsing at oscillator rate, will now also pulse at the R-F rate.

Since this stage is operating on a non-linear portion of its characteristic curve, the results will be about as you would probably expect. There will be four frequencies present in the pulses of the electron stream, corresponding to (1) the oscillator frequency, (2) the R-F frequency, (3) the sum of the oscillator and R-F, and (4), the difference between them.

The plate load, which is the tuned circuit of *L-5* and *C-5*, will accept only one of the four, which we already know to be the difference between the oscillator and the R-F values. This difference then becomes the I-F value of the receiver. As we already know, all of the I-F tuned circuits are pre-adjusted to this resonant frequency, so that of the four frequencies conceived in the oscillator-mixer stage, only the difference will be able to find its way through the I-F stages to the second detector.

As in the case of separate oscillator and mixer stages, (Fig. 5) the audio modulation riding on the R-F carrier has now been transferred to the I-F carrier. Demodulation in the second detector stage will recover the audio signal which originated at the broadcasting studio. This signal will then be amplified in the audio section and converted into sound energy by the loud-speaker.

This system of oscillating and mixing in the same stage has had wide application. However, it contains certain limitations which have been mentioned before, but deserve to be brought to your attention again.

The first disadvantage of this oscillator-mixer, employing a 6A8 tube, is that it becomes unstable at the higher frequencies. In communications receivers, as well as in commercial models designed for foreign reception, this is a distinct limitation. For this reason, receivers built to bring in foreign or amateur stations in the 6 to 18 megacycle band, will employ a separate oscillator stage, similar to that shown in Fig. 5.

Another disadvantage of the 6A8 type of oscillator-mixer is that the AVC voltage, acting upon the R-F signal grid, may affect the oscillator output. While the variations in frequency are not too wide, the variations in oscillator amplitude may be considerable. This is because a changing AVC voltage will affect the space charge around the signal grid. The oscillator section transconductance, as well as the input capacity of the oscillator grid, are dependent upon the stability of the space charge within the tube.

It should be remembered that there are literally millions of receivers in use today which use the 6A8 oscillator-mixer tube or its equivalent. This is proof of the fact that while the limitations mentioned are present, this type of oscillator-mixer tube has proven highly acceptable.

Section 7. TYPE 6SA7 MIXER-TUBE

Fig. 7 indicates how the limitations due to variable trans-conductance and oscillator grid input capacity in the 6A8 tube are overcome by the use of the single-ended 6SA7 type tube. The chief differences between the 6SA7 type tube and the 6A8 type may be observed by comparing Figs. 6 and 7.

While the 6A8 has a separate oscillator anode *(G-2)*, the oscillator anode of the 6SA7 is internally connected to *G-4*. This change places *G-3* in the 6SA7 between two grids which carry high positive potentials. It is evident that any D-C field due to AVC voltage around the R-F signal grid (*G-3* of the 6SA7) will be cancelled out by the proper spacing of *G-2, G-3,* and *G-4* with relation to each other. Further, the transconductance of the oscillator section of the tube has been found to be less variable when a double anode, as in the 6SA7, is used, rather than with the single anode employed in the 6A8 tube.

In addition, the input capacity of the oscillator grid is found to be less affected by the arrangement within the 6SA7. The 6A8 tube does not contain an element corresponding to the suppressor grid of a pentode, in order to minimize secondary emission from the plate. The 6SA7 contains this element, *G-5* in Fig. 7. It is internally connected to the cathode of the tube.

Notice also that the 6SA7 contains no minimum bias, since its cathode is connected directly to ground (with respect to D-C) through the center-tapped Hartley Series oscillator coil. This permits G-3, the R-F signal grid, to receive its total bias from the AVC line. Then the oscillator grid is biased by the drop across *R-1*, its grid leak resistor.

So far we have examined three types of oscillator-mixer circuits. We have found that while the 6A8 type oscillator-mixer employs but one tube for the mixing and oscillating functions, its instability at high frequencies and its variable output even within the range of the broadcast band

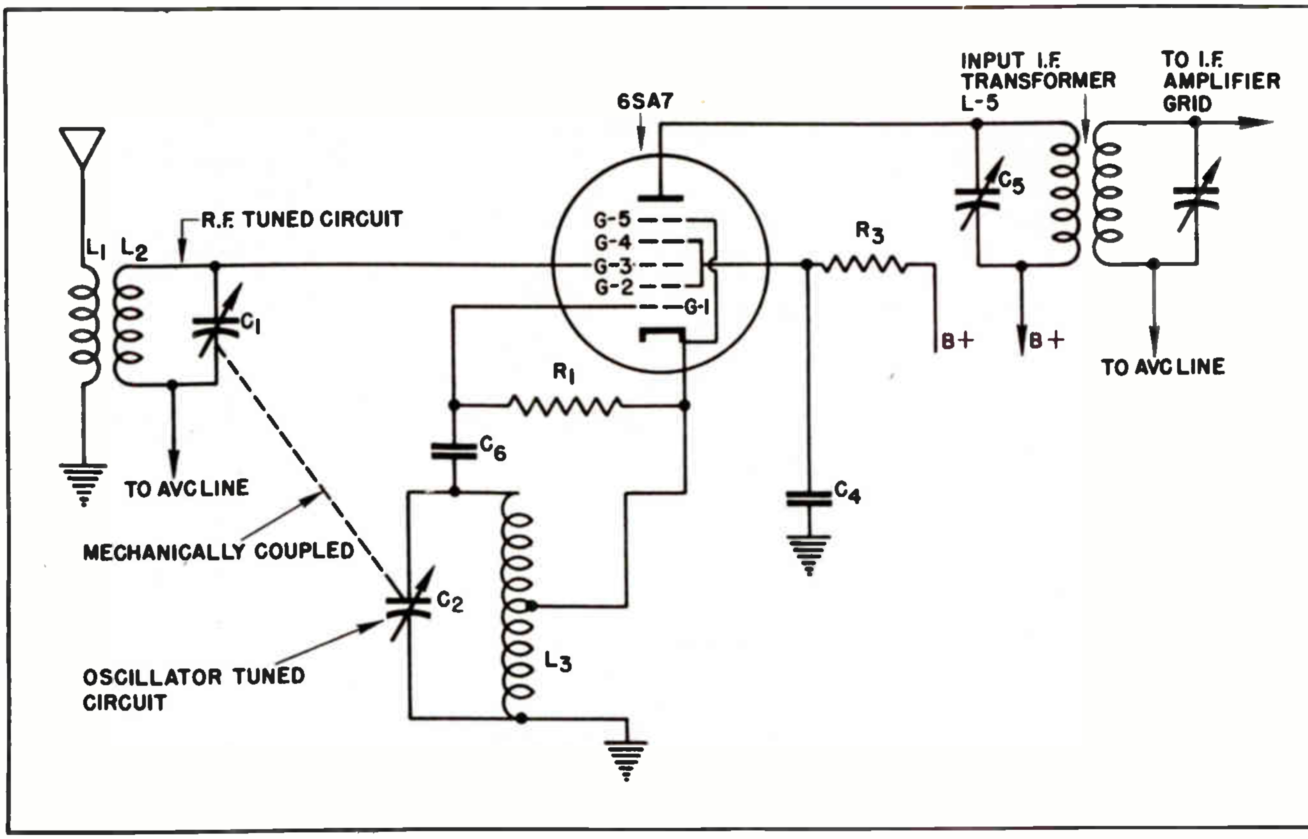


Fig. 7. Mixer-Oscillator Circuit Using a 6SA7.

leaves something to be desired. Some of these objections to the 6A8 tube have been overcome by the use of the more modern 6SA7 type oscillator-mixer tube, which has greater stability within the broadcast band, but still fails to measure up to all requirements necessary at high frequencies.

These two types of mixer or converter tubes are therefore not well suited to the multi-band radio receiver, such as the communications and foreign-reception models. However, their great popularity is due to their satisfactory performance on the broadcast band and on the lower of the short-wave bands. Both the 6A8 and the 6SA7 type stages are advantageous to modern broadcast receivers because of the compact nature of circuits essential to superheterodyne principles. The 6SA7 is frequently used as a mixer on high frequency by using a separate oscillator tube.

The 6L7 type mixer, with its separate oscillator stage, is ideally suited to multi-band reception up to and including the 28-megacycle band. In some receivers it functions very well at even higher frequency. The 6L7 mixer, however, has one disadvantage for small receivers; it requires two separate tubes. Table model and portable receivers are limited in the space available for component parts. Automobile receivers, too, have certain rigid space limitations. Since these receivers operate on the broadcast band only, except in rare cases, the pentagrid converter type oscillator-mixer stage is suitable for their use.

In communications and multi-band receivers, on the other hand, superior operation is required, on all bands. If space is limited, more space is added to contain circuits necessary to enable the receiver to operate with top performance. Since most communications and multi-band receivers are more or less permanent installations, they are expected to occupy somewhat more space. For this reason a mixer circuit employing two separate tubes is not objectionable in these large receivers, and the 6L7 type mixer is extensively used.

Section 8. HEPTODE AND HEXODE CONVERTERS

The automobile receiver presents some problems of its own, which can be traced to

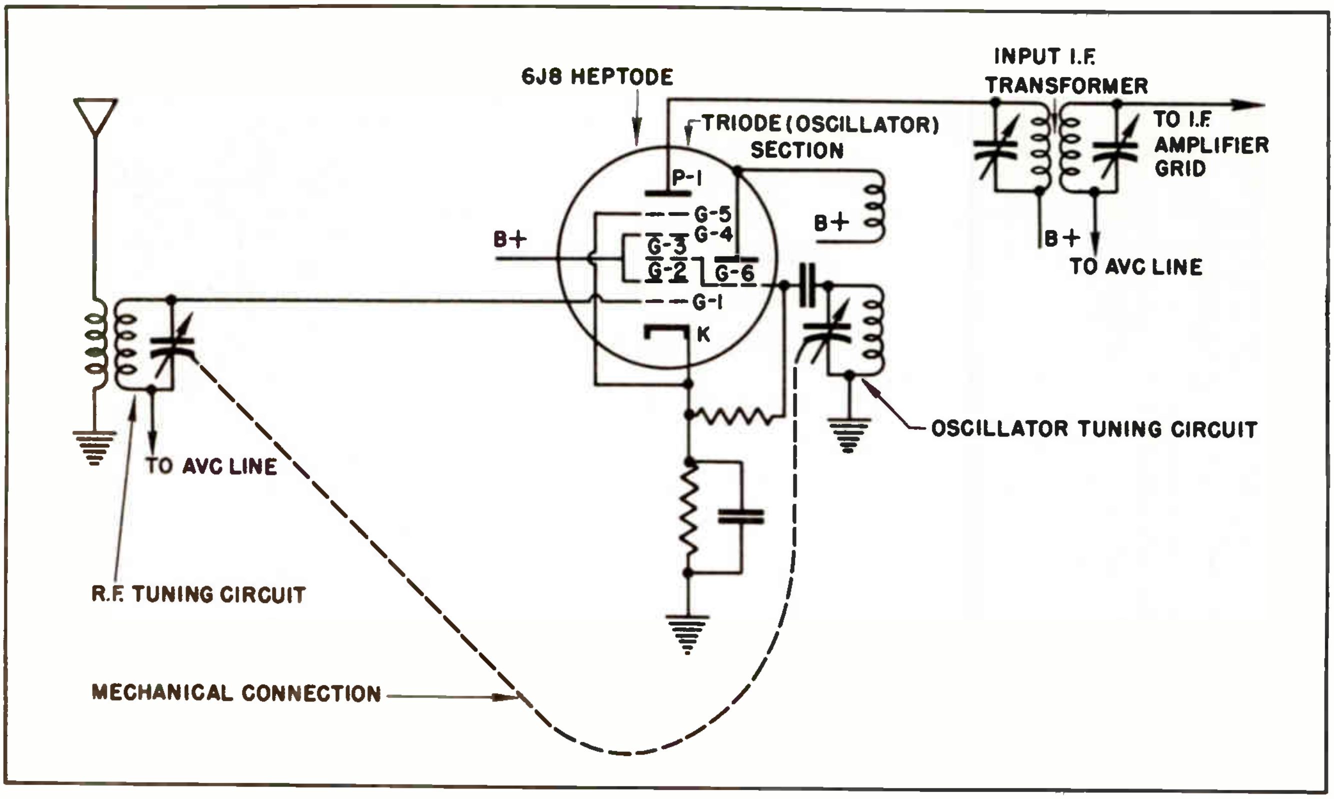


Fig.8. Circuit of a Heptode Converter.

the mobile nature of the installation. Automobile receivers for the most part operate on the broadcast band only, so the shortcomings of an electron-coupled-oscillator are not serious so far as high frequencies are concerned. However, since this receiver is mobile, the strength of the received signal at the antenna will vary considerably due to the change of location from moment to moment. The automatic volume control voltage will therefore change in accordance with signal strength at the antenna, and the result will be a frequent tendency for the oscillator to drift due to the space-charge changes within the oscillator-mixer tube. This effect is minimized, of course, by the use of the 6SA7 type tube.

Another answer to this problem, and similar problems in home receivers, is met by the use of the heptode and hexode converters. The objective in the use of these tubes is to gain the advantage of separate mixer and oscillator stages without the loss of necessary space. This is accomplished by combining the two stages physically only, within the same glass envelope. Electrically, they still act as two separate stages, which indeed they are. But they can be put in the same tube, thus saving valuable space. This is not an electron-coupled-oscillator, as is evident from Figs. 8 and 9.

The heptode converter is illustrated in Fig. 8, together with the oscillator, mixer, and R-F components associated with such a stage. The I-F output is also indicated.

The most salient characteristic of this circuit is that the control grid of the oscillator section of the tube is directly connected within the tube to *G-3* of the heptode section. (The name heptode refers to the seven separate tube elements -- exclusive of the heater -- in this half of the tube.) Such connection between the oscillator control grid and the oscillator grid of the heptode makes it possible to inject the oscillator frequency into the heptode electron stream and still maintain suitable isolation between the two tube parts. Changes of oscillator amplitude and frequency, due to changes in space charge in E.C.O. circuits, are therefore averted. Under these conditions, too, the Armstrong oscillator circuit surrounding the triode section of the tube is capable of much higher frequency than in the electron-coupled system.

Notice the interesting fact, in Fig. 8, that the two sections of this tube possess a common cathode, which originates electrons for the oscillator section as well as the mixer. The plate circuit of the triode section consists of a primary winding on an R-F transformer of which the secondary forms part of the oscillator tuned circuit. G-2 and G-4 act to accelerate the electrons through the heptode section, and G-5 minimizes secondary emission from the heptode plate. This type of tube is often found in automobile receivers, and is usually in the form of the loctal type 7J7 tube. A loctal tube is one with a large center pin in the base which locks into a spring clip in the socket.

In home receivers of the A-C type, this tube is represented by a 6J8, and in the AC-DC type by the 12K8 which is a similar tube called a hexode converter.

Illustrated in Fig. 9 is a circuit represented in a hexode converter stage. A striking similarity may be noticed between the hexode and heptode circuits. They differ chiefly in that the former does not contain the suppressor grid element. Otherwise the circuits are electrically identical. From the serviceman's point of view it is interesting to note that the 6A8, the 6K8, and the 6J8 may be replaced by each other. This is due to the fact that their heaters are rated identically, and while the 6A8 is an E.C.O., the 6K8 is a triode-hexode, and the 6J8 is a triode-heptode, their base pin connections are wired in a way to make all pins functionally correspond. It is often possible to make a replacement of one type by one of the others. It is usually necessary to make slight adjustments of the oscillator trimming condenser. This will be discussed later.

Section 9. TROUBLE-SHOOTING THE MIXER STAGE

Operational check for the stage. -- If all tubes have been previously checked, and if tests of the I-F, detector, and audio sections show them to be in operating order, the following procedure may constitute a specific check of the mixer stage:

Introduce a modulated R-F signal to the R-F signal grid of the mixer stage. Set the receiver tuning dial at the frequency being introduced. If the audio modulation of the test signal is not heard at the receiver speaker, the oscillator mixer stage may be considered at fault. Fig. 10 shows the connections to be made during this test.

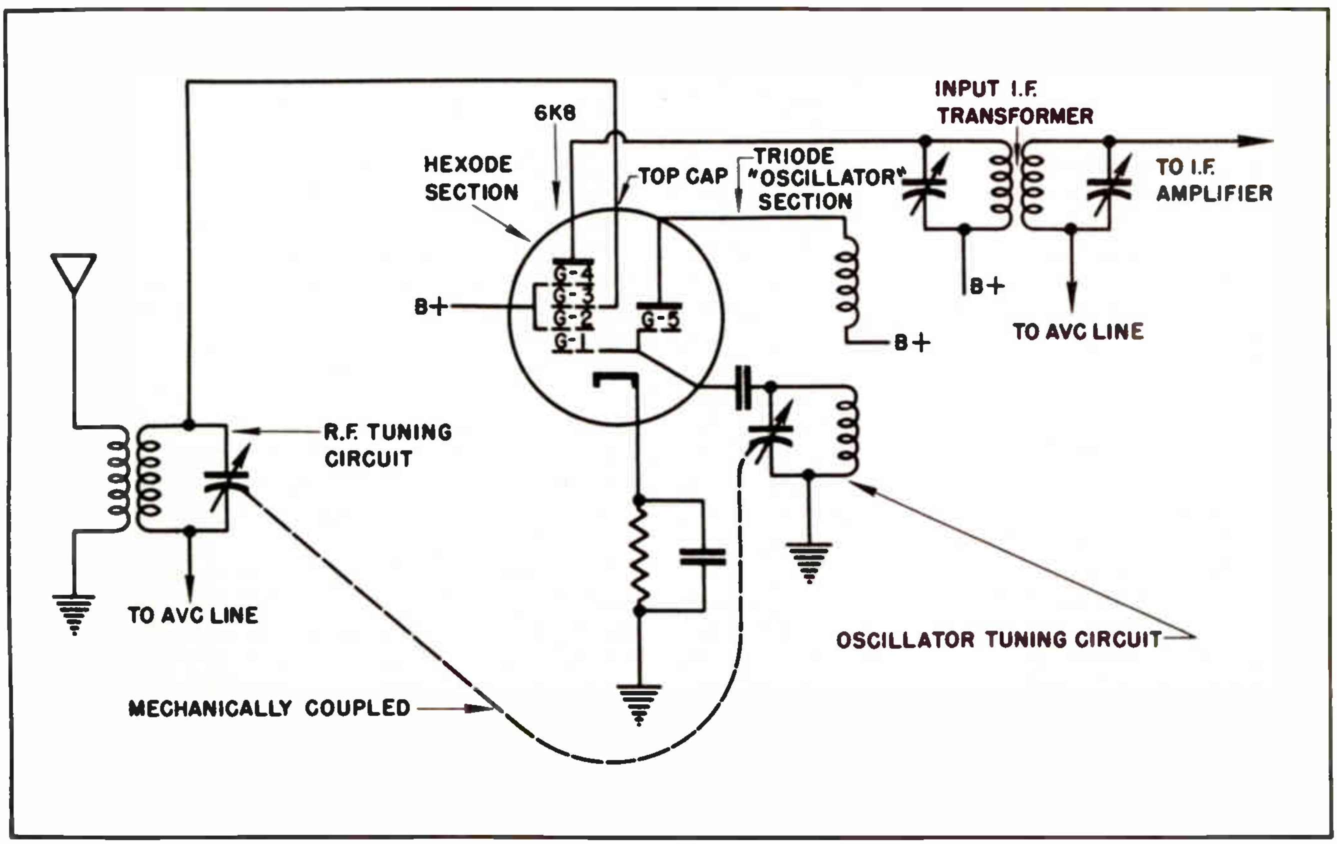


Fig.9. Circuit of a Hexode Converter Tube.

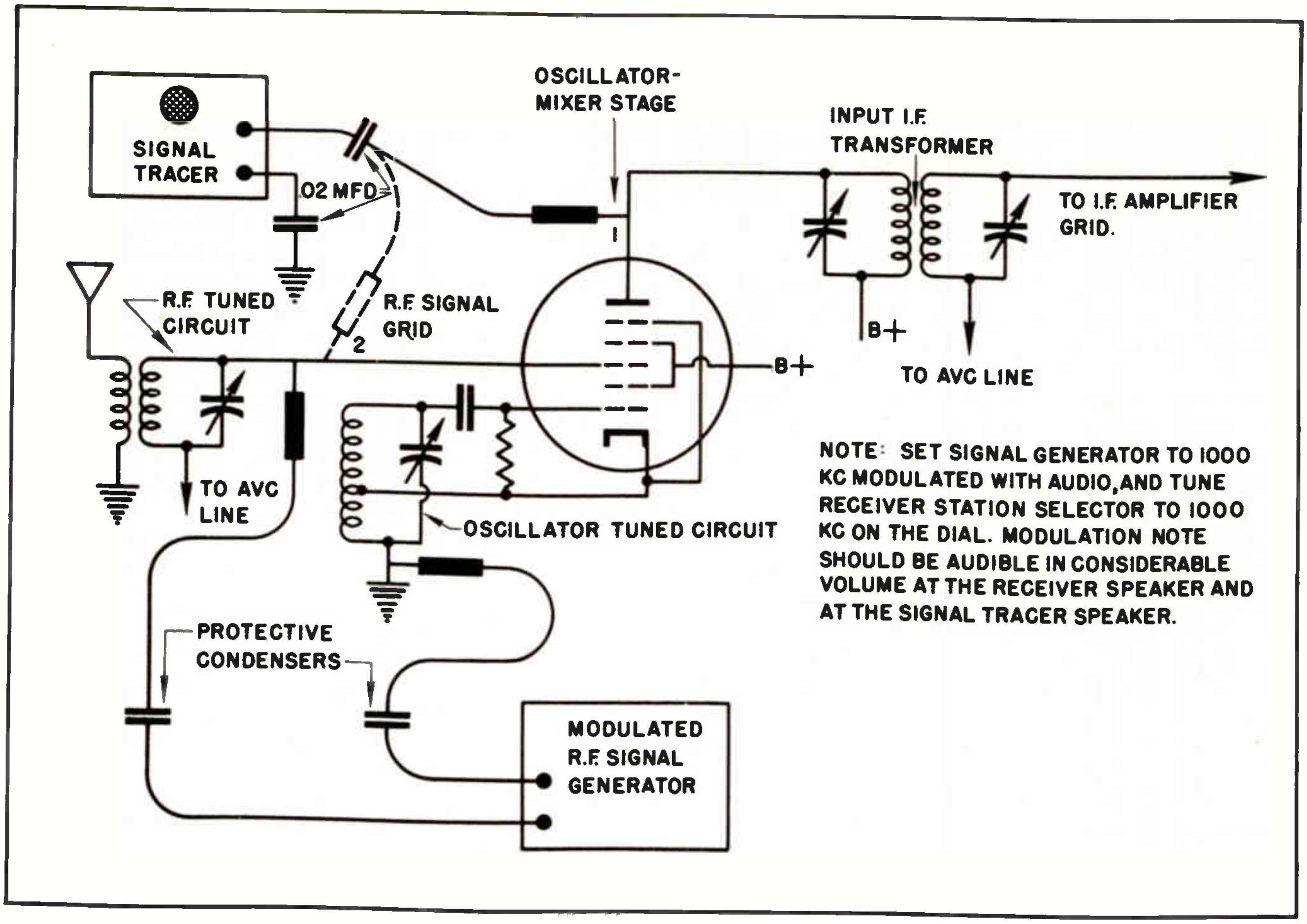


Fig. 10. Two Methods of Testing the Oscillator-Mixer Stage.

The interpretation of this test is extremely simple, amounting to this: If a 1000 k.c. signal, modulated by an audio component, is not heard at the speaker when all circuits following the mixer stage are known to be good, then this stage is not accomplishing its purpose. Since an R-F signal is being introduced at the proper place, and all circuits are good, about the only remaining place for the fault is in the oscillator-mixer stage itself.

This operational check for the mixer stage may be varied in the following way, as illustrated in Fig. 10. The test probe of signal tracer is placed upon the plate of the mixer stage, point *1*, and then upon the signal grid, point *2*. If there is not a distinct and noticeable drop in volume as the probe is moved from plate to grid, then the mixer stage may be suspected.

The advantage of using the signal tracer test is that it is not necessary to previously check the succeeding stages. The signal generator method, however, presupposes that all the succeeding stages are in good order.

If either, or both of these tests do not result in an audible signal, then the mixer stage should be investigated in detail with voltmeter and ohmmeter to locate the exact cause of the trouble.

General indications of mixer troubles. -- In addition to the two equivalent operational tests just outlined, there are several important general symptoms that unmistakably point to trouble in the mixer stage. Exclusive of a burned-out (open) heater in the mixer tube, which should be revealed by an initial routine check of all the tubes, mixer stage troubles will be indicated by the following easily observable conditions:

The speaker will contain the normal residual hum characteristic of "live" receivers. There will be considerable background static as the manual volume control is advanced. There will be no signal of any kind at any place on the dial, although sometimes a very weak signal may be brought in at the lower end of the dial (550 k.c.) All tubes in the receiver will light, and they may all check good on the tube-checker, including the mixer tube. If a measure of B-plus is taken with a meter, it will be found normal, in most cases.

As the functions of the mixer stage components are described, the presence of the symptoms mentioned above, indicating an inoperative stage, will become evident.

Section 10. FUNCTIONS OF THE COMPONENTS

If the operational test of the mixer stage indicates that this section of the receiver is at fault, a detailed analysis of the stage must be made with ohmmeter, voltmeter, and reference data. Fig. 11 is a typical oscillator-mixer stage using the 6SA7 type circuit, and may be used as a data sheet for the oscillator-mixer stage of an A-C radio receiver.

Inductances L-1 and L-2. These are the primary and secondary, respectively, of the R-F transformer. Their purpose is to transfer the antenna signals to the oscillator-mixer stage, and -- with the aid of *C-1* and *C-1-t* -- to select the desired signal from all others. Note: This transformer may be in loop antenna form. Loop antennas will be discussed in a subsequent section of this lesson.

Tuning Condenser C-1. This condenser resonates *L-2* at the frequency of the desired signal. It is mechanically attached to the station selector knob.

Trimmer Condenser C-1-t. Its purpose is to serve as a fine adjustment, or trimmer, for *C-1*, on the structure of which it is generally mounted. (See Fig. 12.) This trimmer is adjusted during the alignment procedure of the R-F tuned circuits of the receiver. Since it is electrically in parallel with *C-1*, it serves to increase the maximum and minimum capacity across *L-2*.

L-3 is the Oscillator Transformer. In the Hartley series circuit, its purpose is to provide feedback from the cathode circuit to the grid circuit. Consisting of a center-tapped winding, the lower turns may be considered as the primary and the upper turns as the secondary.

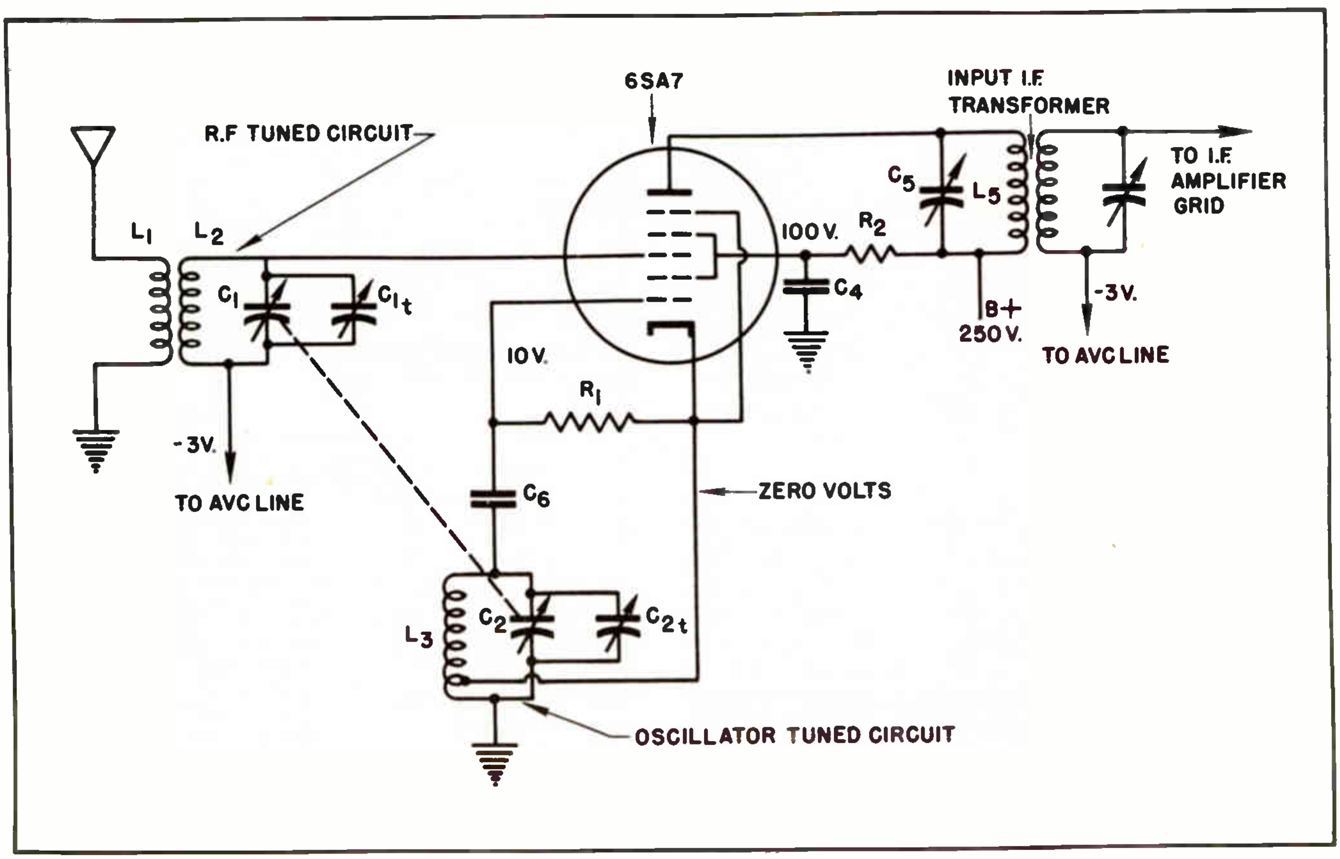


Fig. 11. Test Data of a Circuit Using a 6SA7 Oscillator-Mixer Tube.

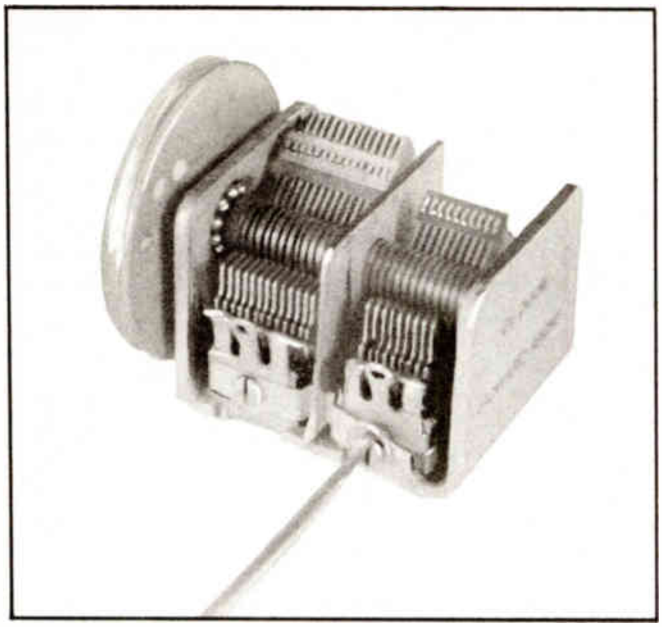


Fig. 12. Variable Gang Condenser Showing The Adjusting Trimmer Condensers.

C-2, the Oscillator Tuning Condenser. This condenser is mechanically coupled to the R-F tuning condenser, and both are attached to the tuning knob of the receiver. Its purpose is to resonate *L-3* to the desired frequency for any given station setting of the tuning dial. That is, to a frequency equal to the I-F plus the frequency of the incoming signal.

C-2-t, the Oscillator Trimmer. The purpose of this component is identical with *C-1-t*, its counterpart in the R-F tuned circuit. It is in parallel with *C-2* and serves to raise the maximum and minimum capacity across *L-3*. Like the R-F trimmer, it is adjusted only during the alignment procedure. It is generally mounted upon the structure of the oscillator tuning condenser *C-2*. (See Fig. 12.)

Oscillator Coupling Condenser C-6. Its purpose is to couple the fed-back plate voltage to the oscillator grid of the stage. It also keeps the oscillator grid voltage from shorting out to ground through the low ohmic resistance of the coil *L-3*. This is an important component. If it is open, oscillation may take place only at the high frequency end of the tuning dial, but not in the middle or low frequency ranges. If shorted, this condenser will remove the bias from the oscillator grid and will probably suppress oscillations by driving the entire stage toward saturation.

Oscillator Grid Resistor, R-1. The purpose of this component is to permit excess electrons to leak off the oscillator grid to ground, to prevent blocking of the stage. It also serves as the biasing agent for the oscillator grid, developing a bias voltage of around minus-10 volts with respect to ground through its usual resistance of 20,000 ohms. This grid and resistor *R-1*, are important in that they indicate whether or not the stage is oscillating. A D-C voltmeter, placed across *R-1*, should read somewhat negative (about 10 volts) if the oscillator section of the stage is operating properly. This constitutes the quickest reliable check for oscillator operation, as indicated in Fig. 13.

If the ordinary 1000-ohm-per-volt meter is used for this test, it will yield a wealth of information. If the meter reads approximately minus-10 volts, oscillation may be assumed, and the trouble sought for elsewhere. If, however, the meter reads zero voltage, then it is doubtful if oscillation is taking place, and the cause of failure should be further investigated.

The meter may indicate an excessively high voltage. In this case, if the receiver

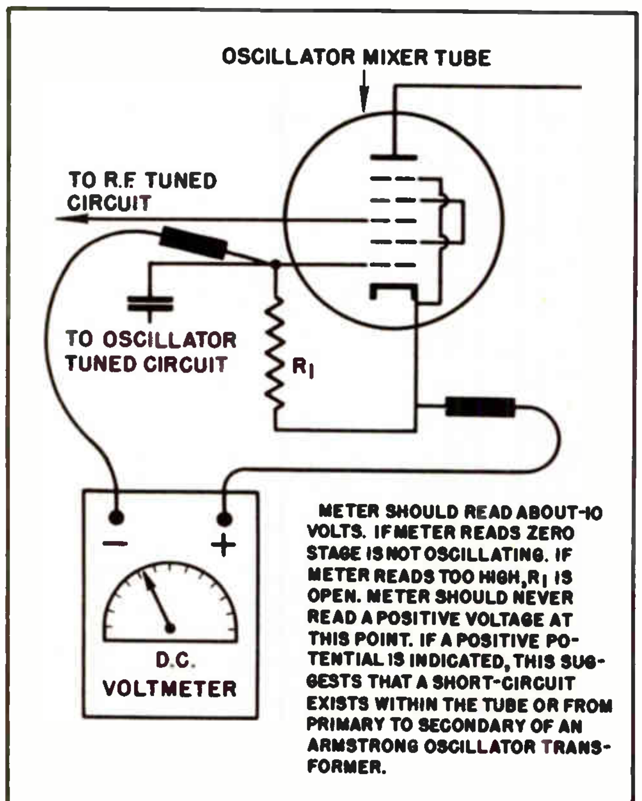


Fig. 13. Testing for Oscillations in an Oscillator-Mixer Stage.

signal was altogether absent, chances are good that so long as the meter is in the circuit, a signal will be brought in; this signal will drop out again when the meter leads are removed. Such action indicates that *R-1* is open (or has greatly increased its resistance), and should be replaced. The fact that the signal can be brought in by placing the meter leads across *R-1* is easily explained by the presence of a discharge path for excess electrons provided by the meter itself, while it is in the circuit.

Dropping Resistor, R-2. This resistor will not be found in AC-DC receivers. Where present, it serves to lower the value of B-plus to conform to voltage required by the screen grids of the pentagrid converter. According to the tube manual the screen grids (one of which is also the oscillator anode) will require 100 D-C volts, regardless of whether B-plus is taken at 100 volts or at 250 volts. If *R-2* is open, or has appreciably increased its value, then the signal will be completely lost. For not only does the absence of D-C potential on grid *4* reduce by a considerable amount the gain of the stage, but connection of grid *2* (the oscillator anode) to a D-C power source is positively essential for oscillation to take place.

Screen By-Pass Condenser, C-4. This condenser serves the function of rendering grids *2* and *4* at ground potential as far as the high frequency A-C is concerned. It does so by opposing the change of voltage at the common junction of these two grids which may result from voltage drops in *R-2*. In AC-DC receivers where *R-2* is not used condenser *C-4* is, of course, omitted since by-passing in these receivers is accomplished by the output filter condenser of the AC-DC power supply.

With *C-4* open, the gain of the stage is decreased and the signal becomes weak, but tunable. If *C-4* becomes short-circuited, *R-2* will become overheated and may eventually open up completely. In this case, *R-2* should be tested for proper resistance (about 25 K to 50 K) and replaced after replacing condenser *C-4*. Voltage at grids *2* and *4* may be easily ascertained by voltmeter check, while the condition of both *R-2* and *C-4* may be determined by an ohmmeter check with the receiver power turned off. Analysis of *C-5* and *L-5*, the tuned circuit components of the input I-F transformer primary, has been covered in the lesson on the I-F amplifier system.

Section 11. CHECKING THE OSCILLATOR-MIXER TUBE

This tube is the heart of the converter-mixer section of the receiver. In most cases, the tube checker may be relied upon to give certain information about a tube. The oscillator-mixer tube, however, has certain peculiarities which make a routine check of this tube somewhat unreliable.

If the heater of this tube is burned out it will, of course, fail to light up in the set when power is applied. Moreover, if the set is of the AC-DC type none of the other tubes will light, since AC-DC receiver tubes are wired with their heaters in series. A tube-checker will yield this information readily.

The tube-checker will also indicate the presence of the inter-element short circuits or leakage in the oscillator-mixer tube. In most cases it will also show the degree of emission from the cathode. The test for an open grid in this tube is not reliable when the tube is tested on a tube-checker. This does not infer that the tube-checker used is below standard. It is simply that an open grid, especially one which is somewhat removed from the cathode, will not be able to block all the electron current in this tube. The result will be that the tube-checker indicator will still indicate a good tube when the tube is actually poor. Since the "BAD--?--GOOD" dial of the tube-checker

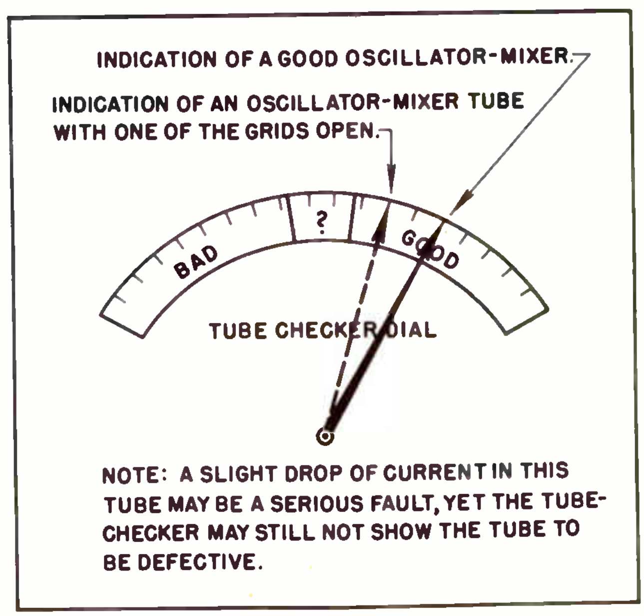


Fig. 14. The Meter Scale of a Tube Checker Showing Why a Bad Converter Tube Might Actually Read "Good".

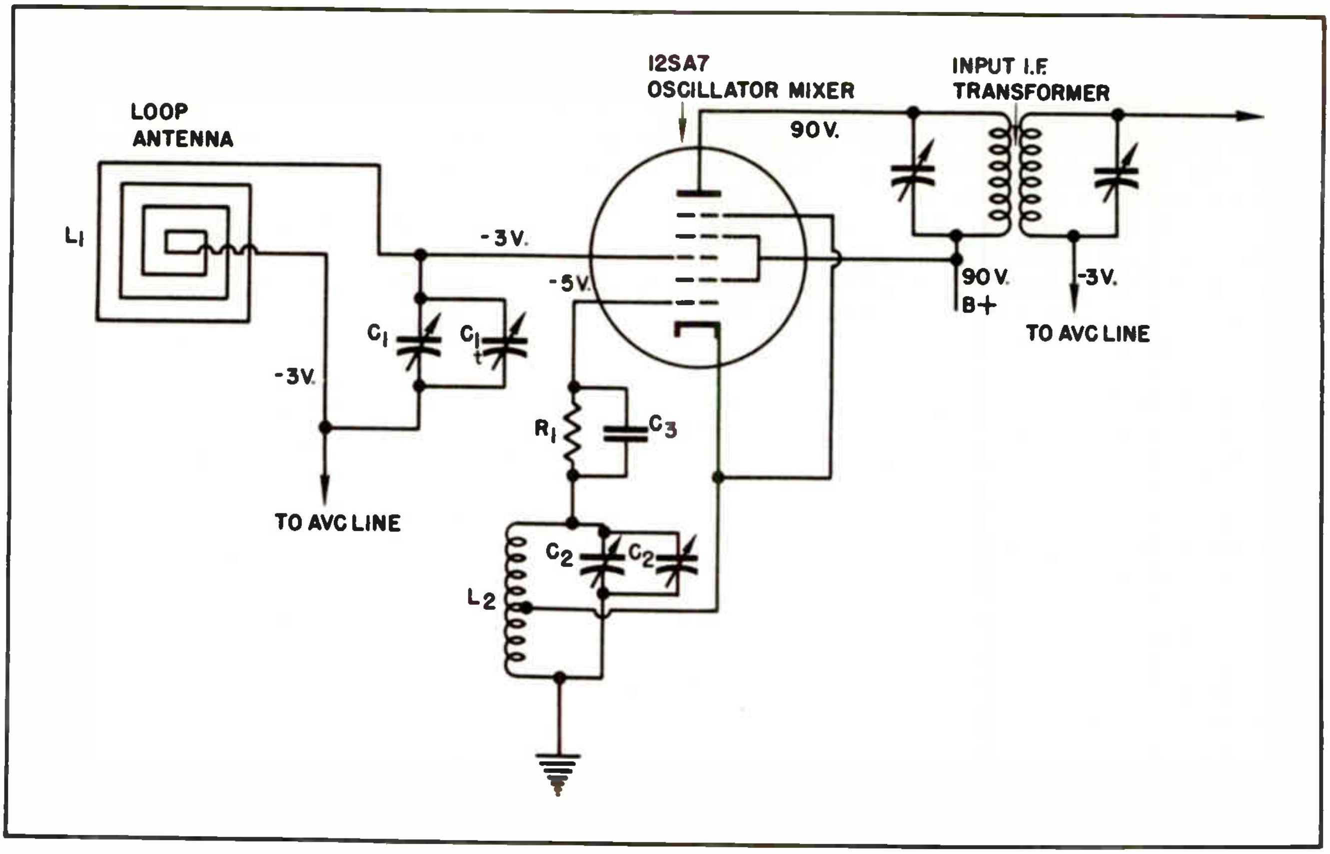


Fig.15. Diagram and Data Sheet of an AC-DC Converter Stage.

has very broad divisions (see Fig. 14), the plate current decrease due to an open grid may not be sufficient to bring the pointer all the way over to the "questionable" or "bad" division.

To eliminate doubt due to this peculiarity of the oscillator-mixer tube, a suspected tube should be replaced with one known to be good. If, for instance, a 6SA7 tube works well in one receiver, it can be placed into the corresponding socket of the receiver under analysis to make sure that the trouble lies in the tube and not in another component. This is probably the easiest and the most accurate verification of the suspicion of a bad oscillator-mixer tube.

In connection with this replacement method of checking the quality of an oscillator-mixer tube, it must be borne in mind that the 6SA7 will successfully replace only another 6SA7. This means that with rare exceptions any oscillator-mixer tube should be replaced only with its exact duplicate, for test purposes. The exceptions are: The 6A8 may be replaced with a 6K8; and either may be replaced by a 6J8. The 1LC6 may be replaced by a 1LA6; and the 1A7 by the 1B7. The 12A8 may be used for the 12K8. Even knowing which tubes may be substituted for each other for the sake of tests, it is still always better to make replacements with the exact tube types. In some cases, however, it may be inconvenient to run a test with an exact replacement, and a substitute may be made on a temporary test basis.

Functions of the component parts of the oscillator-mixer stage in AC-DC receivers, illustrated in Fig. 15, are identical with those in the 6SA7 pentagrid converter. The heaters of AC-DC receivers as we already know, are wired in series, and the heater rating of this tube is 12 volts, the tube being a 12SA7 type. An important divergence, however, is noted in the value of B-plus in the AC-DC receiver. Due to the half-wave nature of this type of power supply, maximum available plate and screen potential is seldom greater than 100 volts, and usually is found to be about 90 volts. This lowered voltage, in comparison to A-C receivers, accounts for the absence of both the screen by-passing condenser in this stage, as well as the screen-dropping resistor. Both the plate and the screens of this tube should read about 90 volts, since the drop in the plate load is negligible so far as D-C is concerned.

Note, also, that Fig. 15 includes the symbol for the loop antenna. Electrically, the loop antenna replaces the R-F transformer, and, in large cities where strong stations are on the air, the loop antenna is more than sufficient to bring in a satisfactory signal. The appearance of the loop antenna is illustrated in Fig. 16.

The basic operating principle of the loop antenna is that it combines both the inductance of the tuned R-F circuit with a comparatively broad cross-sectional area, thus gathering enough energy from the transmitted electromagnetic wave at the same time that the selected frequency is resonated between the turns of the loop and the variable tuning condenser which it parallels. On most loop antennas, a primary winding is interwoven with the secondary, and one end of the primary may be attached to an outside antenna while the other is connected to receiver ground. This aids the loop in bringing in signals that the loop, by itself, would bring in very weakly or miss altogether.

Note that *C-1* (and its trimmer *C-1-t*) are in parallel with the loop winding, and as such act to resonate it at the desired frequency. Since the loop contains only a very few ohms resistance, the voltage on the signal grid of this tube should read about

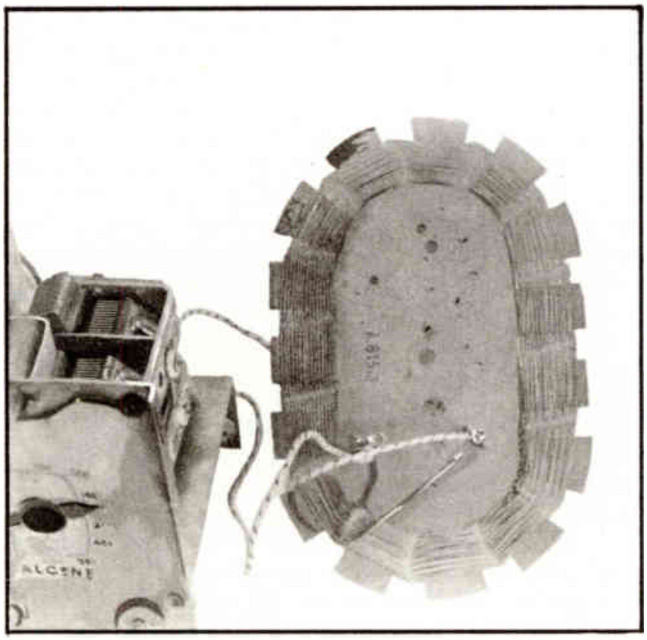


Fig. 16. Loop Antenna for an AC-DC Receiver.

minus-3 volts, which is the AVC voltage under normal conditions. Oscillator grid voltage, negative with respect to ground, is indicated in Fig. 15 at approximately minus-5 volts. This voltage may be expected in an AC-DC receiver, and its absence at the oscillator grid is sufficient evidence of an inoperative mixer stage. The type of oscillator shown is a Hartley series-fed circuit, although Armstrong (tickler) type oscillators are also often employed in the AC-DC receiver.

Fig. 17, A and B, illustrate two Armstrong oscillators employed in AC-DC oscillator-mixer stages. In type A, the conventional Armstrong circuit, transformer *T* serves as the feedback agent from the oscillator anode to the tuned grid circuit, since oscillator current, flowing through winding *P* (the primary) induces triggering voltages in S (the secondary) in order to initiate and sustain oscillations.

Type B is essentially the same, with the exception that feedback is accomplished through the cathode circuit of the tube. Winding *P*, carrying the total of all the current in the tube, induces voltage changes in S that initiate and sustain oscillations at the frequency to which the oscillator tuned circuit is resonant. In this modified Armstrong oscillator circuit, since *P* is untuned, it has no effect on any other frequency involved in the oscillator-mixer stage. One advantage of the modified Armstrong oscillator is that it minimizes the chances of shorts and arcing in the thin wires with which this coil is wound, simply because no part of it is at a high D-C potential.

In the conventional Armstrong circuit, Fig. 17-A, a short across the windings of the feedback transformer may destroy the rectifier tube of an AC-DC receiver. In an A-C receiver, such a short would not bring full B-plus to ground through the secondary windings, but it would result in burning up the dropping resistor supplying voltage to the oscillator anode. In addition, the coil windings carrying this excessive current, may themselves burn open. Meter readings in this case would have to be carefully interpreted, to locate the original source of the trouble, and then to replace the individual parts which were damaged as a result of the original trouble.

Corresponding connections are made to the 6SA7 tube, such as are used in most auto-

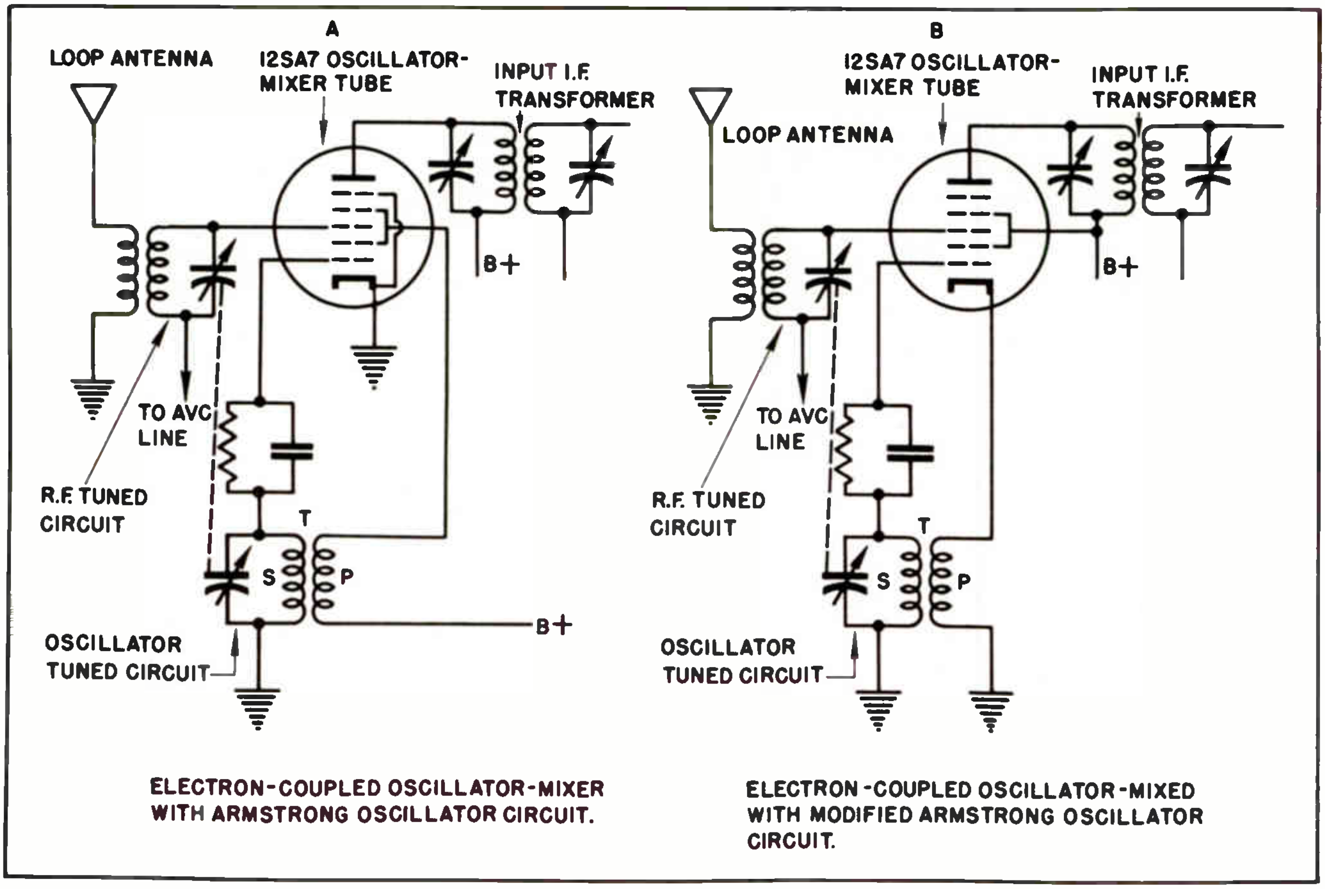


Fig.17. Armstrong Oscillator Circuits Used in Some Radio Receivers.

mobile and A-C receivers, and in AC-DC receivers with a 12SA7. All three types of oscillator circuits are used, depending upon the choice of the manufacturer. Trouble-shooting the oscillator-mixer stage in automobile and home receivers, therefore, closely corresponds to trouble-shooting the same stage in an AC-DC set.

In portable and 3-way portable receivers the type of oscillator is limited to any which do not contain feedback through the cathode circuit. The reason is evident from Fig. 18, which shows an oscillator-mixer stage in a typical portable receiver. The tube used may be among others, either a 1A7 or a 1R5, both of which are converters employed in portable receivers. Note that the cathode is directly heated. This is a universal practice (except for rectifier tubes in the 3-way portable models), and shows why neither the Hartley nor the modified Armstrong oscillator circuits are normally used with this type of tube. As is to be expected, in portable models, anode feed-back oscillator circuits are almost universally employed, for only in this type can tube current be controlled without disturbing the already existing connections to the "A" voltage supply.

Notice, also, in Fig. 18, that the oscillator anode is not operated at full B-plus potential, but at 67 volts, D-C. This is the reason for the dropping resistor and by-pass condenser at this tube element. However, both the 1A7 and the 1R5 have a wide tolerance of plate and screen voltages. It is noteworthy that the portable model from which this circuit was taken operates on a rated "B" voltage of 67.5 volts. Considering the small amount of current in the oscillator anode circuit, the drop across the 20,000 dropping resistor, while present, is practically negligible.

We may, therefore, look upon the dropping resistor and its associated by-pass condenser more as a decoupling circuit than a voltage-dropping circuit, although it has the function of both. The dropping characteristic would be more noticeable in cases where a 3-way power supply is used, and B-plus is nominally at 90 volts. In that case, more current would flow through the resistor, and a greater voltage drop would occur. This would bring the oscillator anode closer to its operating value of 67 volts while the mixer plate could still use the full 90 volts for its operation.

Among the many troubles inherent in the oscillator-mixer stage of any type of radio receiver is a faulty tube. Previous discussion has indicated that the nature of this tube, with its many grids, makes it subject to internal shorts and leakage to a greater degree than the simpler types of tubes. Besides, the nature of this 5-grid tube often renders the information of a tube-checker unreliable in certain respects, primarily with reference to an open (or "free-hanging") grid.

The technician who analyzes and repairs an oscillator-mixer stage, after having specifically traced the trouble to this stage by systematic use of the signal generator or the signal tracer, as previously outlined, will need to exercise keen analytical judgment and ingenuity in locating these troubles. He must realize that simply because a tube-checker shows an oscillator-mixer tube to be good, this does not necessarily mean that this tube is good. Where the trouble has been localized to the mixer stage by any of the three methods suggested (the signal generator, the signal tracer, and by the displayed symptoms) it is a wise procedure to outrule tube trouble by first substituting one known to be good.

If the results of replacing the tube still show the stage to be at fault, then the best procedure is to analyze the stage with voltmeter and ohmmeter, comparing the readings with a standard set of stage data. However, in order to make comparisons to a suitable standard, you should realize that it is most important to identify the type of receiver under analysis. Otherwise comparison cannot be made in a dependable manner.

As a means of identifying the various types of receivers, in order to know about what kind of oscillator-mixer stage to expect, the table on the following page is presented.

Section 12. ALIGNMENT OF THE OSCILLATOR-MIXER

Previous discussion has outlined the alignment procedure for adjusting the I-F tuned stages for maximum efficiency in receiving broadcast programs. You will recall that I-F alignment is but a part of a general alignment procedure applied to the entire receiver. This general procedure may be divided into three major steps:

(1) Alignment of the I-F tuned circuits.

(2) Alignment of the oscillator tuned circuit.

(3) Alignments of the R-F section.

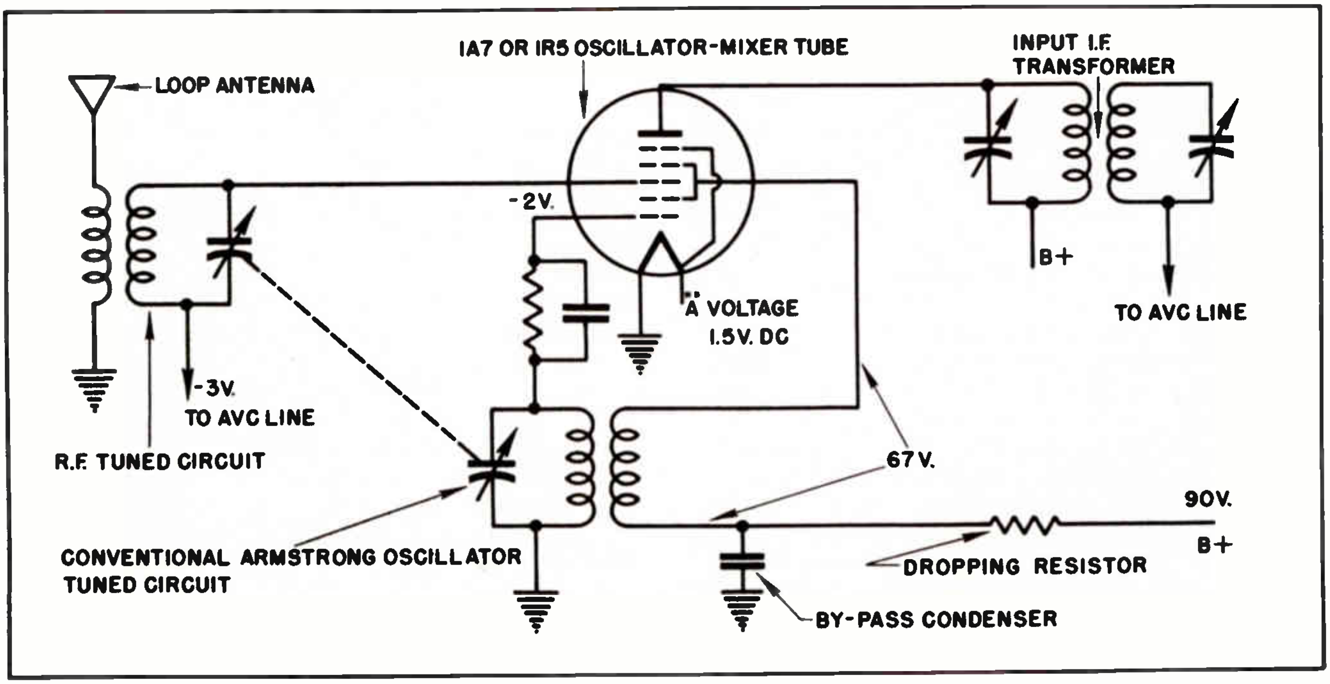


Fig. 18. Oscillator-Mixer Stage of a Portable Receiver.

RECEIVER TYPE	IDENTIFY BY	OSCILLATOR-MIXER
AC-DC	At least one tube with a 12-volt heater.	Hartley or Armstrong Electron-coupled mixer.
A-C (broadcast)	Power Transformer, tubes with 6-volt heaters.	Hartley or Armstrong Electron-coupled mixer.
A-C (multi-band)	Band Selector Switch.	Triode Oscillator of Hartley or Armstrong type, feeding into separate pentode or pentagrid mixer.
Automobile	Vibrator Power Supply.	Electron-Coupled Mixer, or Heptode or Hexode tube. Any type oscillator.
Portable	Batteries or Space for Batteries.	Electron-coupled mixer of conventional Armstrong type; Occasional Special Oscillators of unconventional design. In case of doubt, consult manufacturer's wiring diagram.

While the alignment procedure for the I-F tuned circuits was outlined in detail in a previous lesson, it is repeated here for the same of completemess. References are to Fig. 19.

Step (1). *I-F Alignment and setting Up the Alignment Equipment.*

I. Connect the output meter to the secondary of the speaker matching transformer, as shown in Fig. 19. Short out the AVC voltage with a jumper, as in the diagram. Connect a R-F signal generator, modulated with audio and adjust to the I-F frequency, with one probe to common ground of the receiver and the other to point *1* in the figure. Apply power to the receiver, and leave the manual volume control set at maximum.

Adjustment: With an insulated screw driver adjust *C-7* for maximum output meter reading. Do the same with *C-6*. These are the trimmers of the output I-F transformer secondary and primary, respectively. Notice that the audible sound of the modulating frequency will be the loudest when the output meter reads maximum.

II. Move the high (ungrounded) lead of the signal generator from point *1* to point *2* as in Fig. 19.

Adjustment: Turn the trimming screw on *C-5* for maximum meter reading, and then do the same for *C-4*. These are the trimmers of the secondary and primary, respectively, of the input I-F transformer.

III. With the signal generator probe still on point *2*, *C-7*, *C-6*, *C-5*, and *C-4* are then re-adjusted for maximum meter reading, in the order named.

This completes Step (1), alignment of the I-F tuned circuits.

Step (2). *Alignment of the Oscillator Circuit.*

I. Move the signal generator probe to point *3* as in Fig. 19. Now set the signal generator at 1500 k.c., with audio modulation. Tune the station selector to 1500 k.c. on the broadcast dial, and do two things.

First, listen for the modulation note in the speaker; and second, watch the output meter for maximum deflection. If the audio signal is the loudest, and the meter deflection the greatest, when the station selector is tuned to 1500 k.c. on the dial, then the oscillator is correctly adjusted. If maximum reading of the meter occurs when the station selector is set below 1500 k.c., the oscillator frequency is too high and should be reduced. To effect the necessary reduction, re-set the station selector to exactly 1500 k.c., and turn the oscillator

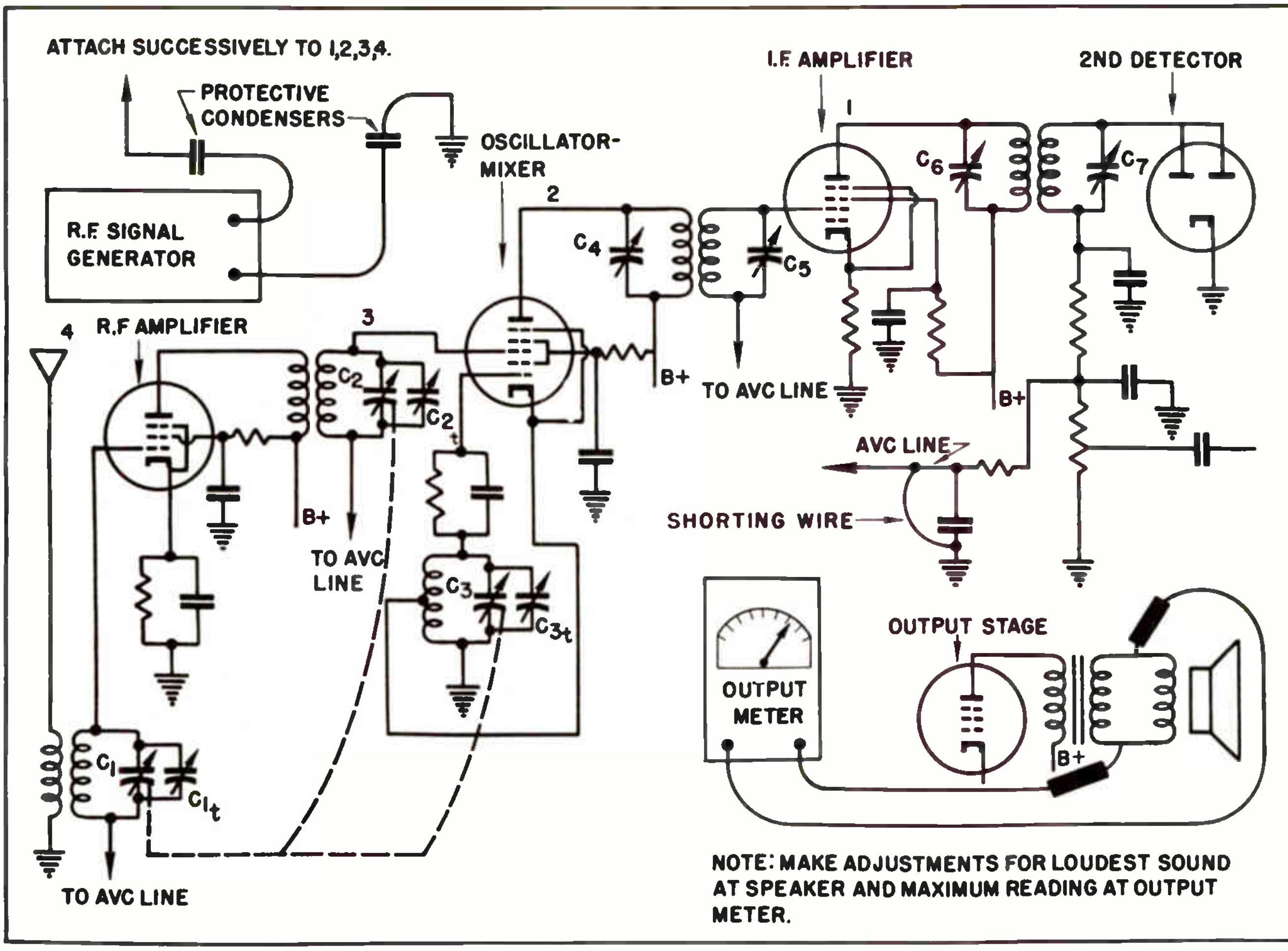


Fig. 19. Aligning a Superheterodyne Receiver.

trimmer *(C-3-t)* clockwise until the meter reading goes up and the audio signal at the speaker is the loudest. (This increases the capacity of this condenser and lowers the resonant frequency of the oscillator tank circuit.)

If maximum reading of the meter, and the loudest signal at the speaker occur when the station selector is above 1500 k.c., then the oscillator frequnncy is too low and should be increased. This increase is effected by re-setting the station selector exactly at 1500 k.c. and turning the oscillator trimmer *(C-3-t)* counter-clockwise until the meter reading goes up and the audio signal at the speaker is the loudest. (This decreases the capacity of this condenser and raises the resonant frequency of the oscillator tank circuit.)

II. After this adjustment, "rock" the station selector dial back and forth across the 1500 k.c. mark, making sure that maximum reading of the meter and loudest tone occur at this point. Keep readjusting *(C-3-t)* until these results are achieved.

III. Leaving the signal generator set at point *3*, adjust the signal generator to 600 k.c., modulated, and repeat the oscillator trimmer adjustment so that the station selector picks up the loudest signal, and maximum meter reading, at 600 k.c. on the dial. In most cases, if the 1500 k.c. setting is properly made, all others on the dial will be correspondingly correct. The oscillator is now properly adjusted. An oscillator which is properly adjusted for all points on the tuning dial is said to "track" properly.

With one exception, to be mentioned later, this completes the oscillator alignment. Step (2) of the superheterodyne alignment procedure. We are now ready to make the final adjustment.

Step (3). *Alignment of the R-F Circuits.*

I. Move the signal generator probe from point *3* to point *4*, as in Fig. 19. Point *4* is the receiver antenna. In cases where a pre-selector R-F amplifier is used (as shown in Fig. 19) there will be two separate trimming adjustments in this step of the alignment procedure. If there is only one R-F tuned circuit, however, only one adjustment will be necessary to properly align the R-F section.

II. Adjust the R-F signal generator to 1500 k.c. once more, and set the station selector to 1500 k.c. Turn condenser *C-2-t* for maximum reading of the output meter, and for loudest audio signal at the speaker.

III. If a pre-selector R-F stage is employed, adjust *C-1-t* for maximum meter reading and loudest audio signal.

It is not normally necessary to make the R-F trimming adjustments at any other frequency, since the small capacities of trimmers *C-1-t* and *C-2-t* are negligible when the main tuning condensers are fully meshed (lowest frequency). It is evident that such small capacity changes at the low end of the tuning dial will not be noticeable.

While this completes the third step in the superheterodyne alignment procedure, there are still a few loose ends to tie up. We recall that a certain amount of bandwidth in the I-F stages is necessary for proper tonal response of the receiver. The process of "staggering" the I-F tuned circuits, "flat-topping" their audio response curves, has been described and should be included in the general alignment procedure at this time. When the tonal characteristics of the receiver are satisfactory, and it "tracks" properly, remove the jumper across the AVC. The receiver may be considered in a state of satisfactory alignment.

Section 13. THE OSCILLATOR PADDER

In our previous discussion, exception was taken in the case of the oscillator alignment. This exception concerns the use of another semi-adjustable condenser which lies in series with the main variable oscillator condenser. Fig. 20 is a sketch of this "padder", and illustrates its electrical character. To simplify the analysis, we use a simple triode oscillator in the diagram. Here the padder is shown in series with the main variable condenser and its trimmer. The function of the trimmer is already known. It raises the total capacity of the tuned circuit and will thus enable us to adjust the minimum capacity of the main tuning condenser.

The padder, on the other hand, has the opposite effect. Since it is in series with the tank capacity, it can only serve to lessen the total capacity of the tuned circuit. Its use springs from the fact that some variable condenser gangs, (see Fig. 21) originally made as exactly equal R-F condensers, were adapted to the superheterodyne receiver. We already know that in the superheterodyne receiver the oscillator tuned circuit must resonate at a frequency equal to the R-F plus the I-F value. In order to accomplish this result, either the oscillator capacity or its inductance must be lower than those of the R-F stage.

Today oscillator variable tuning condensers are of the cut plate type, illustrated in Fig. 21. But in the older superheterodyne receivers, before the cut plate type was introduced, the capacity of a standard-sized condenser had to be reduced by electrical means. We know that two capacities in series will have a net value somewhat less than the least of the two. This fact is utilized in installing the padder to raise the oscillator frequency by the desired amount.

The effects of padder adjustments can best be illustrated by comparing them to trimmer adjustments. While the trimmer will serve to shift the entire band either to the left or right on the dial, the padder will serve to either stretch the band wider or narrow it down.

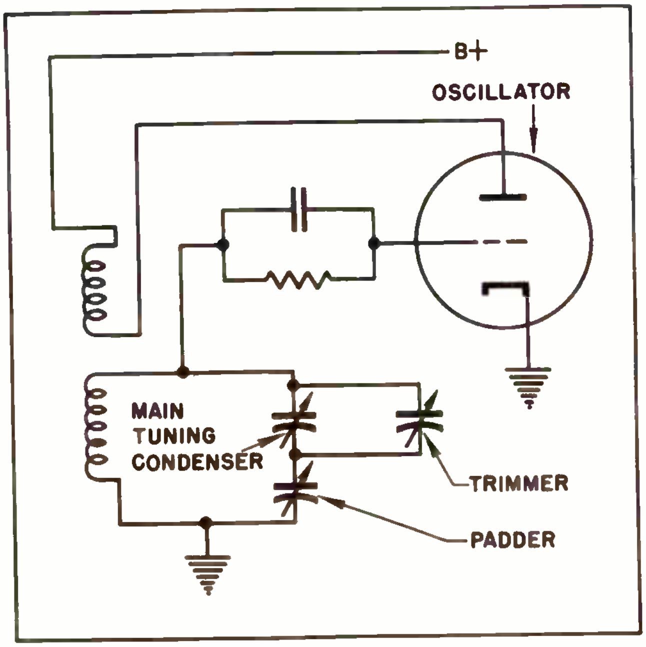


Fig. 20. Location of an Oscillator "Padder" Condenser.

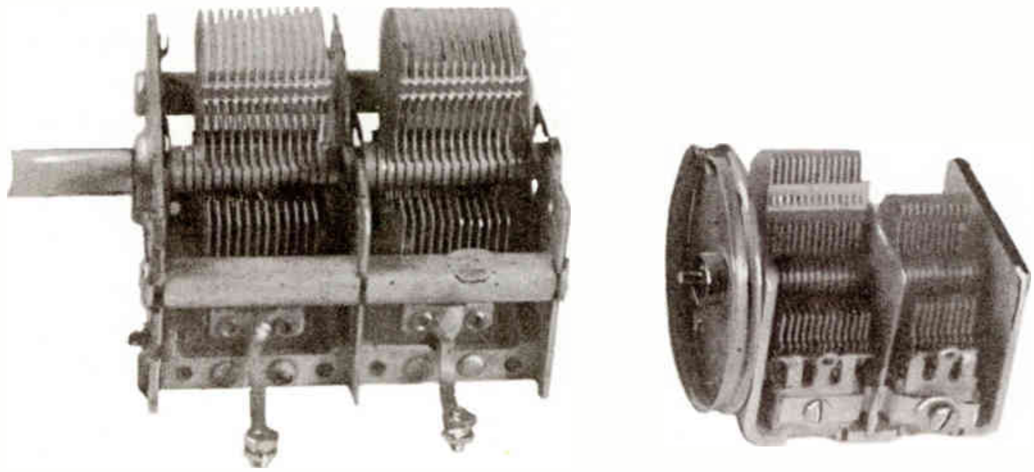


Fig.21. Two Types of 2-Gang Variable Condensers Used in Radio Receivers.

The necessity for padder adjustment can be easily ascertained during the alignment procedure. First of all, if the variable condensers of the gang are not all of the same physical size, then we know that the oscillator condenser is the smaller and therefore there is no need for the padder. This automatically eliminates any padder adjustment in most superheterodyne receivers.

If, however, we identify the receiver as a superheterodyne and also notice that all of the main variable condensers are of the same physical size, we may infer the existance of a padder beneath the chassis, and will be prepared to make a padder adjustment if necessary.

If the receiver has a padder, and the band is either too wide or too narrow, then padder adjustment is indicated. This adjustment is made whenever the receiver tracks at the high end of the tuning range, but fails to track at the low end. It is worthy of note that the trimmer is most effective at the high end of the dial, while the padder is most effective at the low end. It must be added, however, that adjustment of either the trimmer or the padder will affect both ends of the dial to some degree, and that a good alignment involves a delicate balancing of both adjustments, if both are present. As stated, padders have become less popular with the introduction of the cut-plate variable condenser. Read the note on Condenser Calculations at the end of this lesson.

Section 14. IMAGE FREQUENCIES

Superheterodyne receivers, by the very nature of their circuits, contain a peculiarity known as "Image frequencies". This phenomenon, which may often show up as whistling, howling, or cross-talk in receiving certain stations, is not found in the TRF receiver. This does not mean that a TRF receiver cannot be subject to spurious whistling, howling, or cross talk. It means that this type of interference in a TRF receiver cannot be due to "image frequencies."

The correction for image frequencies in a superheterodyne receiver, and for whistling and cross-talk in a TRF receiver are two distinctly different techniques, as will soon become evident.

Section 15. WHAT CAUSES IMAGE FREQUENCIES IN THE SUPERHET?

Let us precede the answer to this important question by first defining an image frequency. An image frequency is an undesired signal which interferes with the desired signal to which the receiver is tuned. We may now provide the answer to the question of the cause of image frequencies. A typical case will suffice.

In the City of Chicago, the frequency of WMAQ is 670 k.c. This is the dial setting required whenever a receiver is tuned to this station. What do we know about the oscillator frequency while the R-F circuits of this receiver are tuned to 670 k.c.? We know, first, that the oscillator is tuned to a value equal to the R-F (670 k.c.) *plus* the I-F frequency of the receiver. Assume the I-F is 456 k.c. This gives us the oscillator frequency (when the R-F is tuned to 670 k.c.) equal to 670 plus 456, or 1126 k.c. This means that so long as we are listening to WMAQ our oscillator frequency is 1126 k.c. This is as it should be, for the 670 k.c. R-F and 1126 oscillator frequency beat together provide the desired 456 k.c. I-F frequency. But what else is happening at the same time?

Evanston, Illinois, is a northern suburb of Chicago. Station WNMP, Evanston, broadcasts on an assigned frequency of 1590 k.c. While the power of WNMP is somewhat lower than WMAQ, it comes in strongly to radio receivers located on Chicago's north side. If any of these receivers, located within a radius of about three or four miles from WNMP, are attempting to receive WMAQ (the 670 k.c. station in Chicago) their oscillators will be set at 1126 k.c. Since the plate load impedance of these receivers are tuned to the I-F (456 k.c.) they will pick up any signal whose difference from the oscillator is 456 k.c. It can now be seen that both WMAQ and WNMP must meet the required conditions.

The signal of WMAQ is brought in because 1126 k.c. minus 670 k.c. equals 456 k.c.

The signal of WNMP (not desired at this time) is brought in because 1590 k.c. minus 1126 k.c. very nearly equals 456 k.c.

The results are that the signals from both stations will be sent through the I-F amplifier, the audio stages, and will be heard in the speaker at the same time. This is known as *cross-talk*. In addition, since WNMP's frequency is 1590 k.c. and not 1582 (exactly 456 k.c. above the oscillator) a beat frequency audible to the ear, will be developed. This will be evident as a whistle which accompanies the crossed signals when the receiver is tuned to WMAQ.

From the above example, with which those of us in Chicago are quite familiar, we may draw some important general conclusions.

For every setting of the receiver tuning dial there is a corresponding oscillator frequency. And for every setting of the oscillator, there is a corresponding possible image frequency which is undesired.

The following table will illustrate the relationship between the R-F frequencies and images of a superheterodyne receiver whose I-F is tuned to 456 k.c.

Note that the oscillator frequency for each R-F setting is given, and that it equals the R-F plus the I-F values.

R-F SETTING, k.c.	OSCILLATOR FREQUENCY, k.c.	POSSIBLE IMAGE FREQUENCY, k.c.
500	956	1412
600	1056	1512
700	1156	1612
800	1256	1712
900	1356	1812
1000	1456	1912
1100	1556	2012
1200	1656	2112
1300	1756	2212
1400	1856	2312
1500	1956	2412
1600	2056	2512
1700	2156	2612

Note also that the possible image frequency is equal to twice the I-F plus the R-F values.

RULE: To find the oscillator frequency for a given R-F setting, add the I-F to the incoming R-F frequency.

RULE: To find the image frequency for a given R-F setting, add twice the I-F to the incoming R-F frequency; or (which is the same thing) add the I-F to the oscillator frequency.

From the point of view of trouble-shooting, we may take several further steps in our analysis of image frequencies. We shall attempt to satisfactorily answer the question of how do we eliminate, or at least minimize, image frequencies?

Casting a glance back at Fig. 19, we can see that the superheterodyne receiver represented there contains at least a partial answer to the question of minimizing image frequencies. We notice that any signal hoping to get into the I-F tuned stages must first be delivered through the tuned R-F stages to the mixer. If we are tuned to WMAQ at 670 k.c., the signal from WNMP, at 1590 k.c., is certainly going to meet some discrimination in the R-F tuned circuits. For a tuned circuit, resonant at 670 k.c. is not going to readily accept one at 1590 k.c., unless the 1590 k.c. signal is very strong.

If the receiver, therefore, is either located very close to the interfering transmitter, or picks up a strong signal from the interfering transmitter, then an image is almost inevitable, for even if the R-F circuit is tuned to reject the image, the strength of the image may still impress itself on the signal grid of the mixer. Images from WNMP, in the previous example, are a case in point. Under certain conditions, WNMP comes in as an image only in its immediate vicinity, when the receiver dial is tuned to WMAQ.

This suggests several possible answers to the question of eliminating or minimizing images. The first and most obvious answer is that if we include an additional tuned R-F stage in the receiver, the ability to reject even a strong image will be an aid to minimizing the interference. For in this case, the image will have to crash through two circuits tuned to another frequency. Such an added tuned R-F stage is called a *pre-selector stage,* and comes as standard equipment with most large home model receivers which are usually better engineered than the less expensive receivers.

While technically correct, this answer has certain important and practical drawbacks. If, for instance, a receiver already containing a pre-selector stage still brings in an image frequency, then it will be necessary to add a third R-F tuning stage. This is not a simple matter, from the practical point of view. The variable condenser gang will have to be replaced to include another section, a new R-F transformer must be included, and another amplifier tube must be supplied. Seldom is there room on a commercially made radio chassis to mount all these necessary parts.

In the case of a small receiver the conditions are even more acute. Table model AC-DC and portable receivers, as well as automobile sets, are so compact that one wonders how all the components were originally made to fit the small available space. Adding several large-sized components to minimize image frequencies is almost out of the question.

There is, happily, another answer to the question of minimizing image frequencies, one that is as simple as a twist of the wrist, in most cases.

Today many radio receivers are made with loop antennas. The loop antenna is essentially a coil of wire, and sometimes consists of two coils wound together in the manner of a transformer.

The radio wave, as was pointed out many years ago by James Clerk Maxwell, and known to be true today, consists of both electromagnetic and electrostatic components. The loop antenna, being a coil, is responsive mostly to the electromagnetic waves, and further, the loop antenna will pick up these electromagnetic waves better in one position than in any other. This is equivalent to saying that the loop antenna is highly directional. This means, of course, that by changing the position of the loop antenna with respect to the direction of the interfering station, we can readily minimize its image interference.

This principle is illustrated in Fig. 22. If WNMP comes in as an image when the receiver is tuned to WMAQ. It is simply necessary to rotate the loop antenna as

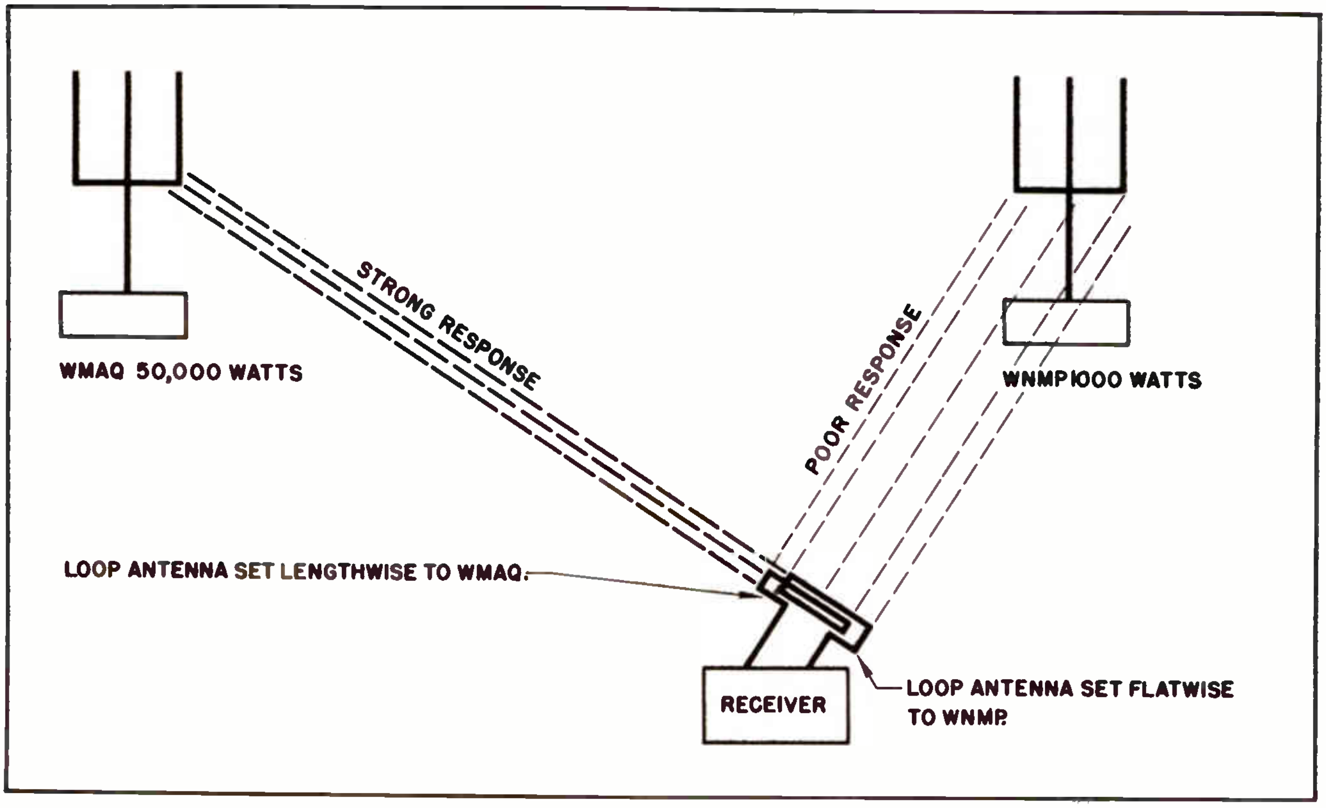


Fig.22. How a Loop Antenna can be Rotated to Eliminate Image Reception.

indicated, flatwise toward WNMP and lengthwise to WMAQ. This decreases the sensitivity of the loop to the image signal and strengthens it to the desired signal.

While it is true that stations interfering with each other do not always line themselves up at 90-degree angles, it is generally found that the stations with highest power are either at the low end or the middle of the dial, while the lower powered stations are at the high end of the dial. This is not an accidental arrangement, but was planned by Federal Communications Authorities specifically for the purpose of minimizing image interference between stations. A high-powered station at the low end of the dial cannot show up on the broadcast band as an interfering image, because its image is below the lower limit of the band. This means simply that the only images which may appear are generally from low-power transmitters. Even if two interfering stations, therefore, are not lined up at a 90-degree angle with the receiver, the position of the loop antenna is not important with respect to the desired station so long as it is flatwise to the interfering station.

One further point should be stressed. You may wonder that if we turn the receiver loop antenna to minimize the image from a station, perhaps we will weaken the signal at the loop antenna so much that we cannot receive this station when we tune to it. The answer can be simply stated: If the interfering station is strong enough to come in as an image, then it is strong enough to come in at its regular place on the dial, even with the loop antenna turned flatwise against it.

Loop antennas come in various forms. In small receivers they are generally mounted behind the chassis inside the cabinet. In some portable models, they are wound around the inside of the cabinet. In cases where the loop antenna is fixed to the receiver, the entire receiver must be turned to turn the loop. This is not as inconvenient as it seems. In the average living room, there is always some spot that the radio receiver can occupy, and still be placed in the best possible electrical position.

The method described for overcoming image frequencies may seem to contradict the general practice of turning a loop antenna broadside to a desired station. But it works.

Outside antennas, on the other hand, are not so easy to turn. However, where no other method is available for minimizing image frequencies, it may be necessary to try several different positions of the outside antenna, and check the results of image interference.

Where all else fails to minimize image interference, as a last resort, it may be possible to detune the I-F stages slightly. This detuning will, of course, alter the tracking characteristics of the receiver, and may not actually eliminate the image. However, it may place the interfering image at some point other than directly on a desired station. If such an adjustment does not seriously affect the tracking of the set, it may be done as a last resort.

Section 16. CONDENSER CALCULATIONS

The capacity of two condensers in parallel is equal to the sum of the individual capacities. (See Fig. 23.) Since the capacity of two condensers in parallel is greater than either by itself, it follows that the *capacitive reactance* of two condensers in parallel is *lower* than that of either by itself.

The formula for finding the capacity of two or more condensers in parallel is:

$$C_T = C_1 + C_2 + C_3 + \ldots$$

The *capacity* of condensers in *parallel* is figured in exactly the same way as the resistance of resistors in *series*. But the *capacitive reactance* of condensers in *parallel* is figured in exactly the same way we figure the resistance of resistors in *parallel*. The reason is that as the capacity increases, the capacitive reactance will decrease. The main point to remember is that when we place two or more condensers in parallel it has the same effect as increasing the area of the condenser plates. We already know that increasing the plate area of a condenser will increase its capacity and reduce its capacitive reactance.

Another important thing about condensers is that when we place two of them in series we reduce the total capacity below that of the smallest individual condenser. The reason is that when two condensers are placed in series it has the effect of increasing the distance between the plates. We already know that increasing the distance between the plates of a condenser has the effect of reducing its capacity.

In Fig. 24 we find a 4 mfd condenser in series with a 3 mfd condenser. It seems rather obvious from our previous studies that C_2, the 3 mfd condenser, is going to present a certain amount of opposition to the flow of A-C. The exact amount will depend upon the frequency. Now, in addition to C_2 we have another condenser in the circuit. This second condenser is also going to oppose the flow of current. Since these two condensers are in series with each other, it is only reasonable to assume that to obtain the total opposition, or reactance, their individual reactances should be added together. Such an assumption would be correct.

The formula for finding the total capacitive reactance of two or more condensers in series is:

$$X_c = X_{c_1} + X_{c_2} + X_{c_3} \ldots$$

Note very carefully that the above formula applies to capacitive *reactances* in series; not to *capacities* in series.

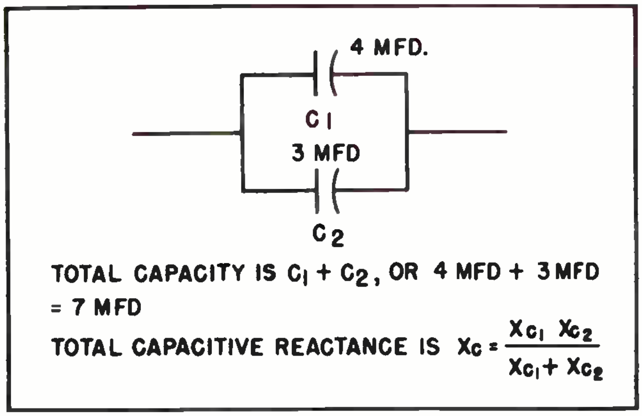


Fig. 23. Condensers in Parallel.

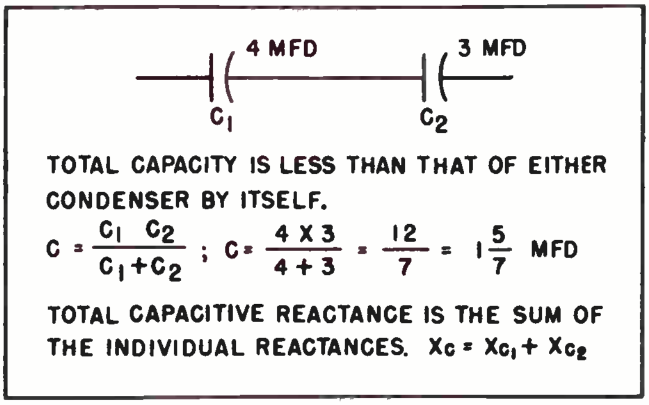
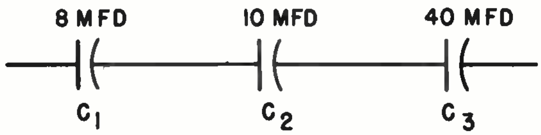


Fig. 24. Condensers in Series.



$$C_T = \frac{1}{\frac{1}{8}+\frac{1}{10}+\frac{1}{40}} = \frac{1}{\frac{5}{40}+\frac{4}{40}+\frac{1}{40}} = \frac{1}{\frac{10}{40}}$$

$$C_T = \frac{1}{\frac{10}{40}} = 1 \div \frac{10}{40} = 1 \times \frac{40}{10} = \frac{40}{10} = 4\text{ MFD}$$

Fig.25. Calculating Condensers in Series.

Unfortunately, when we have two or more condensers in series we do not usually know their individual reactances. We always know their capacities but not their capacitive reactances.

To determine the total capacitive reactance of several capacitors in series we must usually find the total capacity first. Since the reactances of condensers in series add together, it seems reasonable to assume the total *effective* capacity of such condensers would be less. This is true, but we are faced with the problem of determining *how much* less. Fortunately, this problem is not very serious. The total capacity of condensers in series is exactly the same as finding *resistances in parallel*, or of finding *capacitive reactances in parallel.*

Where two condensers are in series, the formula shown in Fig. 24 can be used. This is:

$$C_t = \frac{C_1\ C_2}{C_1 + C_2}$$

Note the similarity between this formula and the one for finding the effective resistance of two resistors in parallel.

When three or more condensers are in *series*, it is better to use the reciprocal method. This is very similar to the reciprocal method for finding effective resistance of three or more resistors in *parallel.*

The reciprocal formula for finding the total effective capacity of three or more condensers in series is:

$$C_t = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ \cdots\cdots}$$

Note the similarity between this formula and that for finding the effective resistance of resistors in parallel.

In Fig. 25 we have an 8 mfd, a 10 mfd, and a 40 mfd capacitor in series with each other. If we wanted to find the total reactance such a combination would present to the flow of alternating current we could go about solving the problem in either of two ways. We could calculate the individual reactance of each condenser by the use of the formula

$$X_c = \frac{1}{2\pi f c}$$

and then add all these reactances together. But the more logical procedure would be to determine the total effective capacity, as in Fig. 25, then find the reactance. The latter method is usually much easier and faster. Once you have found that the effective capacity of the three condensers is 4 mfd, it is a simple matter to find the total reactance by

$$X_c = \frac{1}{2\pi f\ .000004}$$

A further advantage is that if the reactance must be found for several frequencies, much work is saved by first finding the total effective capacity.

You might feel that this business of calculating capacity and reactance is all very interesting, but of what practical value is it to a radio or television technician? The best answer to that is to take the situation of the several capacitors in the resonant circuit of the oscillator section described earlier in this lesson. Here we have a tuned resonant circuit which can be varied to resonate at many frequencies.

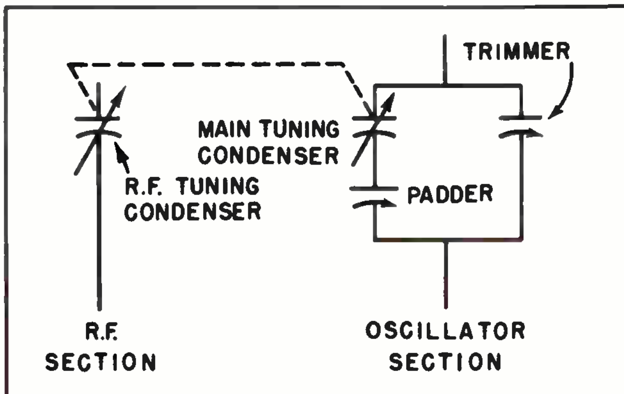


Fig. 26.

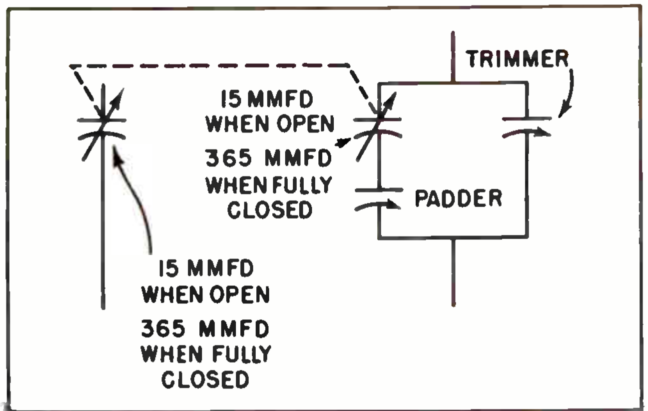


Fig. 27.

The variable component of the circuit is a variable air-core condenser. This condenser is mechanically connected with another condenser in another variably tuned resonant circuit, all of which you are now already familiar with.

Let us study Fig. 26 for a moment. The R-F tuning condenser and the main oscillator condenser are made as a single unit by a condenser manufacturer who specializes in building that one item.

The ganged tuning condenser is well made, precisely made in fact. But by their very nature, it is almost impossible to make any two of them exactly alike. As a practical example, let us suppose we have a gang condenser which has a capacity of 365 mmfds (micro-microfarads) for each section when the rotor is fully closed. This means there will be 365 mmfds in the main section and 365 mmfds in the oscillator section. (See Fig. 27.) But when the rotor is turned out into the position of minimum capacity, each section will have only 15 mmfds capacity. (This is equivalent to .000,000,000,015 farads.) These values are typical of those found in common 2-gang variable condensers.

Now we say the ganged condensers are rated at 365 mmfds. This is the value the manufacturer strives to attain. But a microscopically small variation of the spacing between the plates of the rotor and those of the stator will change the capacity of the condenser. Such variations will creep in, despite all precautions. Such variations affect the resonant frequency of the resonant circuit. Further than this, the coils which are a part of the resonant circuit will vary insofar as their values are concerned. Any variations there will also affect the resonant frequency.

All these things are actual practical matters which must be taken into consideration. They cannot be avoided. Since they cannot be avoided, it becomes necessary to take steps to allow for them. These allowances have been built into radio and television receivers in the form of trimmer and padder condensers.

In Fig. 28 we have an oscillator section in which the capacity of the main variable condenser has been reduced to a minimum of 15 mmfds. This is the condition which would exist when tuning in a station at the high end of the band. Now in series with the main condenser is the padder condenser with 1000 mmfds.

The total capacity of two capacitors in a series circuit is less than that of the smaller one. In this circuit the total effect of the two condensers in series is such that the padder has virtually no effect. The capacity of the main condenser is 15 mmfds, but the capacity of the two in series reduces the effective capacity of that branch of the circuit to approximately 14.75 mmfd, a negligible reduction.

By this we can see that when the capacity of the main variable condenser has been reduced to its minimum value, the effect of the padder is negligible. We could say this in another way by saying the padder has little effect on the high end of the band.

But let's see what effect the trimmer has on the capacity of the resonant circuit when the variable condenser is at minimum value. The trimmer can be varied between 0 and 10 mmfd. If the trimmer has zero capacity, it has no effect on the circuit. But if it's capacity is increased, it will have almost as much effect on the resonant circuit as the main variable.

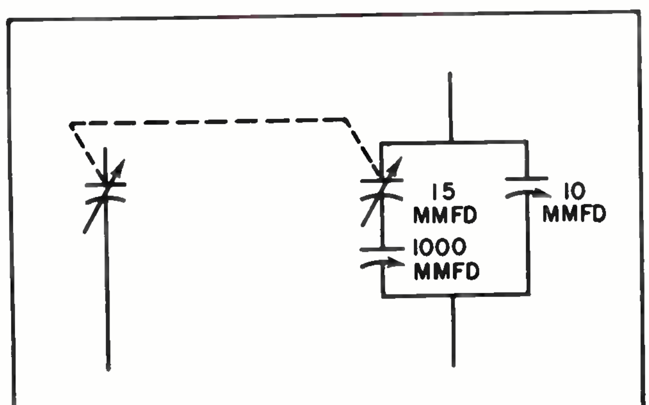


Fig. 28.

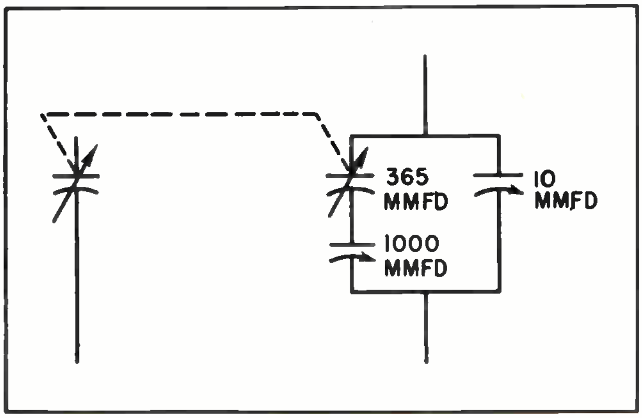


Fig. 29.

Another way of saying this is that at the high frequency end of the band the trimmer has almost a major effect on the resonant frequency.

Now let's see what happens when the capacity of the main variable is increased to its greatest value, 365 mmfds. At this time we could add or subtract the 10 mmfds of the trimmer to the circuit and the effect would be unimportant. Thus, if we had to add some 7 mmfds of the trimmer's capacity to the resonant circuit at the high end of the band to make the two circuits "track" properly, this excess capacity would have little effect on the circuit when the capacity of the main variable is increased.

Another way of saying this is: The trimmer has great effect on the resonant circuit when the main variable is minimum, but little effect when the main variable is maximum.

Let us now see what the effect of the padder is when the main variable is maximum.

The 365 mmfds and the 1000 mmfds are in series. The total capacity will be less than either. With 1000 mmfds in the padder, the total capacity of that branch of the circuit will be approximately 267 mmfds.

Despite the fact the main variable is mechanically coupled to another external variable circuit, and we cannot change the main variable without affecting the other circuit, we can use the padder to vary the capacity of the circuit at the lower end of the band. By properly adjusting the padder's capacity, we can increase the capacity of the circuit, or reduce it, without moving the main variable.

We now find that we can obtain exactly the correct capacity at the high end of the band by properly choosing the correct value of *trimmer* capacity. We can obtain exactly the correct capacity at the low end of the band by properly choosing the correct value of *padder* capacity. Thus we can readily adjust the oscillator frequency so it will always differ from the R-F frequency by exactly the right amount.

While we have used the oscillator circuit for a superheterodyne as an example of the need for being able to calculate capacity, this is not the only place such knowledge is needed. In fact, this particular example was chosen because it was especially easy to understand.

NOTES FOR REFERENCE

The mixer stage is the very heart of the superheterodyne receiver. It is also known by the names: converter, oscillator-mixer, first detector, and frequency-converter.

The purpose of the mixer stage is to transfer the audio modulation from the R-F carrier to the I-F carrier within the receiver.

Heterodyning is the process of beating two frequencies together in a non-linear amplifier for the purpose of capturing their difference. For all practical purposes, heterodyning means fixing. In order to know what kind of a mixer stage to expect in a receiver, the receiver should be identified with respect to its power supply and signal circuits.

Mixer stage troubles may be readily suspected when the receiver tubes light in the set and all test good on the tube checker, and the receiver seems "alive" but produces no signal of any kind.

The tube used in a mixer stage, in spite of the fact that it tests good on a tube-checker, may still be defective. The best test for a suspected mixer tube is to replace it with an equivalent known to be good.

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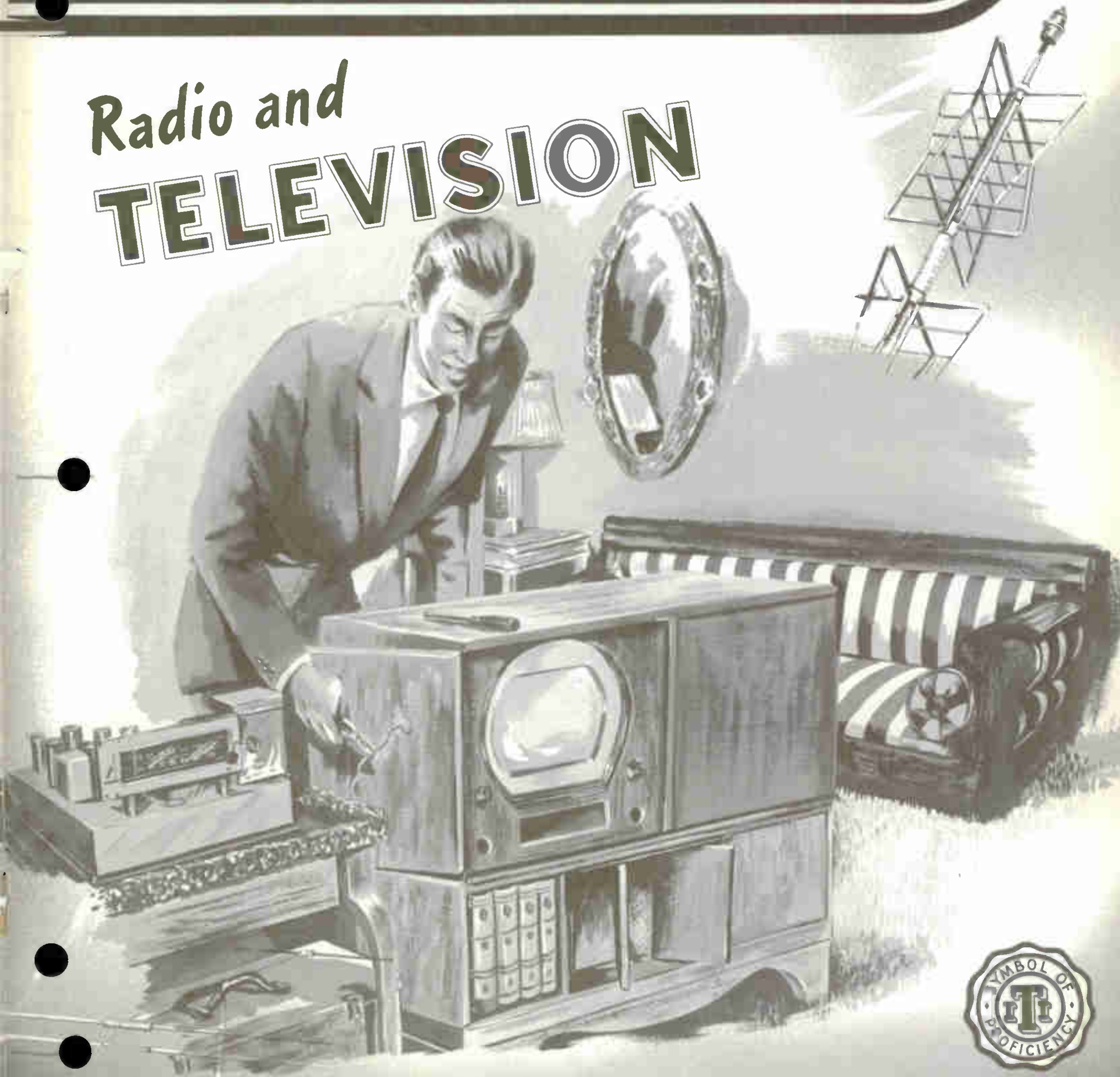

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RADIO TELEVISION

RADIO FREQUENCY CIRCUITS

Contents: Introduction - Operational Test for the R-F Section - General Symptoms of R-F Troubles - The Double-Wound Loop Antenna - Additional R-F Stages - Operational Test for the Pre-Amplifier - Symptoms of Pre-Amplifier Trouble - The Loop Antenna - The R-F Coupling Transformer - AVC Troubles in the R-F Amplifier - Identifying the R-F Section - The Effect of Pre-Amplifiers on Images - Aligning the R-F Section - Notes for Reference.

Section 1. INTRODUCTION

The purpose of the radio-frequency circuits in a superheterodyne radio or television receiver is to amplify the desired radio-borne signal, and select it from all other signals striking the antenna. Fig. 2 shows the block diagram of a superheterodyne radio receiver, emphasizing the R-F circuit and its relationship to the rest of the receiver.

It should be noted that in the TRF receiver (treated in a separate lesson) the R-F circuits comprise all of the tuned circuits, and their associated tubes. This means that all stages proceding the detector are R-F stages. In the superheterodyne receiver, however, the R-F circuits consist of only those preceding the mixer stage. R-F tuning and amplification takes place before, or during, the process that converts the modulated R-F in to the modulated I-F.

R-F circuits, or stages, are found in several different forms. They will be discussed in the order of their popularity. You will soon notice that the more simple R-F circuits are the ones most widely used.

Fig. 1 shows a photograph of a typical modern table model AC-DC radio receiver. There are literally millions of these receivers in use today. They are light, compact, and inexpensive. Their performance is a tribute to modern engineering and technical skill. Fig. 3 represents the schematic circuit of the first three stages of this receiver, and shows the beautiful simplicity of its design. Notice that only two tubes are shown, the functions of oscillating and mixing being combined in the oscillator-mixer tube known as the pentagrid converter. The other tube illustrated is the I-F amplifier, which sends its signal across the output I-F transformer into the second detector for recovery of the audio component.

We are already familiar with the process of converting a modulated R-F signal to a modulated I-F signal, and with the heterodyning principle involved in this conversion. This process takes place within the mixer tube, into which are injected, on separate grids, the two frequencies whose difference is the I-F frequency. Our studies in this

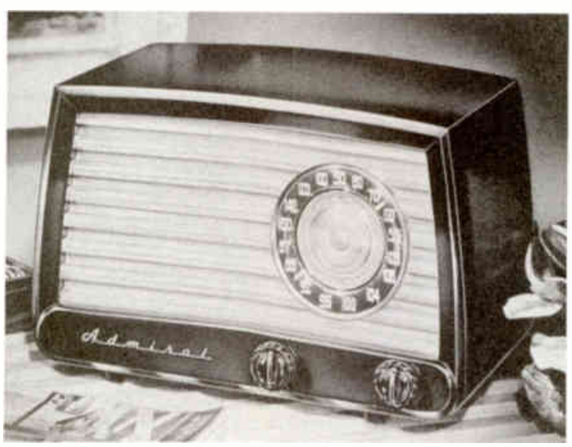


Fig. 1. This Receiver Contains a Simple R-F Section.

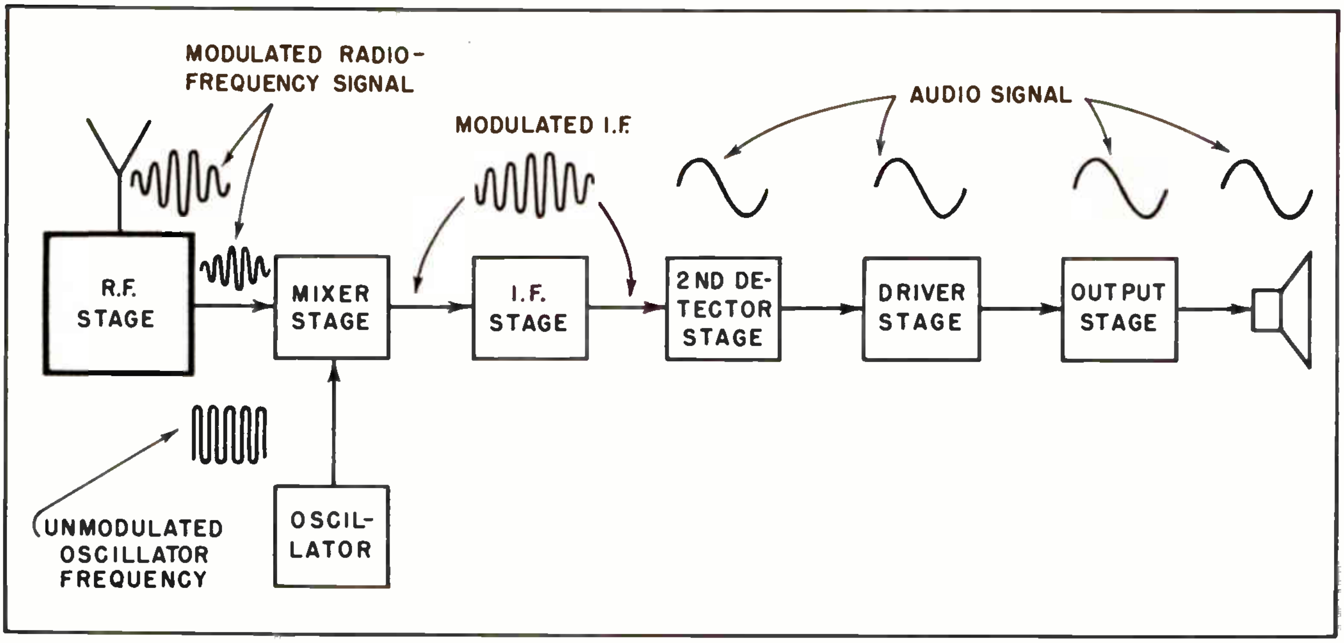


Fig. 2. Block Diagram of the Superheterodyne Receiver, Emphasizing the R-F Stages.

lesson are concerned with the electrical character of the circuits supplying the signal grid of the mixer stage with its pre-selected R-F modulated signal.

Referring now to Fig. 3, we recognize the loop antenna as the source of the R-F signal voltage. Its broad cross-section is continually being cut by lines of magnetic force emitted at the transmitter and traveling past at the incredible speed of 186,000 miles per second.

The loop acts like any coil of wire cut by magnetic lines of force -- a voltage is induced within the turns of the coil, and this voltage corresponds exactly with the frequency of the changes in the lines of force that cut its wires. This frequency we know to be that of the transmitter. The audio signal is borne upon the R-F carrier in the form of amplitude modulation. The result is that the action of the loop antenna can be compared with that of a generator which produces a voltage at radio frequencies.

Needless to say, the loop will be cut, in varying strength, by all lines of force which strike it. In a large American city, such as Chicago, New York, or Los Angeles, there are at least a dozen AM transmitting stations, several FM, from one to seven television stations, and countless low-power transmitters for police, public utility and amateur services. It can be readily seen that the loop of an ordinary broadcast band radio receiver, located in a big city, will be literally overwhelmed with hundreds of assorted radio-frequency carrier signals. If we were to demodulate all these signals, the resulting sound at the loudspeaker would be like the mingled voices in the Tower of Babel.

It is evident that some separating process must take place -- we must select one signal from the multitude, and reject all others. Otherwise we cannot hope to enjoy or appreciate a radio program, or use the receiver to receive any reasonable sort of intelligence. Moreover, there is one more requirement. Not only must we be able to accept one signal, but we must be able to accept a certain range of signals, only one at a time, and we must be able to conveniently switch from one signal within the range to any other within the same range. The circuit of Fig. 3 shows how these requirements are met.

Operating in parallel with the turns of the loop antenna to form a tuned circuit is the R-F tuning condenser. The magical property of a tuned circuit is already known to us. We recall that the frequency to which an inductance and a capacitor are resonant is given by

$$F_r = \frac{1}{2\pi\sqrt{LC}}$$

where F_r is the resonant frequency, L is the inductance in henrys, and C the capacity in farads.

By selecting the proper values of capacity and inductance in the components of this R-F tuning circuit, we can predetermine the frequency to which it is resonant. Notice that the tuning capacitor is variable. This simply means that there is a certain minimum and a certain maximum capacity which can be shunted across the coil of the loop antenna. This tuning condenser is mechanically attached to the station selector knob on the face of the receiver. When the knob is turned to increase the capacity, the resonant frequency of the circuit decreases. When the knob is turned to reduce the capacity, the resonant frequency of the circuit increases. In the light of the above formula for resonant frequency, this action is in keeping with both the mathematical and electrical facts.

The variable air condenser of the typical superheterodyne receiver is so made as to resonate the coil which it parallels somewhere between the frequencies of 550 k.c. as a minimum and 1600 k.c. as a maximum. This not only provides the necessary range of frequencies for this receiver, but also the ability to select any station within that range from all the others.

As an illustration, let us take this receiver within the City of Chicago. At the low end of the dial, 560 k.c., we find that the tuning condenser is almost fully meshed when we pick up WIND. At the middle of the dial, 1000 k.c., we find WCFL, with the variable tuning condenser about half-way open. At the upper end of the dial, WNMP, operating at 1590 k.c., comes in when the tuning condenser is almost all the way open. There are, of course, many other stations located at convenient intervals between those mentioned, the broadcast band being practically overflowing with transmitting stations.

That the modern superheterodyne receiver can select one -- and only one -- of these many signals on the same band is a miracle

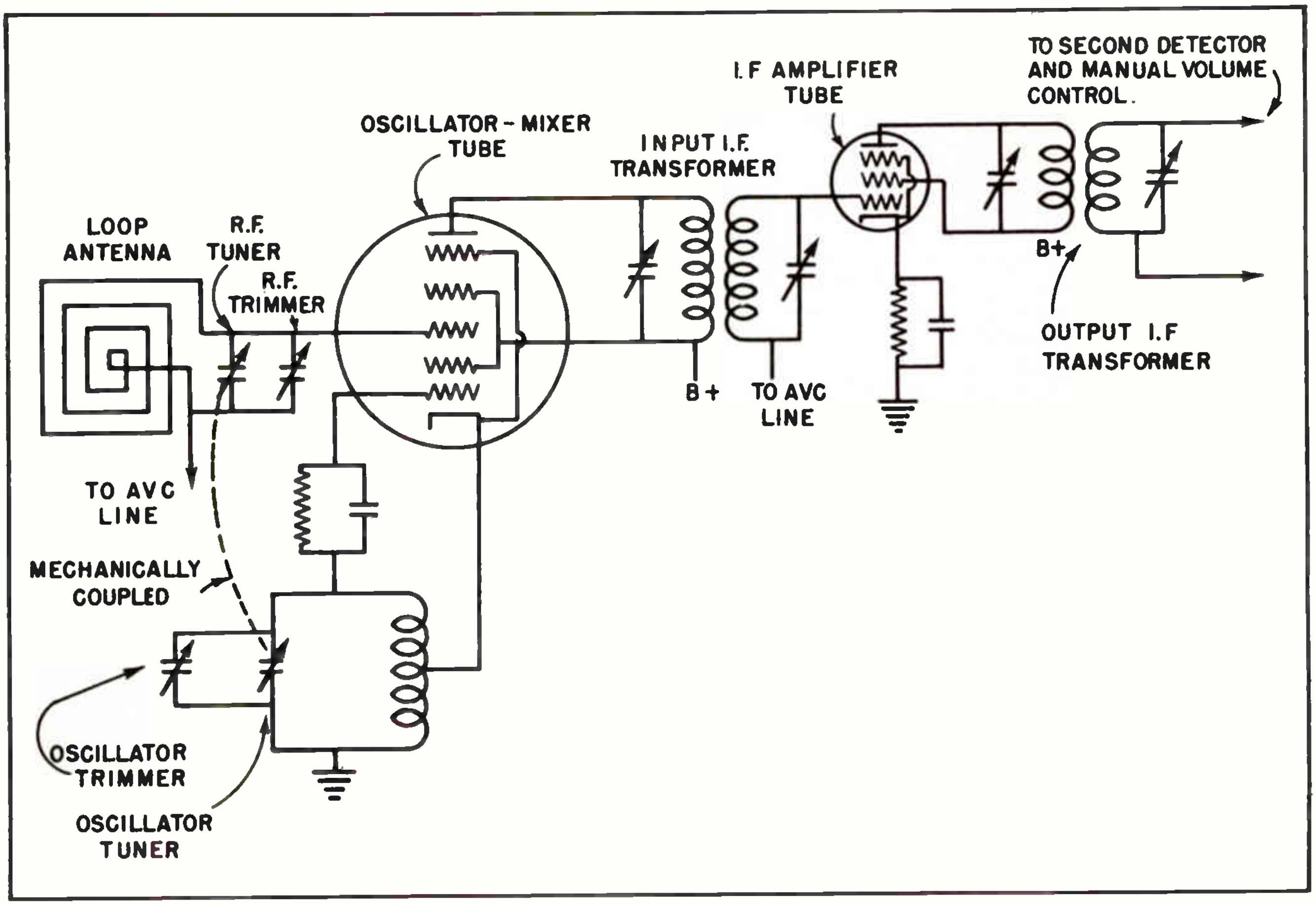


Fig.3. The Input R-F Circuit of the Table-Model Superheterodyne Receiver, Using a Loop Antenna.

of circuit design. This has especial reference to the radio frequency circuits which are the subject of this lesson.

The purpose of the loop antenna, then, is to "capture" the signal impulses from the transmitted wave as it travels through space, and at the same time to act as the inductance of the R-F tuned circuit in which the tuning condenser is the capacity. Since the loop is wound with a fixed number of turns, it is not variable. The tuning condenser, however, is variable, and provides the range of resonant frequencies within the broadcast band. Although the average user of this radio receiver does not realize it, he is actually changing the capacity of the tuned R-F circuit when he manually selects a station on the broadcast band. (We already know that the oscillator variable condenser is mechanically coupled to the R-F tuning capacitor. The user of the receiver is also varying the capacity of the oscillator condenser when he selects a station.)

The tuning condenser in parallel with the loop antenna serves the important function of resonating the R-F Inductance-Capacity combination to a desired frequency. This frequency, of course, is that of the station to which the user wants to listen.

The trimmer, in parallel with the main R-F tuner, is adjusted only during the alignment procedure, as was mentioned in an earlier lesson. This alignment procedure, with special emphasis on the R-F circuits, will be discussed at length.

We may now see how simple this R-F tuning circuit is in the small receiver. Notice in Fig. 3, that one end of the loop antenna leads to the AVC line, and the other to the signal grid of the oscillator-mixer stage. A previous lesson has explained the purpose of AVC voltage at this grid, indicating that the gain of the oscillator-mixer stage with respect to the R-F signal is determined by the value of AVC voltage developed in the second detector stage. This value of AVC voltage at any moment is dependent upon the strength of the signal at the antenna, being high when the signal is strong and low when the signal is weak. In order to fulfill its function of maintaining the signal volume to the speaker at a constant level, the AVC voltage, acting upon the signal grids of both the I-F and oscillator-mixer stages, varies the gain of these stages in accordance with antenna signal strength.

The signal grid of the oscillator-mixer stage, like that of the I-F amplifier, is biased by AVC voltage which takes advantage of the remote cut-off characteristics of the tube used in that stage. The special characteristics of a remote cut-off tube are discussed in another lesson. The AVC voltage is fed to the grid of the oscillator-mixer through the windings of the loop antenna.

We also recall from our earlier study of tubes that all grids within a tube must have some path by which they may dispose of excess electrons which they pick up from the electron stream. The loop antenna provides this leakage path, permitting excess electrons to flow through the AVC circuit to common ground.

Amplification of the R-F signal in the oscillator-mixer stage is accomplished by the transconductance characteristics of the tube. This enables the tube to produce rather large plate current changes while the signal grid is driven with relatively weak R-F voltages. It should also be pointed out here, as it was in a previous lesson, that the heterodyning process also takes place within the electron stream of this tube. In this case we see that the process of heterodyning (or mixing) is coincident in this stage with the process of amplification. The sketch in Fig. 4 will help to emphasize and clarify the action which takes place in the oscillator-mixer stage.

The simplicity of this circuit, illustrated in Fig. 3, is quite evident when we consider that the entire R-F section consists only of the loop antenna, the R-F tuning condenser, and its trimmer.

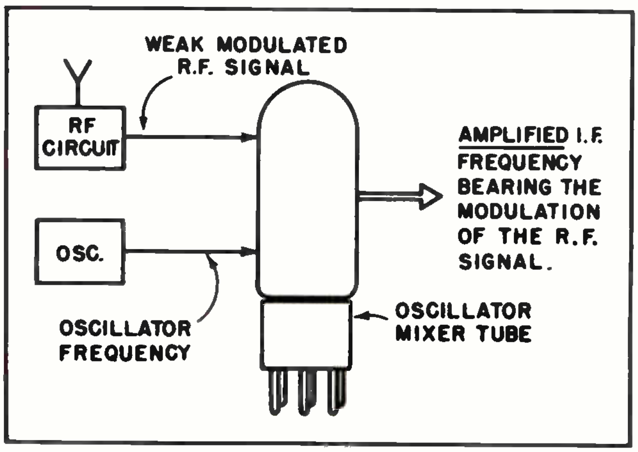


Fig.4. The Input and Output Frequencies of Oscillator-Mixer Tube.

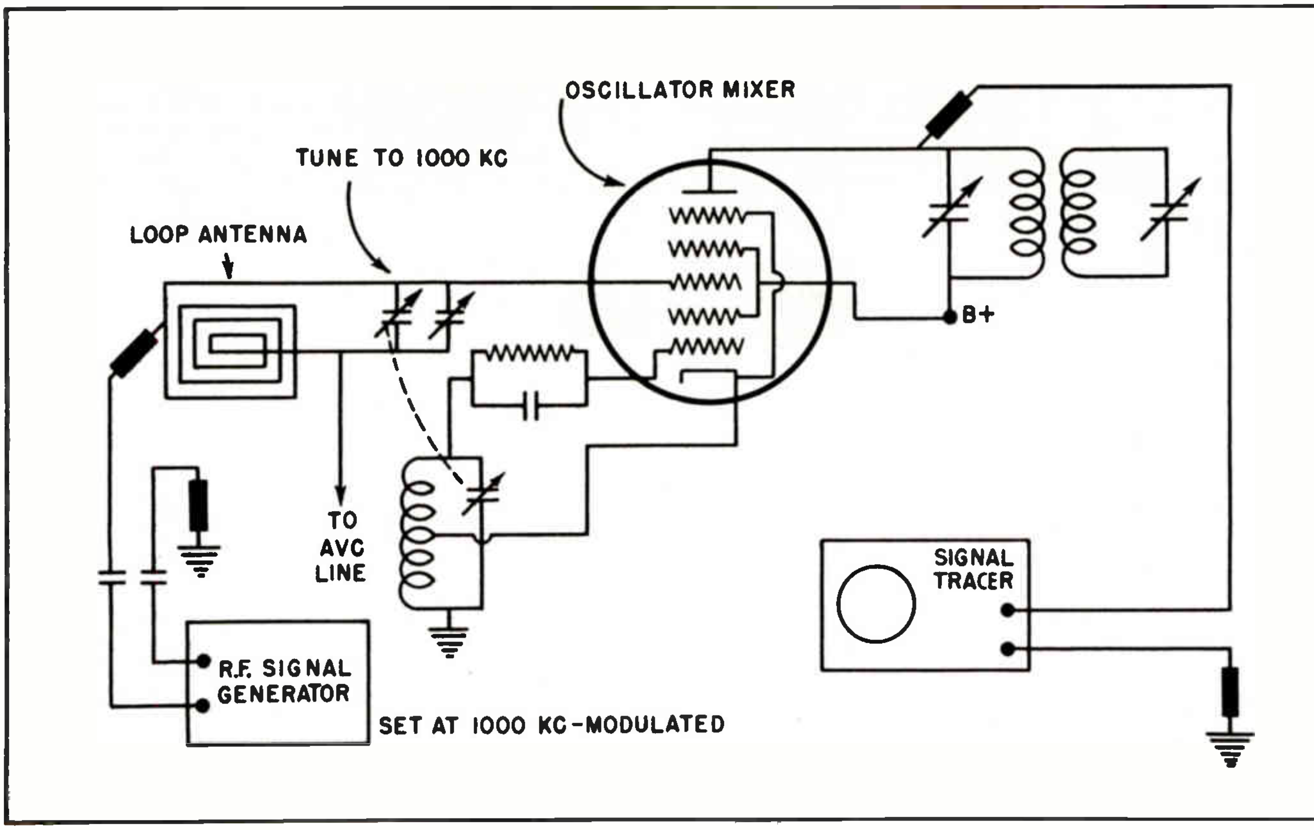


Fig.5. Locating a Defective R-F Section in a Small Superheterodyne Receiver.

Trouble-shooting this type of R-F circuit then becomes a simple matter of: (1) Determining that the trouble lies in the R-F section, and (2) Testing these three components for specific faults.

Section 2. **OPERATIONAL TEST FOR THE R-F SECTION**

Trouble in an R-F section of a superheterodyne receiver may be readily determined from a few simple facts.

If the power supply and all the tubes are known to be good, and if operational checks for all other stages prove them to be good, then the only remaining place for trouble is the R-F section. As is quite evident, this is simply a matter of elimination. If the tests of other component circuits have been carefully made, this method of elimination is extremely reliable.

A specific test, using a signal generator and signal tracer, can also be employed, with the arrangement shown in Fig. 5. We may interpret the action of this test in the following manner: If an R-F signal generator, tuned to 1000 k.c., is applied to the loop antenna, and the oscillator-mixer stage is known from previous tests to be good, the absence of the modulation sound as picked up by the signal tracer at the oscillator-mixer plate, indicates a defective R-F section.

The same test may be varied by omitting the signal tracer, but listening at the speaker for the modulation note. This assumes, of course, that all stages following the R-F section have been tested and found good. Bear in mind that in these two tests it must first be definitely established that the oscillator-mixer stage -- at least -- must be properly operating. This test was outlined in detail in the lesson on the mixer stage.

Section 3. **GENERAL SYMPTOMS OF R-F TROUBLES**

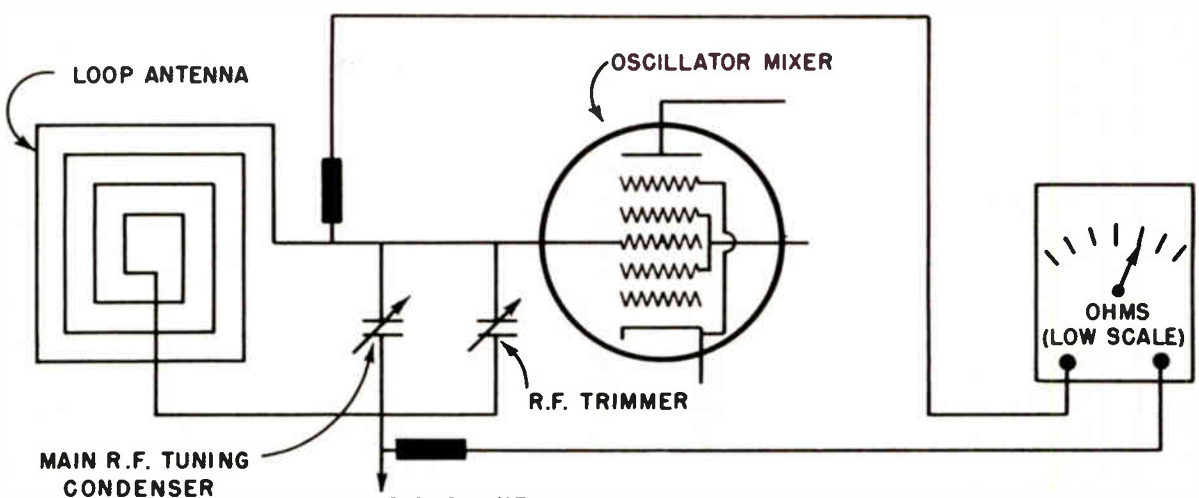
Trouble in the R-F circuits of a superheterodyne receiver may be readily inferred from the following easily observable facts and conditions:

If the value of B-plus is correct, and all the tubes check good, the received signal will be tunable throughout the dial, but will be very quiet. In addition, the quiet signal will be accompanied by a rushing or hissing sound which can be varied by the manual volume control.

In considering these symptoms which indicate trouble in the R-F circuits, two important things stand out. A quiet signal may be due to many troubles, including an open audio coupling condenser. A rushing or hissing sound may be due to many things, including an open .00025 R-F by-pass condenser in the second detector stage. But when a rushing or hissing sound is found in combination with a tunable quiet signal, then R-F troubles are indicated. The oscillator-mixer stage cannot be at fault, for the signal is tunable across the dial. The audio coupling condensers cannot be at fault for then the signal would be quiet, but there would be no hissing. The .00025 R-F by-pass cannot be at fault, for in this case there would be hissing, but the signal would be normally loud. In this way we may analyze this R-F trouble and show that the presence of certain symptoms, readings, or conditions automatically outrule many possible troubles. We then test each of the remaining possible troubles with the ohmmeter and the voltmeter, and thus quickly and accurately determine exactly what is wrong with a certain exact component in the R-F section.

The specific meter tests in the R-F section of Fig. 5 may be easily made with an ohmmeter on the R-F components. These, as we know, consist solely of the loop antenna, the R-F tuning condenser, and its trimmer. Fig. 6 shows these components by themselves, and indicates correct and incorrect ohmmeter reading, with their interpretations. Note that the lowest scale of the ohmmeter should be used. This is due to the very low ohmic resistance of the loop.

If the ohmmeter reads infinity, the loop winding must be open. If the ohmmeter reads zero -- and care should be exercised in reading the difference between zero ohms and one ohm -- then a short across the loop is indicated. In most cases, this short will be due to either scraping plates of the R-F variable condenser, or a shorted trimmer. Since both of these are electrically in parallel with the loop, the meter will read zero if either is shorted. To determine which of the two is shorted, it may be necessary to disconnect one lead from each of them, and then measure each of them separately. This, as we already know, isolates the condenser from the circuit that is in parallel with it, and insures a reliable ohmic reading of that condenser alone.



NOTE: WITH RECEIVER TURNED OFF, PLACE OHMMETER LEADS AS INDICATED. LOOP RESISTANCE SHOULD READ 1-5 OHMS.

IF READING IS INFINITE, LOOP WINDING IS OPEN.

IF READING IS ZERO, EITHER THE R.F. MAIN CONDENSER, OR ITS TRIMMER, MAY BE SHORTED.

Fig. 6. Checking for Opens and Short-Circuits in Loop Antenna Circuit.

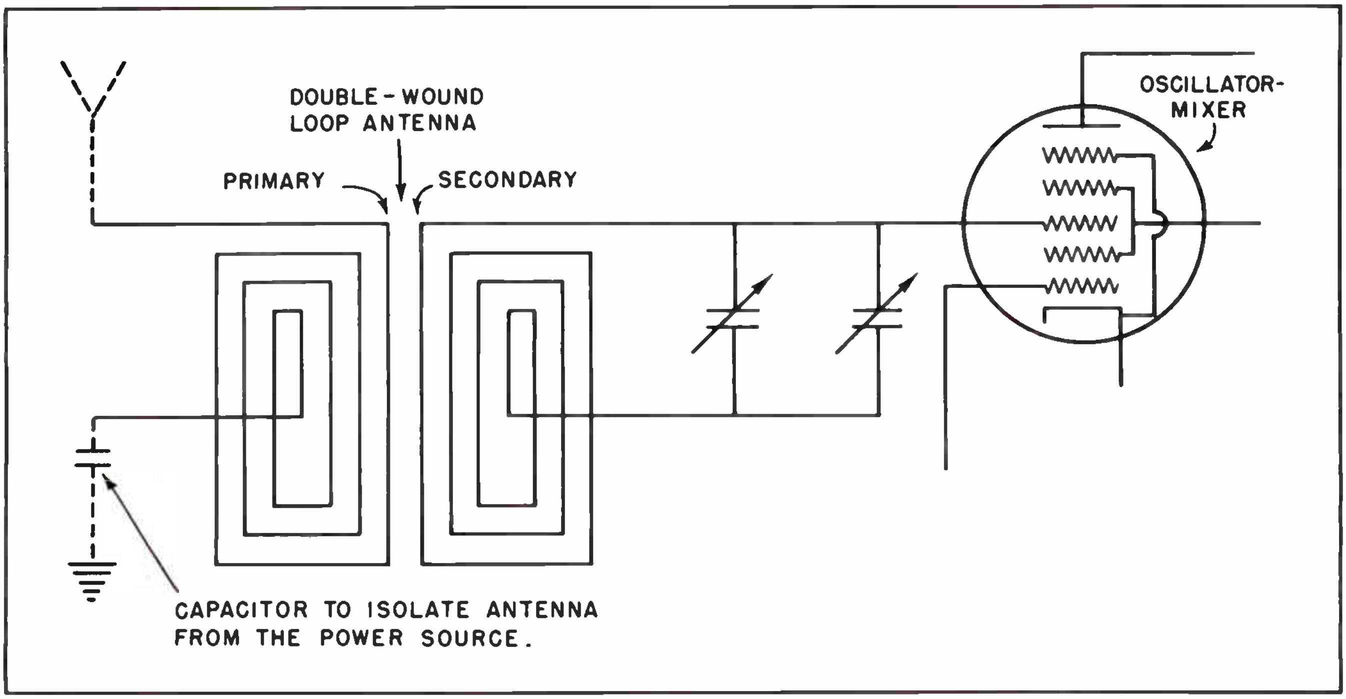


Fig.7. How the Double-Wound Loop Antenna Acts Like an R-F Transformer.

Another important point should be mentioned here. If we read a value of one to five ohms as the resistance across the loop, and still are confident that the trouble lies in the R-F section, we may infer that the main R-F tuning condenser is open. An open in this unit simply means that one of the wires connecting to its two sets of plates must have become disconnected. A visual inspection of the terminals of this condenser will reveal such a condition should it exist.

Section 4. THE DOUBLE-WOUND LOOP ANTENNA

The loop antenna symbolized in the previous Figures contain only one winding which acts to "capture" the R-F signal from the air. It also acts as the inductance of the resonant R-F circuit tuning the R-F signal. There is an important variation in the general construction as is shown in Fig. 7. Here the loop antenna consists of two separate windings and contains four lead wires. Two of the leads are for the primary winding and two for the secondary. A photo of this type of loop is shown in Fig. 8.

In reality, this is an R-F transformer, but of large dimensions. It has primary and secondary windings, isolated from electrical contact with each other, but wound close enough together to be magnetically coupled. If the receiver is in a large city, or near to strong transmitters, then the secondary only is used, and connected as in Fig. 3. If the receiver is to be operated at some distance from strong stations there is a provision for attaching an outside antenna to one end of the primary winding and attaching the other end to ground in the receiver. The windings, while still of large enough dimensions to pick up local stations with sufficient strength, is now also able to act as an ordinary transformer with primary connected to an outside antenna, and secondary feeding to the signal grid of the oscillator-mixer stage.

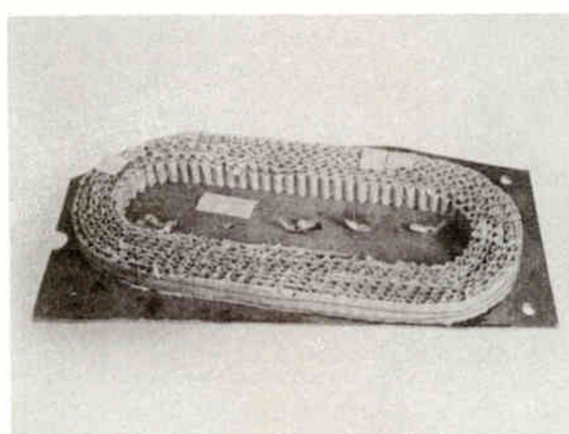


Fig.8. Double-Wound Loop Antenna. Note the Four Connecting Leads.

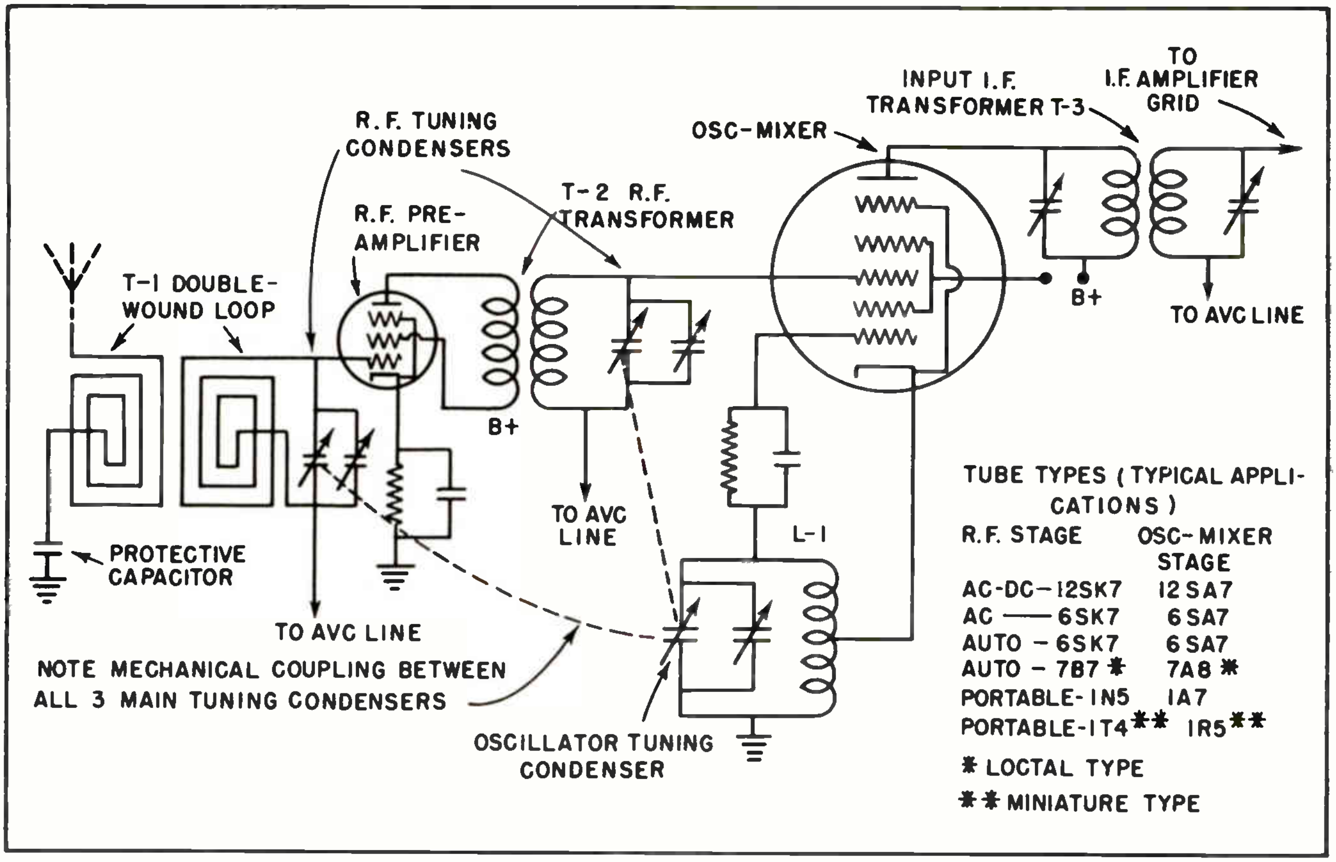


Fig.9. R-F Circuit Containing a Pre-Amplifier and a Loop Antenna.

This arrangement has these advantages: It permits the manufacturer to design and produce large-scale quantities of the identical receiver unit and yet make possible the use of the same receiver under varying conditions of signal availability. Used on the farm, or in small towns remote from major transmitting stations, the outside antenna would be connected. If used in large cities where the outside antenna is often inconvenient, the signals are strong enough to use the receiver without making any connections whatever to the loop primary.

In most cases where the double-wound loop is used, a capacitor, shown between the loop primary winding and ground, is installed to keep any voltage on the chassis from being fed through the primary to the antenna. In the case of AC-DC receivers, the chassis may be "hot" by as much as 115 volts with respect to earth ground. If this voltage were to be directly applied through the loop primary to the antenna, it would be dangerous to handle. Furthermore, it might short out the power supply and blow the supply fuse.

The danger of an antenna with line voltage on it, with respect to earth ground, can best be exemplified in cases where "outside" antenna is really not outside, but consists of a piece of not-too-well-insulated wire laid out of sight behind a davenport, or under a rug. Soapy water, during the washing of the floor, or direct contact with a portion of the bare antenna wire may easily result in very serious, perhaps even fatal results. The isolating capacitor, described above, is usually of about .001 mfd capacity, with a voltage rating of at least 200 volts.

Section 5. **ADDITIONAL R-F STAGES**

Even with its great popularity, the simple R-F circuit just described has its shortcomings. While satisfactory for the great majority of cases, it lacks adaptability for certain special, and common circumstances. These limitations can best be described as the lack of gain and lack of selectivity.

If the owner of such a small receiver is located at some remote part of the country that is not near any major transmitters, he will of necessity have to receive his programs from considerable distance. He will notice that while the signal is discernable at these comparatively long distances, it will not be quite strong enough for comfortable listening.

In order to add gain to such receiver, a common practice is to add to the R-F circuits one additional amplifying stage. Where exceptional gain is required, or desired, two additional amplifying stages may be added. Let us first consider the addition of one pre-amplifier stage, and show that if we add an amplifier stage, we will also be adding a measure of selectivity to the receiver.

Fig. 9 shows a schematic diagram of the single pre-amplifier stage and its connection to the oscillator-mixer of the superheterodyne receiver. The tubes shown are examples taken from a receiver using the A-C power supply, although corresponding tubes, with identical circuit design, would be used in the AC-DC receiver, as well as in the portable and automobile receivers.

Let us first identify the major components of this circuit layout.

T-1 is the double-wound loop antenna, which is identical in every way with that used in the receiver without a pre-amplifier. The primary may or may not be used, depending upon the proximity of the receiver to strong local signals. The secondary, instead of feeding an R-F signal voltage to the signal grid of the oscillator-mixer stage, now feeds it to the R-F pre-amplifier stage grid. Note the capacitors in the secondary loop circuit. The main tuning condenser is mechanically coupled to the other R-F tuning condenser in the oscillator-mixer signal grid circuit, as well as to the main oscillator condenser.

The pre-amplifier stage accepts the R-F signal, already selected from all others at the antenna by the tuned loop secondary, amplifies this voltage, and feeds it in turn to the signal grid of the oscillator-mixer. Here, this already selected frequency is again tuned, resulting in sharper selectivity of the desired signal. *T-2* is the R-F transformer, of the ordinary (non-loop) type. *T-3*, at the output of the mixer stage, is our already familiar first I-F transformer, the primary and secondary of which are both tuned to the intermediate frequency of the receiver. *L-1* is the auto-transformer of the oscillator tuned circuit. It is shown here in the form of a Hartley series oscillator circuit. In some cases this tuned circuit may be of the Armstrong type, in which case *L-1* would be shown as a transformer containing secondary and primary turns isolated from each other electrically, but magnetically related.

Let us pause for a moment to consider the R-F transformer *T-2*. For want of a better term, it is called the "ordinary" type of R-F transformer. The purpose of this "ordinary" R-F transformer is simply to couple the signal from the R-F amplifier stage to the oscillator-mixer stage. Its tuned secondary, of course, also aids in effecting additional selection of the desired signal from all others. The main difference between this ordinary coupling transformer and the loop-type transformer is that the latter is made so that it also acts as a signal-catcher. The ordinary R-F transformer is not designed with this feature in mind.

Fig. 10 is a photograph of an "ordinary" R-F coupling transformer, such as is used in the modern superheterodyne receiver. The windings of this transformer are often shielded by a metal can such as the one shown in the photograph.

Section 6. OPERATIONAL TEST FOR THE PRE-AMPLIFIER

The performance test for the pre-amplifier stage is identical in principle with that of the R-F circuit not involving the amplifier tube. Fig. 11 sketches the significant circuit components and the connections to signal generator and signal

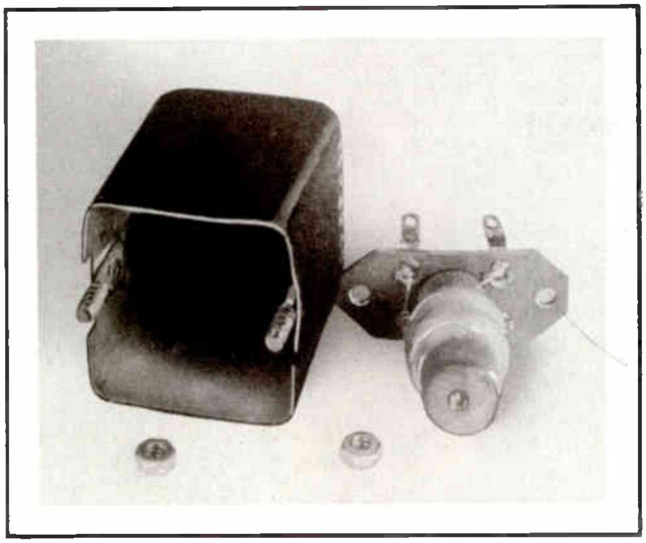


Fig.10. Ordinary R-F Transformer Removed from its Shielding Can.

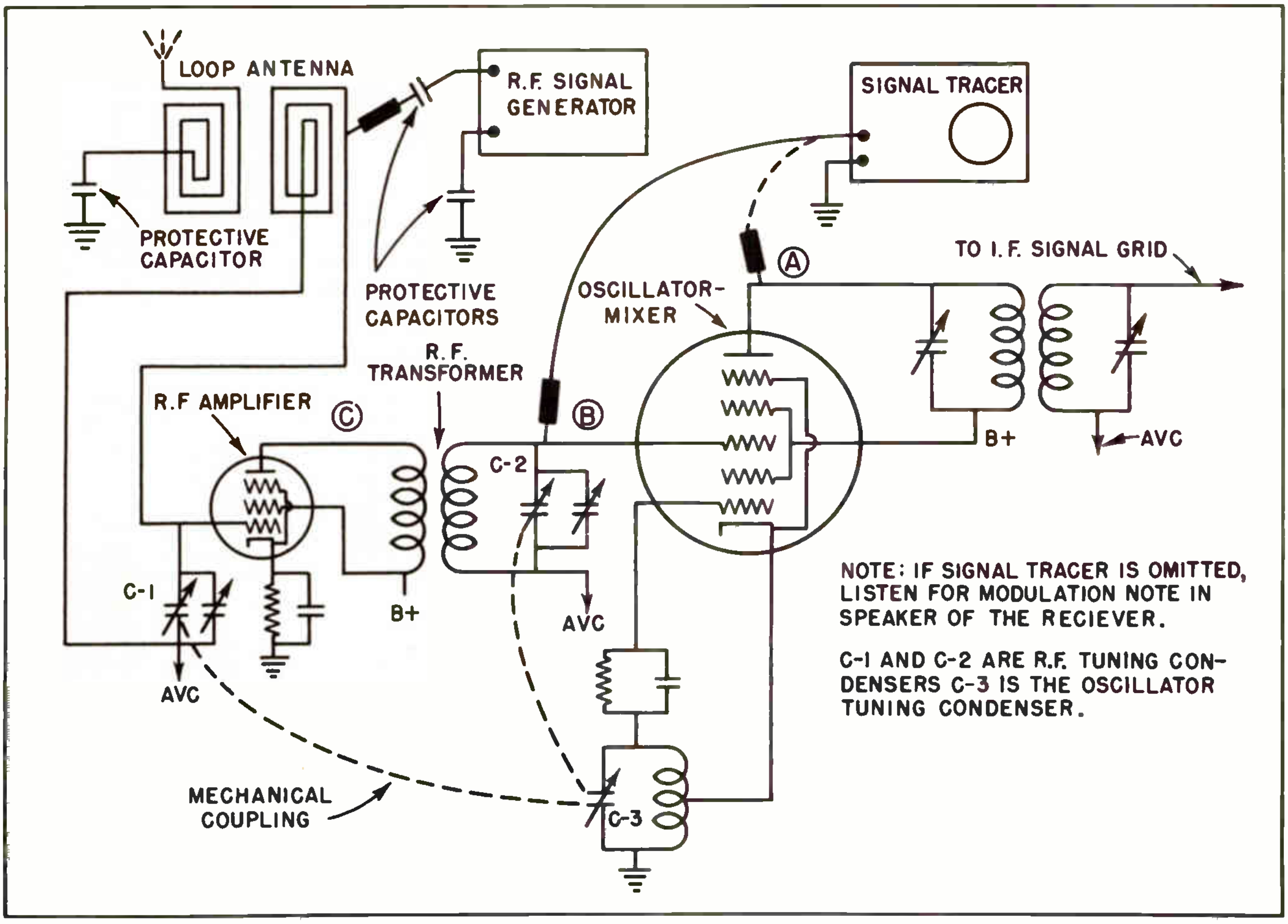


Fig. 11. Locating Trouble in a Pre-Amplifier Stage.

tracer. If the R-F amplifier is in working order, a 1000 k.c. signal, with audio modulation, introduced at the loop antenna will be heard in the speaker of the signal tracer when its probe is placed at the grid of the oscillator-mixer. This point is marked *(B)* in the diagram. While the presence of signal at this point indicates the R-F preamplifier stage to be in good order, it tells us nothing about the oscillator-mixer stage.

If we next move the ungrounded signal-tracer probe from point *(B)* to point *(A)* and pick up a louder modulation tone, we may assume both the R-F pre-amplifier and the oscillator-mixer stage to be in working condition. Placing the signal-tracer probe at point *(A)* therefore is a more complete test, since it checks the operation of all the R-F circuits, and the oscillator-mixer stage as well. If the signal fails to arrive at *(A)*, we would move the tracer probe one step forward to *(B)*. If we get the signal at *(B)*, we assume that the trouble lies in the oscillator-mixer stage. If, however, we get no signal either at *(A)* or *(B)*, we move another step forward and try to pick up the signal at *(C)*. If this produces a signal, we assume the trouble to lie somewhere between *(C)* and *(B)*, and make a detailed search in that area with ohmmeter and voltmeter. The failure to pick up a signal at *(C)* will immediately tell us that the R-F amplifier tube and its immediately associated circuit must be checked. Since presumably the tube has been checked as a routine matter previous to this, we can expect to find a discrepancy in the circuit components themselves. An ohmmeter and voltmeter should soon reveal the trouble.

If all of the stages following the oscillator-mixer have previously been tested and found good, this procedure may be varied to omit the signal tracer. Listening for the modulation tone in the speaker of the receiver, the signal generator probe is moved progressively from the loop antenna, to *(C)*, to *(B)*, and (changing over to the I-F frequency) finally to *(A)*. This tests each portion of the circuits separately and the sudden appearance of the signal will clearly indicate the area containing the trouble. This area can then be checked in detail to reveal the fault.

Section 7. SYMPTOMS OF PRE-AMPLIFIER TROUBLE

In the superheterodyne receiver not containing the pre-amplifier tube, the presence of a rushing or hissing sound together with a weak signal indicated trouble in the only components comprising the R-F section. In the receiver containing a pre-amplifier stage, the number of such components is considerably increased. Comparison of Fig. 9 and Fig. 7 will indicate this increase in the number of parts in which R-F troubles can occur.

The symptoms of a faulty R-F section in a set containing the pre-amplifier will likewise be somewhat different, although they will follow the same general pattern. Since an additional tube is involved, we are now concerned with the value of B-plus in the R-F stage. A short-circuit across the B-supply in this stage will, of course, be felt throughout the rest of the receiver, and will immediately suppress any signal. Besides this, all the other possible troubles that occur in R-F circuits not involving B-plus are also possible. We must also bear in mind that the presence of additional amplification will affect the symptoms of trouble in the pre-amplifier stage.

The result will be that even if the pre-amplifier tube fails to provide the gain for which it is designed, a quite perceptible value of R-F signal will be fed from the loop antenna across the tube by the distributed capacity between the grid and the plate. This will act to produce a secondary voltage in the R-F transformer, which will still be tunable, and will activate the receiver with an audible signal.

With the manual volume control advanced, the signal may sound almost normal, with one important exception. It will be accompanied by an unmistakable hissing sound. On closer inspection, it will be found that the signal volume is high only because the manual volume control is abnormally advanced. The hissing, which is simply an abundance of background static and spurious tube noises, will likewise be loud when the manual volume control is advanced.

Boiling these symptoms down, we may state that when a fairly loud, yet not quite loud enough, signal is accompanied by a high level of hissing or rushing, we can expect to find the trouble in the pre-amplifier stage of the receiver. We may immediately infer that the tube designed for R-F amplification has -- for some reason -- failed in its purpose. If this tube has been checked and found good, we may then suspect some other closely associated component.

While the symptoms mentioned above are general indicators of trouble in the R-F section of the receiver, the possible symptoms are by no means limited. Let us pursue this point by analyzing the separate components of the R-F section and show the inevitable results of their failure.

Section 8. THE LOOP ANTENNA

If the primary of the loop antenna were to become open when an outside antenna is used, most of the signal from the outside antenna would be lost. The signal volume would drop considerably and the presence of background static would become evident. However, if no outside antenna is used, there would be no perceptible difference when the loop primary is open.

An open loop antenna secondary, however, would have distinctly different effects. The grid leak path for the pre-amplifier stage is through this secondary winding, and any open in its turns would mean a free-hanging R-F grid. The resulting symptoms may take several forms, depending upon exactly where in the secondary the open has occurred. One effect is to lower the signal volume, but not completely suppress it. Another effect is to cause a motor-boating sound in the speaker. Other symptoms are howling, screeching, or a 60-cycle hum. In the last case, that of a 60-cycle hum, the signal has a "growling" character, and is definitely quieter than normal. This growling may simulate the "hoarse" signal due to an open input filter condenser. The method of distinguishing between these two common troubles is to notice if the growling disappears when the volume control is turned to minimum. If it does, then the trouble is an open secondary in the loop antenna; if not, then the trouble is an open input filter condenser.

A short-circuit in the loop antenna would most likely not be due to actual antenna trouble, but to a shorted variable or trimmer condenser shunting the loop secondary. Shorts in the main tuning condenser are generally due to scraping together of the variable condenser plates. The specific symptoms of such trouble are the loss of the signal only at certain places on the tuning dial. The loss of signal here will take place suddenly as the station selector is adjusted, and static will be heard in the speaker at the time that such adjustment is being made.

Correction for this condition is to carefully observe, under good light, the variable condenser as it moves through its entire range, noticing the point where the plates are closest together. They can be bent slightly at this point, and tried for scraping again by turning the station selector knob. However, if the condenser plate is seriously distorted, the best correction is a new gang condenser.

In the trimmer condenser, a short is usually due to the breaking down of the dielectric material, such as mica or celluloid. If the trimmer is suspected, it is wise to dismantle it and examine the parts for defects.

Indication of a short in either the trimmer or the main tuning condenser is given by an ohmmeter check across the loop antenna. If the loop resistance reads one ohm or less, disconnect one end of the loop secondary and measure the resistance across the isolated capacitors. It should be infinute in resistance.

The Cathode Circuit of the R-F Amplifier. -- The capacitor and resistor of this circuit are meant to provide a stabilized bias for the stage. An open resistor will mean the loss of the signal through the stage, but not necessarily the loss of the signal at the speaker. This is because the wiring following the R-F stage may act as an antenna and still produce sufficient voltage to introduce an R-F signal at the oscillator-mixer grid. This signal, however, will be below normal in volume and will be accompanied by a hissing or rushing noise.

A shorted cathode by-pass condenser will not affect the signal very much, except to make it somewhat quieter. The gain of this stage is considerable, and the loss of signal due to degeneration caused by an open cathode condenser will be negligible. Many owners of receivers with pre-amplifier R-F stages are not aware of it when this condenser opens up; they merely compensate for the small loss of signal without knowing it by advancing the volume control slightly.

Section 9. THE R-F COUPLING TRANSFORMER

If the primary of this transformer is open, the signal will be lost in this stage. However, here again this may not mean that the signal is lost completely at the speaker. The reason is, there is still enough stray wiring following this portion of the R-F circuit which will often act as an antenna and pick up enough signal to drive the signal grid of the oscillator-mixer stage. As we may expect, the signal will be below normal volume and accompanied by background static. This possibility may be verified by a voltmeter check at the plate of the R-F amplifier tube.

If B-plus is present at the screen, but altogether lacking at the plate, we may assume an open R-F primary winding. If B-plus is absent at both the plate and the screen, there is a short across the power supply and the trouble should be sought in that quarter. Other possible causes for the absence of B-plus at both the plate and screen of the R-F amplifier are a poor rectifier tube, and a short-circuited screen by-pass condenser, either in this stage or in another stage employing a screen-dropping resistor and condenser combination.

Notice that the primary of this transformer is untuned. The reason why tuning is not used here is that the signal frequency will vary with the station selected. A variable condenser in this primary winding would mean that another condenser section would have to be added to the gang. More than this, it would have to be insulated from chassis mountings because it will be at B-plus potential. To save space, weight, cost, and complications, the primary of the R-F transformer remains untuned. The results of not tuning this circuit are not serious; in fact, are quite satisfactory for all practical purposes.

An open secondary in the R-F coupling transformer will mean that grid electrons from the signal grid of the oscillator-mixer stage will not find their normal path through the winding to the AVC circuit, and finally to ground. This will result in a partial blocking of the oscillator-mixer stage. As in the case of an open loop secondary, the symptoms may be loss of most of the signal, motorboating, or a 60-cycle hum. An ohm-

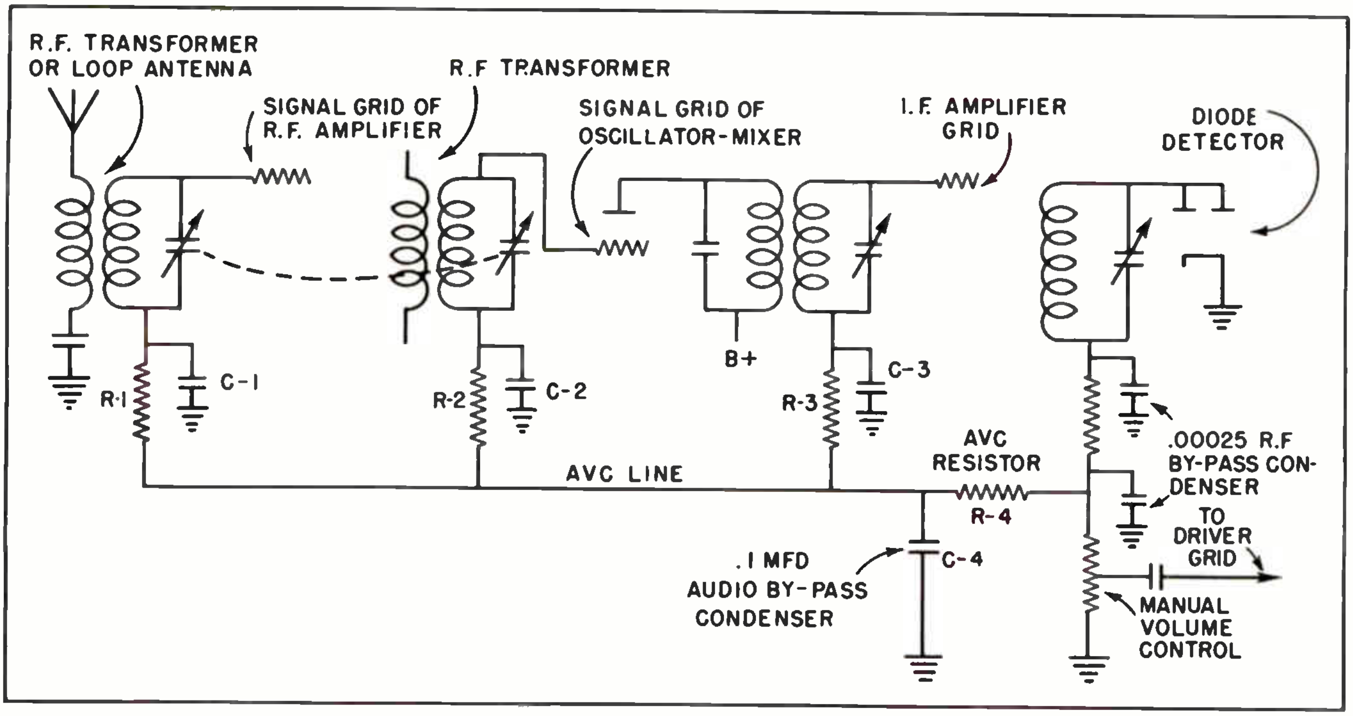


Fig. 12. How AVC Trouble May Appear to Center in the R-F Circuits.

meter check across this secondary winding will soon reveal its condition. Ohmic resistance should read about 20-40 ohms. Anything more than this value should be looked upon with suspecion. A very low reading here, less than 2 ohms, will throw suspicion upon the R-F tuning capacitor and its trimmer. Shorts in these two components are identical in nature with those of their prototypes in the grid circuit of the R-F amplifier, and should be tested and corrected in the same manner.

Section 10. AVC TROUBLES IN THE R-F AMPLIFIER

A complete family of troubles not taking place in the R-F circuits themselves, but felt very strongly by these circuits are those due to AVC component failures. We already know that the R-F circuits, as well as the grid circuit of the I-F amplifier, are fed with a variable bias originating in the AVC circuit. Since the AVC components determine the nature and the extent of this varying bias, we may well look to the AVC circuits as the source of trouble that appears to center in the R-F section of the receiver. Fig. 12 shows a sketch of the fundamental components involved.

In this diagram the AVC voltage, originating across the manual volume control and distributed to the I-F amplifier, the oscillator-mixer and the R-F amplifier, require that *R-1*, *R-2*, and *R-3* be intact. *R-4* and *C-4*, of course, are needed for the proper operation of any of the three stages to whose signal grids the AVC voltage is fed. If *R-1*, for instance, were to open up, the grid of the R-F amplifier would not only be left free-hanging, but it would also lack any control provided by the AVC voltage. The results are as if the secondary winding of the loop antenna were to open. The receiver would lose a good portion of its signal, would produce considerable volume of background static (hissing) and in addition may go into a state of motorboating with a fairly low frequency.

When a resistor supplying AVC voltage to a signal grid (and also a path for excess grid electrons to ground) is suspected of being open, the best and simplest test is to place the leads of an ordinary D-C voltmeter across this suspected resistor. If the resistor is open, the signal will clear up, the background static will disappear, and performance will approach normal operation, The interpretation of this procedure is that the resistance of the voltmeter, while it is actually in the circuit mentioned, takes the place of the open resistor and provides the necessary leakage path for excess grid electrons, and a means of getting AVC voltage to this grid. If this test proves that the resistor is open, by eliminating the symptoms while the meter is applied, then the correction is to replace the suspected resistor by one with the proper resistance and wattage.

The behavior of *R-2* and *R-3* would correspond closely with that of *R-1*. If an open should occur in these resistors, the stages with which they are connected will have free-hanging grids. Testing for opens in *R-2* and *R-3*, therefore, is identical with the test outlined for *R-1*. If the test leads of an ordinary 1000-ohm-per-volt meter eliminate the symptoms while they are across the suspected resistor, replace the resistor with its equivalent.

By contrast, trouble in *R-4* and *C-4* would show up in a completely different way. If *R-4* were open, none of the signal grids connected to the AVC line would be supplied with AVC voltage. In the R-F stages this would not result in a complete suppression of the signal. In the I-F stage, however, a free-hanging grid would completely block the signal and the result would be a lack of signal while a small amount of static could be discerned with the manual volume control advanced to maximum. If *C-4* is short-circuited, all the AVC voltage would be shorted out to ground. Since ground is as highly positive as the AVC voltage can possibly go, such a short would result in the loss of all AVC control and the consequent raising of the volume of both the signal and static.

Section 11. IDENTIFYING THE R-F SECTION

We have so far discussed several types of R-F sections commonly found in a modern superheterodyne receiver. We notice they differ chiefly in the number of tuned R-F circuits. We may tabulate these conclusions in the following manner:

Type of Receiver	Number of R-F Tuned Circuits	Number of Sections on the Ganged Variable Condenser
AC-DC	One tuned circuit; no pre-amplifier.	Two---the R-F and oscillator sections.
Portable	One R-F tuned circuit; no pre-amplifier.	Two---the R-F and oscillator sections.
A-C	Two tuned R-F circuits; one pre-amplifier tube.	Three---two R-F sections and one oscillator section.
Automobile	Two tuned R-F circuits; one pre-amplifier tube.	Three---two R-F sections and one oscillator section.

There are exceptions, of course, to this table of reference. For instance, some of the portable receivers are equipped with a pre-amplifier. Also, a very compact and inexpensive automobile receiver may omit the pre-amplifier. The information in the table is typical, however, and will cover the great majority of cases.

The last column, indicating the number of sections on the ganged tuning condenser assembly, is significant in that it will immediately reveal the presence of a pre-amplifier stage. If this condenser gang contains only two sections, we know at once the receiver contains no pre-amplifier stage. If there are three sections to the variable condenser gang, this tells us that a single pre-amplifier stage is employed in the receiver. In rare cases, including some models of communications receivers, there will be four variable condenser sections, indicating the presence of two separate pre-amplifier R-F stages. (See Fig. 13.)

Section 12. THE EFFECT OF PRE-AMPLIFIERS ON IMAGES

Considerable discussion has been devoted earlier in these lessons to the subject of image frequencies. These, as we know, are undesired signals which are brought in by a superheterodyne receiver at some place on the dial other than where they belong. The electrical reasons for images have already been outlined. The correction for image frequency interference was at that time suggested. To minimize image interference, add pre-amplifier stages, or change the physical position of the antenna.

The suppression of image interference by the addition of pre-amplifier stages is easily explained on the basis of the discriminating nature of a tuned R-F circuit.

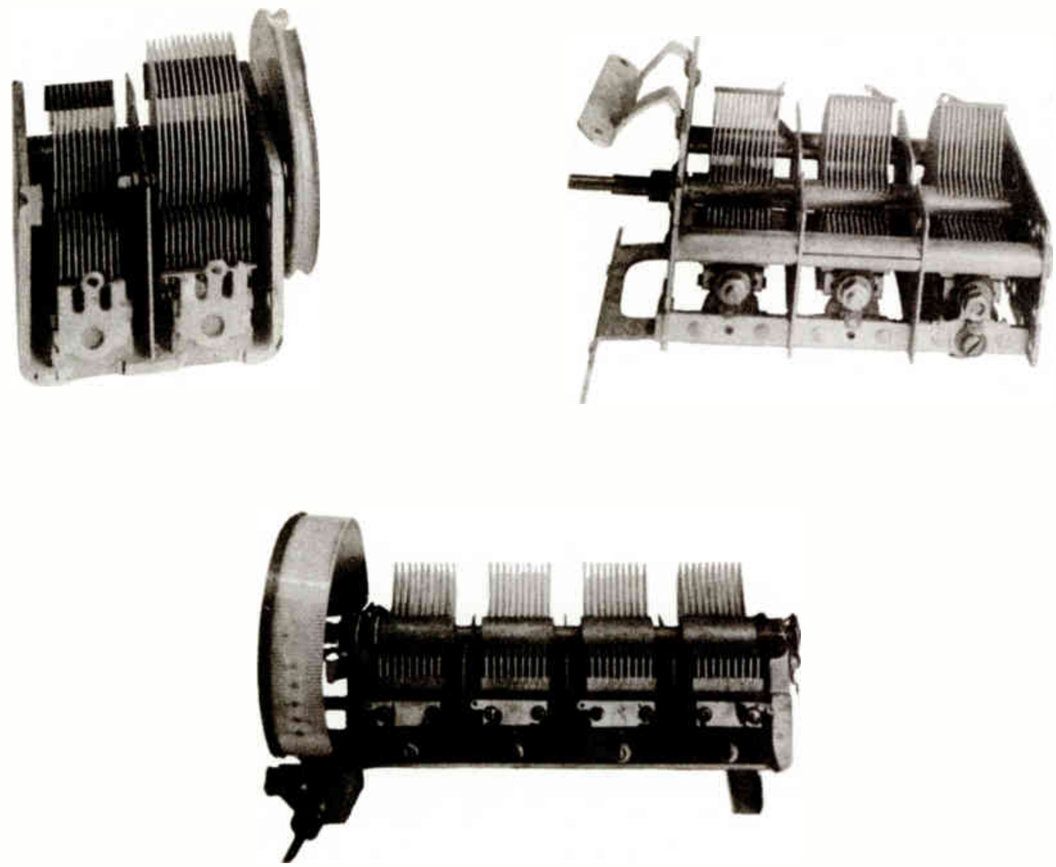


Fig. 13. Two-, Three-, and Four-Gang Variable Condenser Assemblies.

If we suppose an incoming signal to be of a 1000 k.c. frequency, we must tune all of the R-F tuned circuits to resonate at this value. In a receiver employing one pre-amplifier, this means we must resonate two separate R-F circuits to 1000 k.c. Furthermore, these two tuned R-F circuits follow each other, and any remnant of a strong signal whose frequency is different from that which is resonant in these two tuned circuits, will be barred from passing successfully through both tuned circuits. If, on the other hand, only one tuned R-F circuit had been used to keep out a strong image frequency, it may be only partially successful.

In the pre-amplifier stage the addition of an extra tuned R-F circuit effectively bars the passage of the image interference into the oscillator-mixer stage and therefore keeps it altogether out of the receiver speaker. If a strong local image frequency does somehow get past the first R-F tuned circuit, it will be stopped at the second R-F tuned circuit.

Section 13. **ALIGNING THE R-F SECTION**

The general alignment procedure applying to the I-F, oscillator, and R-F stages has been outlined in detail in another lesson. The alignment of the R-F circuits constitutes the final step of the general alignment of the superheterodyne receiver.

For convenient reference, and so you will better understand the final alignment steps, we repeat the essential adjustments involved in the complete alignment procedure:

I. Connect a signal generator to the plate of the oscillator-mixer stage. Turn on receiver power and set the signal generator to the I-F frequency of the receiver. Connect an output meter across the two leads of the voice-coil of the speaker.

(a) Starting with the last I-F trimming condenser, and progressing toward the first, adjust all I-F trimmers for maximum deflection of the output meter. If the meter tends to over-read the scale, reduce the output from the signal generator.

(b) Starting again at the last trimmer, and progressing toward the first, repeat the adjustments.

This completes the alignment of the I-F stages.

II. Connect the signal generator to the antenna of the receiver and adjust it for an output of 1500 k.c. Tune the receiver station selector to this frequency.

(a) If the signal generator modulation is heard in the receiver speaker exactly at 1500 k.c., and maximum meter reading occurs at this setting, then the oscillator needs no adjustment.

(b) If the modulation note, and maximum meter reading, occur at some place on the dial other than 1500 k.c., adjust the oscillator trimmer so that response at both the speaker and the meter is best at 1500 k.c.

(c) Now adjust the signal generator for a modulated output of 600 k.c. and tune the receiver station selector to this frequency. If maximum response of both the meter and the speaker takes place at exactly this point on the receiver dial, no padder adjustments are necessary. If maximum response takes place at some point other than 600 k.c. on the dial, adjust the oscillator padder so the modulation note, and highest meter reading, occur exactly at 600 k.c.

(NOTE: If one section of the variable condenser assembly is physically smaller than the other, or others, there will be no oscillator padder in the receiver. If all the sections of the variable condenser are of the same physical size, the receiver *will* contain an oscillator padder, which will be found in series with the main oscillator tuning section.)

This completes the oscillator alignment.

We are now ready to make the final adjustments, those in the R-F section of the receiver.

III. Leaving the connections of the signal generator as they were in the last operation, again adjust it for an output of 1500 k.c. Re-tune the receiver to this frequency. Adjust the R-F trimmer of the oscillator-mixer signal grid circuit for maximum meter and speaker response. Then adjust the trimmer of the R-F pre-amplifier signal grid circuit, also for maximum meter and speaker response. If the receiver contains two pre-amplifier stages, repeat this trimmer adjustment in the first pre-amplifier signal grid circuit.

Remove the leads from the signal generator, disconnect the output meter, and tune in any strong local station. "Flat-top", or "stagger" the I-F tuned circuits by adjusting their trimmers only a very small amount while listening for the best tone response of a muscial program.

This completes the entire alignment procedure.

NOTES FOR REFERENCE

Each R-F stage is tuned to the frequency of the incoming signal. It must therefore be made adjustable.

In a superheterodyne receiver, the R-F section first selects the desired frequency from all others at the antenna, then amplifies the signal for delivery to the signal grid of the mixer stage.

Alignment of the R-F tuned circuits can be employed to shoot trouble in these circuits. The sudden appearance or disappearance of the signal during this procedure will indicate the location of the trouble.

An indication of trouble in the R-F stages of a superheterodyne receiver is the combination of a low signal volume with a hissing, or rushing, sound.

Motorboating and a 60-cycle hum, both of which are adjustable by the manual volume control, are also good indicators of trouble in the R-F section of the receiver.

The superheterodyne receiver alignment cannot be performed on the TRF receiver; and the TRF alignment procedure cannot be performed on the superheterodyne receiver. Each requires special techniques, in keeping with their circuit differences.

In connecting up test equipment to any receiver, be sure to use protective series capacitors in the leads. This will avoid the possibility of damage to equipment and injury to yourself.

Pentode amplifiers are almost universally used in the R-F stages of a superheterodyne receiver. Typical examples are:

AC-DC receivers ------- 12SK7, 12K7, 12J7, 14A7, 14H7, 12BA6

A-C receivers --------- 6SK7, 6K7, 6J7, 7B7, 7A7, 6BA6

Automobile receivers -- 6SK7, 6K7, 6J7, 7B7, 7A7

Portable receivers ---- 1N5, 1U4, 1LN5, 1T4, 1LC5

NOTES

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THE TRF RECEIVER

Contents: Introduction - Fundamental Principles of the TRF Receiver - The TRF Power Supply - Power Transformer - Screen Grid By-Pass Condenser - The RF Section - Plate and Screen Voltages - Bias Voltage - The Audio Section - The AC-DC Power Supply in the TRF Receiver - Signal Tracing and Alignment in the TRF Receiver - Notes for Reference.

Section 1. INTRODUCTION

While Tuned Radio Frequency (TRF) receivers have to a great extent been supplanted by the more modern, more compact, and more efficient superheterodyne receivers, they still represent several important points of interest to us now. More than this, many of them were so sturdily constructed they will continue to be with us for years. The training of a television Technician is not complete unless he understands a TRF receiver.

The TRF is the "father" of all modern radio, television and radar equipment employing vacuum tubes. At one time it was the only type of receiver in existence.

In its day, the TRF receiver enjoyed tremendous popularity, and its satisfactory performance in millions of American homes during the early days of radio was in part responsible for the acceptance by broad sections of our population of radio as a means of communication and entertainment. Furthermore, it was capable of a fidelity that few, if any, superheterodynes have been able to match.

The TRF receiver paved the way for the superheterodyne receiver, for FM receivers, for television and for the thousands of applications of electronic equipment to military purposes. Rapid developments in all these fields have culminated in the incredibly precise circuits of radar, the electron microscope, electronic computers, and television.

Trouble-shooting the TRF receiver is a science in itself. In many respects a thorough knowledge of the TRF is considered a pre-requisite for trouble-shooting any other type of electronic equipment. Its circuits and operation are the very essence of the entire subject of radio and television. In the TRF these electronic principles are found existing in their simplest, most fundamental form. An understanding of TRF troubles, how to locate them and correct them should be a part of the "basic training" of all modern electronic technicians. There are TRF receivers in use today which have been successfully operating for two decades,

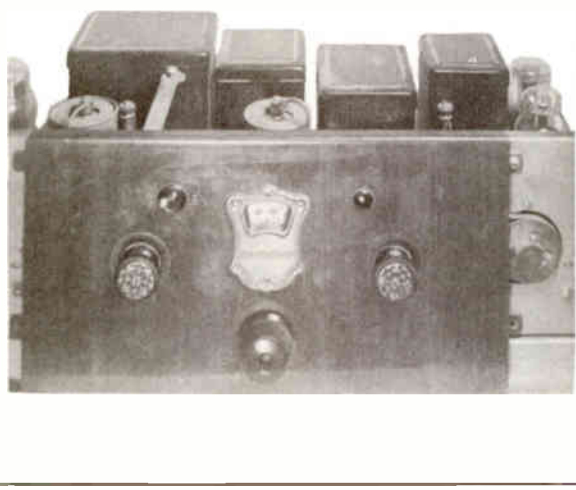

Fig. 1. A Typical TRF Receiver.

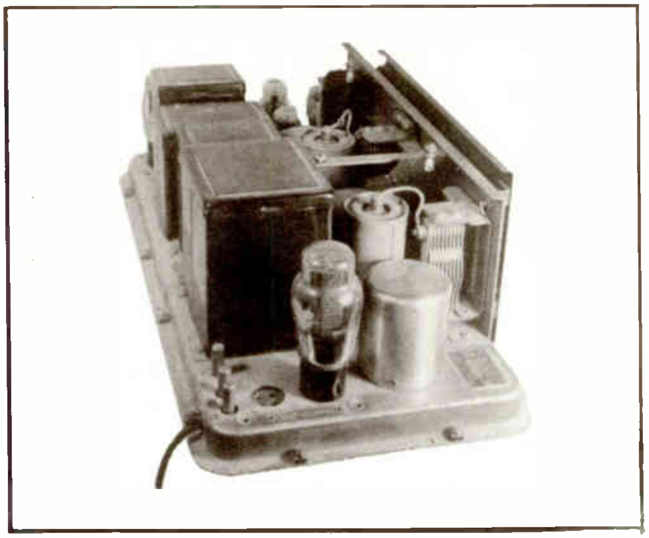

Fig 2. Chassis View of a Typical TRF Receiver.

and if properly serviced, will turn out satisfactory performance for another decade or two.

Fig. 1 shows the photograph of a standard TRF receiver, manufactured in the early thirties. Fig. 2 shows the chassis of this receiver.

Simply because the circuits involved in this receiver have been replaced by more modern design, we should not underestimate the importance of this high-quality piece of radio equipment. It was built of fine materials with precision and care. Its workmanship was of the highest order, and its performance throughout the years has been a tribute to the manufacturer, the designer, and the craftsmen who built it. Many of the once famous names have ceased to exist. These would include Grigsby-Grunow, Atwater Kent, Majestic and several others. But others like Hallicrafters, Motorola, Admiral and Sentinel have come into existence to replace them.

Section 2. FUNDAMENTAL PRINCIPLES OF THE TRF RECEIVER

In the functional block diagram of the TRF receiver, illustrated in Fig. 3, it is evident that only two significant frequencies are involved. These are the RF frequency (that of the station to which the receiver is tuned), and the audio frequency which is eventually produced at the speaker as sound.

The antenna, stretched in the air, is cut by the electromagnetic waves of energy from the transmitter, which broadcasts a fixed radio frequency. This signal, which is modulated by an audio signal riding on the RF wave, is successively fed to the first, second and third RF stages.

In these RF stages the desired frequency is selected from all others striking the antenna and is also strengthened through amplification. The amplified form of the desired RF signal is then led into the detector stage, where its audio component is separated from the carrier frequency.

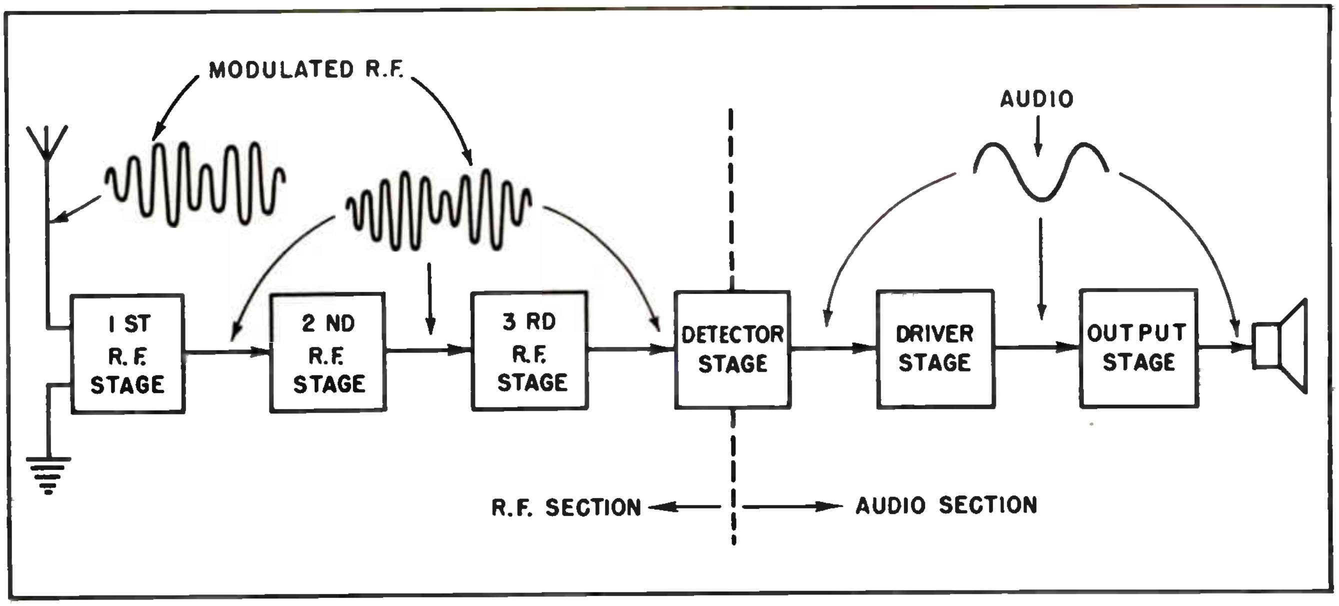

Fig.3. Block Diagram of a TRF Receiver, With Wave Forms Indicated.

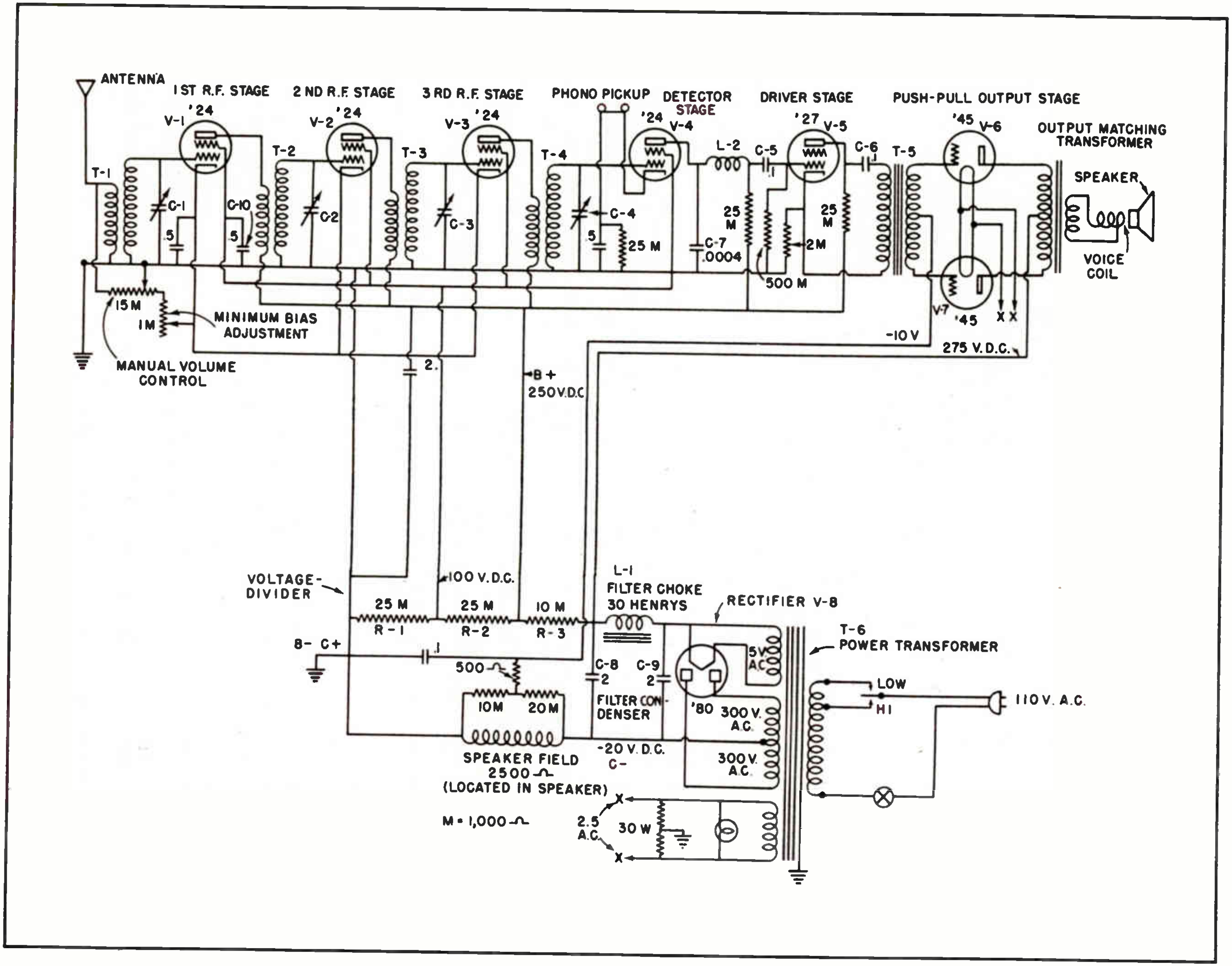

Fig. 4. Full Schematic Circuit of a Console Type TRF Receiver, Powered by a Full-Wave Rectifier.

The carrier frequency, no longer wanted, is led to ground, and the audio is delivered to the driver stage. Here it undergoes voltage amplification suitable for introduction into the output stage. The output stage amplifies the power of the signal and feeds it to the loudspeaker. The loudspeaker, operating on electromagnetic principles, reconverts the electrical impulses into sound energy. This sound energy is a duplicate of the original sound that modulated the transmitter whose signal we are receiving.

In contrast to the superheterodyne receiver, the following facts should be noted:

The TRF receiver contains no oscillator, no mixer, no I-F stages. All tuned circuits in the TRF receiver are resonant, at any given time, to the carrier frequency being received. Within the band of frequencies which the TRF is capable of receiving, a specific frequency may be selected at will. This occurs when the tuning knob is turned to de-tune one station and tune in another. As the result of this action, every tuned circuit in the TRF receiver alters its resonance to the same extent and in the same direction.

Thus the TRF receiver circuits are simple in comparison with those of the superheterodyne. There is no heterodyning of frequencies in the TRF. The frequency received is amplified through two or more stages arranged in succession. The only frequency change which occurs in a TRF receiver is the one which takes place when the detector stage separates the audio from the RF components.

In the TRF we are not concerned with picking up the I-F difference between the RF signal and the oscillator frequency. Since there is no oscillator, such a difference does not exist.

The problem of trouble-shooting the TRF receiver, therefore, is inherently simple. Yet it requires a thorough knowledge of the functions of each of the component parts. A schematic diagram of the typical TRF receiver is shown in Fig. 4. Let us analyze this circuit from the trouble-shooting point of view.

Section 3. **THE TRF POWER SUPPLY**

The purpose of the power supply in this receiver is to provide all the required operating voltages to power the stages of its various circuits. This includes the "B" supply for plates and screen grids of the tubes, the "A" supply for the heaters and filaments of the amplifier and rectifier tubes, and the "C" biasing supply for the output push-pull stages.

The power supply circuit Fig. 5 is a full-wave rectifier system employing an "80" rectifier tube, and a filter system consisting of L-1, C-8 and C-9 arranged in a Pi-type L/C form. The purpose of the filter system is to stabilize (remove the power line hum from) the "B" and "C" supply voltages. The choke L-1 does this by opposing the change of current through the amplifier loads; C-8 and C-9 assist in this purpose by opposing the changes of voltage across the amplifier loads.

C-9 has an additional function. It tends to keep the B-plus voltage at a high maximum value, as well as opposing any voltage changes across the load circuit.

If L-1 were open, there would be no B-supply voltage at any operating point in the set, although a high D-C voltage would be present at the rectifier cathode. If L-1 was short-circuited to ground, there would be no high voltage in the set whatever, including that at the rectifier cathode, and the plates of the "80" tube would become red hot.

If either C-8 or C-9 (the power supply filter condensers) were to short out, the plates of the rectifier tube would also become red hot. This is evident when we consider that a short-circuit across either of the two filter condensers would have the same effect as would a short to ground in the filter choke.

We will later see that several other possibilities could cause the rectifier plates to become red hot.

If C-8 were open (or deteriorated, as it may become with age), then its opposition to voltage changes across the load would be reduced, and a hum would be evident at the speaker. This hum would be of a 120-cycle frequency. In some cases, a violent motorboating may take place at a frequency of about 8 or 10 cycles per second. The motorboating is most likely when C-8 is completely open or disconnected. The hum is more likely when C-8 has lost only part of its capacity.

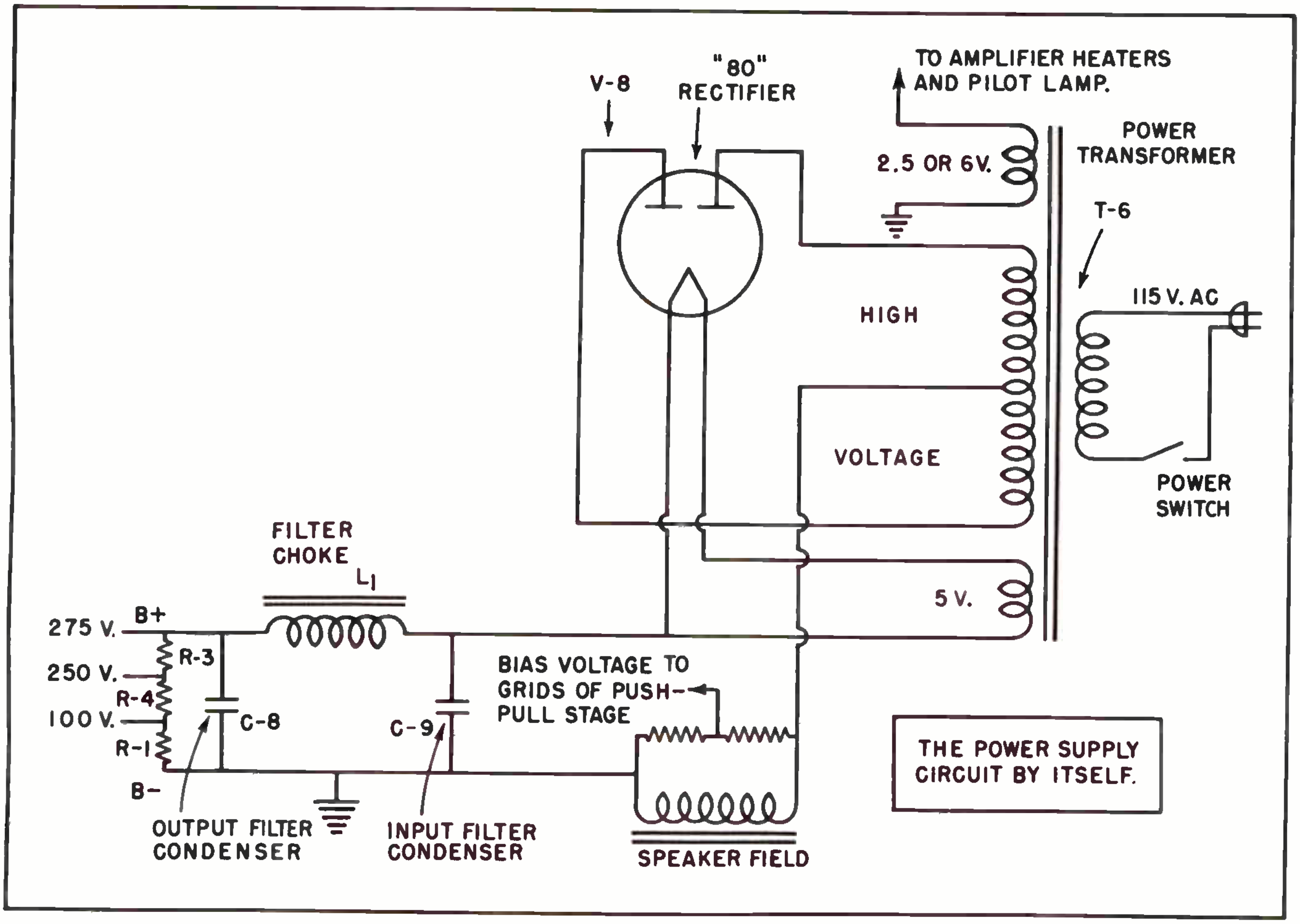

Fig.5. The Power Supply.

If C-9 opens, or loses a considerable portion of its capacity by age or any other reason, then there will be a power supply hum at 120-cycles, and the value of B-plus will drop somewhat.

So far as the signal at the speaker is concerned, this will mean that it will be weaker than normal and will be accompanied by the characteristic power supply hum.

It should be mentioned that many TRF receivers were built before the days of electrolytics. Filter condensers then were huge affairs. Many were oil-filled. Even with comparatively low capacity some were as large as 3 or 4 inches in each direction for each capacitor.

It is to be noted that since the manual volume control is in one of the early stages of this receiver, the hum or motor-boating due to open filter condensers will in no way be reduced when volume control is turned to minimum. This is a significant point to remember.

Section 4. **POWER TRANSFORMER**

The Power Transformer, T-6. Its purpose is to convert A-C line voltage to A-C voltages suitable for use by the rectifier filament (5 v.), the amplifier heaters (2.5v.), and the rectifier plates (300 v. between each plate and center-tap).

If the primary is shorted, the line fuse will blow out. If the primary is open -- and such an open may also occur in the on-off power switch -- none of the tubes will light and the receiver will be completely inoperative.

If the 5-volt secondary is open, all tubes but the rectifier will light, but there will be no B-plus voltage throughout the receiver. The speaker will therefore be completely silent.

If the 2.5 volt secondary is open, the rectifier tube will light, but none of the amplifier tubes will operate. The receiver will be inoperative, with the exception that it will have either normal or slightly excessive B-plus voltages.

(In some of the A-C Tuned Radio Frequency receivers, this secondary will produce 6.3 volts for the amplifier heaters. This value is more common in the later models of the TRF receivers.)

Let us now consider the high voltage secondary of the power transformer T-6. It consists of one winding containing enough turns to meet the step-up voltage requirements, and is center-tapped to a point in the circuit somewhat below ground potential.

If either of the halves of the center-tapped high voltage winding were to open, the system would operate as a half-wave rectifier. Since the filter condensers are designed with only capacity enough for full-wave action, they would lack sufficient filtering ability to oppose the power source hum. The result is that the signal will contain strong traces of this hum.

Should either of the two halves of this high-voltage secondary short out to ground, or if either should develop inter-winding short-circuits, the value of B-plus at the rectifier cathode will drop sharply. The signal will come through in reduced volume, and the power transformer, T-6, will overheat. This will not affect the appearance of the rectifier tube plates, since the overheating of the power transformer, due to excessive primary current, in no way increases the current through the rectifier. In fact, there will be less current through the rectifier, and its plates will not redden with excessive heat caused by excessive current.

As an integral part of the power supply, the speaker field deserves mention under this heading. It forms a dropping agent for the negative bias voltage fed to the grids of the push-pull stages, together with the 10M and 20M resistors whose series connection parallels the speaker field coil. These two resistors divide the full negative voltage up into two parts, one of which, as the diagram shows, is suitable for biasing the output push-pull stage grids.

Thus any current flowing through the grid circuits of these stages will also pass, in part, through the speaker field. This will energize the field and develop in its core the necessary magnetic flux for proper speaker operation.

An open field coil will cause the signal at the speaker to drop to an almost inaudible level, but will not remove the bias from the output stage grids. This is because an open field has no current flowing through it; and the push-pull grids receive their bias through the resistors paralleling the speaker field. Should the speaker field short out from one end to the other, however, the entire "C" voltage supply will go to ground potential and the grids of the push-pull stages will be driven into a state of saturation. The signal, of course, will be lost under these conditions.

The 25M-25M-10M series of voltage-dividing resistors leading from the filter choke provide a convenient method for distributing correct positive voltage to required points in the receiver. At the junction between the 25M and 10M resistors, 250 D-C volts are available for the plate circuits of all of the amplifiers except the output amplifier (push-pull) tubes. These receive their B-plus from the filter choke itself, which represents the highest positive potential in the receiver, usually about 275 volts. A lower positive voltage is available at the junction of the two 25M resistors, around 100 D-C volts for operation of the screen grids of the four "24" amplifier tubes. The tube manual specifies that this type of tube be supplied with a screen voltage of approximately half of that at its plate. Note that all of these screens have a common by-pass condenser, C-10, located on the schematic diagram of Fig. 4 below V-1.

Section 5. SCREEN GRID BY-PASS CONDENSER

Let us look at the possible troubles in this condenser, C-10, first. If open, this condenser would fail in its purpose of maintaining all of the screens at ground potential with respect to signal voltage. This in itself would serve to lower the signal volume at the speaker due to the regenerative action resulting from such an open.

However, this is by no means the full story. If C-10 is open, there will be interaction between the screen grid voltages of all of the tubes in the circuit. The inevitable result of this interplay of voltage changes on screens tied to a common point is motor-boating.

The rate of such motor-boating will generally enable the alert technician to distinguish between the various possible reasons for it. A slow motor-boating (around 8 or 10 cycles per second) is most usually due to an open output filter condenser, represented by C-8 of Fig. 4. Motor-boating due to an open screen by-pass condenser normally takes place at a much faster rate, around 30-200 cycles, with a great deal of tolerance above and below these figures. In relation to this point, a simple rule may be stated: If the screen by-pass condenser is suspected of an open, shunt it with an equivalent; if there is suspicion of an open output filter condenser, shunt it with its equivalent. If the cause of motor-boating is due to either one of these two condensers being open, then this plan will reveal which of the two is at fault.

A short-circuited screen by-pass, C-10, will have some interesting symptoms. One of the other causes for red hot rectifier plates, previously mentioned, may be a shorted screen by-pass condenser. Depending upon the extent of the short, the plates of the rectifier tube will become red hot, the value of B-plus will drop considerably in the receiver, the positive potential on all the screens will disappear, and the signal will be lost through lack of gain in the RF amplifiers. Where the voltages are found to be as described, an ohmmeter check across C-10 will reveal the short-circuit at once.

Some complicated consequences may follow a short-circuited screen by-pass condenser in a TRF receiver. As can be seen by inspecting the circuits involved in this screen voltage supply, a short across C-10 will cause heavy current to flow through R-2 and R-3. These resistors may not be rated for such a high current. If not, then one or the other of them will burn open if C-10 is shorted and power is applied to the receiver for a sustained length of time.

Should R-2 burn open, we may replace the shorted condenser, but the screen grids of the amplifier tubes will still not be getting their positive potentials. The condition of R-2 will have to be determined, and it should be replaced if necessary. If R-3 burned open, neither the screens nor the plates of the amplifier tubes would be supplied with their positive voltages, and here, too, necessary steps must be taken to locate and repair the trouble. We see that in this case, as in several others, that when one trouble occurs it may cause additional defects to take place.

Section 6. **THE RF SECTION**

The RF section of the TRF receiver (See Fig. 6) includes all of the tuned circuits, the amplifier tubes with which they are associated, and the auxiliary circuits supplying them with signals and bias.

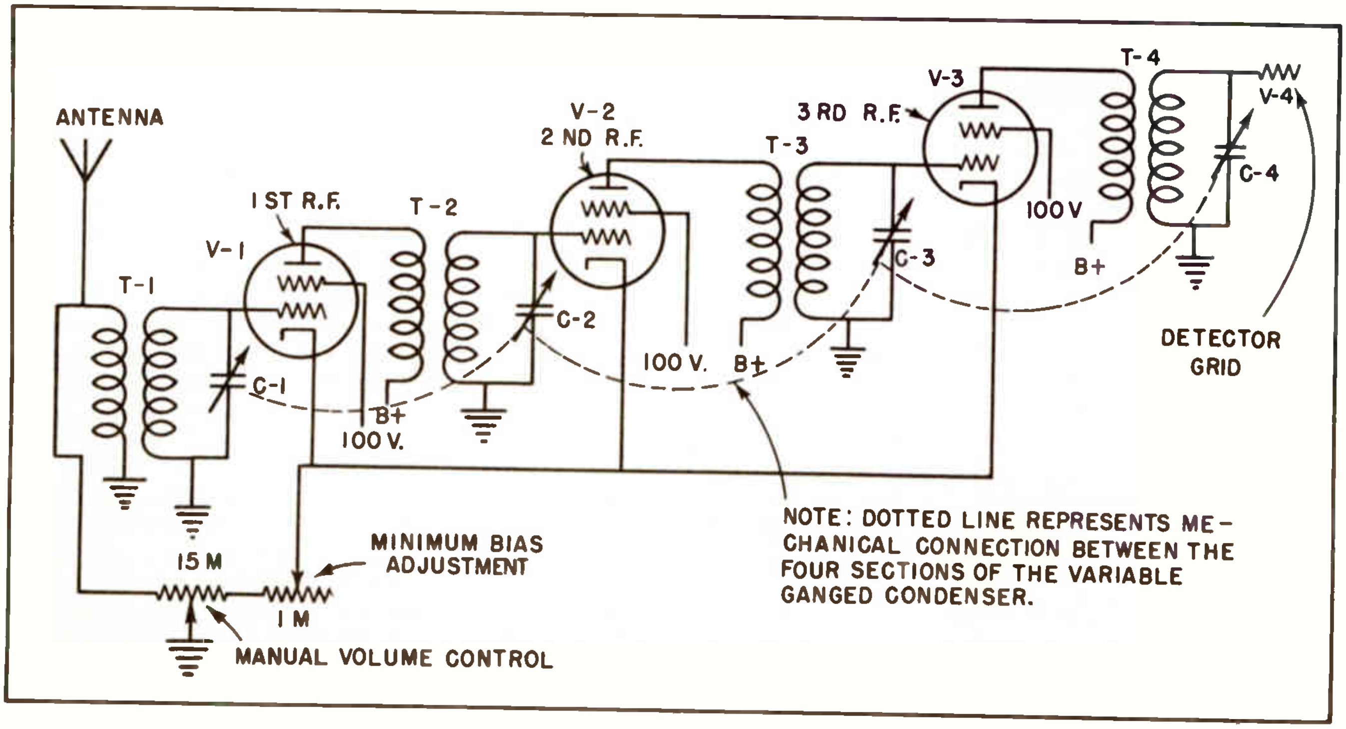

Fig.6. The Radio Frequency Signal Circuit.

T-1, the antenna transformer, is a means of coupling the signal from the antenna to the grid of the first RF amplifier. Because a certain range of radio frequencies (from 500 to 1600 k.c.) must be capable of entry into the receiver, the primary of T-1 is untuned. The secondary, however, is tuned by a parallel capacitor which can be varied in accordance with the frequency of the signal desired.

Because T-1, T-2, T-3, and T-4 are similar in function and construction, their action is identical. If the purpose of T-1 is to couple the antenna signal to the first RF grid, then the purpose of T-2 is to couple the output of the first RF amplifier to the grid of the second RF amplifier. In like manner, the purpose of T-3 is to couple the output from the second RF amplifier to the grid of the third RF amplifier. And the function of T-4 is to pass the RF signal from the plate of the third RF amplifier to the grid of the detector stage.

As in the case of T-1, each of the secondaries of the RF transformers are paralleled by a variable capacitor. The capacitors are C-1, C-2, C-3, and C-4. These condensers are mechanically bound together. All of them are variable, but none can be varied without varying the others by an equal amount, and in the same direction.

The transformer secondaries all have the same inductance. Except for minor differences, capable of compensation by trimmers, the capacitors are also of the same capacity. If we change the capacity (and therefore the resonant frequency) of any one of these four tuned circuits, we automatically change the resonant frequency of them all. The resonant frequency is the same for all of them at any given setting on the tuning dial.

This condition of equal resonance throughout all of the RF tuned circuits is, of course, no accident. We see at once that this condition permits us to select a given signal from the antenna, tune and amplify it in the first stage, pass it on to the second, tune and amplify it there, pass it on to the third, tune and amplify it there, and deliver it to the detector stage for extraction of the audio component.

Transformers T-1, T-2, T-3, and T-4 are subject to certain natural and common troubles. Either winding (primary or secondary) of any of these transformers may open up. This means that the signal will be lost in the winding which contains an open circuit. Except in the case of the primary of the antenna transformer, T-1, an open in any of the primaries may be deduced from the absence of B-plus voltage on the tube plate connected to this winding. For instance, if the plate of V-2 were not to show the presence of B-plus voltage when measured with a D-C voltmeter, while B-plus is present throughout the rest of the receiver, we may correctly deduce that the primary of T-3 is open. Should this occur the receiver would, of course, produce no sound.

In similar manner, the absence of B-plus at the plate of V-3, and at this plate only, would mean that the primary of transformer T-4 is open. This can be further verified by an ohmmeter check across this winding with the receiver power turned off. A good primary will have about ten ohms of resistance.

T-1, the antenna transformer, may be approached from a different point of view in suspecting it to be open. Since the primary of the antenna transformer contains no B-plus potential, the best check for an open in it is to measure it with an ohmmeter with the receiver power turned off. It, too, should contain D-C resistance of about ten ohms.

Open windings in the secondaries of these four RF transformers may be readily checked by the use of the ohmmeter, set to the lowest scale. Their D-C resistance should read approximately 25 ohms. There will be no D-C voltages present, which eliminates a voltage test procedure for analyzing trouble in these transformers.

Suspicion of an open circuit in one of these secondary windings should be considered when the signal is lost in the receiver and B-plus voltages are present in normal measure throughout all of the receiver, including all of the plates and screens of all of the tubes.

The primaries of these four RF transformers are not likely to short out, except for accidental displacement of connecting wires. The secondaries, however, are subject to considerable short-circuits due to the presence across them of the variable tuning sections of the ganged condensers. Physical warping of the condenser plates, separated by a few thousandths of an inch, will cause the condenser to short out. This, of course, is the same as a short across the transformer secondary with which it is paralleled.

Here the ohmmeter will be of invaluable assistance in locating the trouble. Setting it at its lowest scale, apply the ohmmeter leads (with receiver power turned off) across any of the transformer secondaries suspected of a short circuit. The resistance, normally reading 25 ohms, will read zero if the section of the condenser is shorted that parallels this secondary.

In this ohmmeter test for a shorted secondary, extreme care should be taken to set the ohmmeter on its lowest scale, and to read the results accurately. The ohmmeter pointer does not swing very far in reading the difference between 25 ohms and zero ohms. On a high scale, they will both read as a short circuit, or zero ohms. This error must be avoided to accurately shoot this type of trouble.

Correcting this trouble is a matter of physically separating two adjacent variable condenser plates which have somehow been warped into electrical contact with each other. This can best be done by carefully examining the shorted condenser under good light to determine the actual point of contact. A thin knife-blade, carefully inserted at this point, will serve as a means of bending the plates back into alignment. Repeat the ohmmeter test to confirm the results of this correction.

Dirt, dust, and corrosion are also responsible for shorts in this variable condenser gang. It is a wise idea to blow out these plates with an air-compressor, if available, or by mouth, to clean any accumulated foreign matter from between them.

It should be emphasized here that the short-circuit across a variable condenser section, due to contact between adjacent plates, will be indicated by an ohmmeter as a short across the RF transformer secondary with which this section of the variable condenser is in parallel. Actually, the transformer secondary will be innocent of any faults. The zero resistance reading across the winding is simply a manner of indicating the nature and location of the fault, which is really in the condenser.

These suggestions are reviewed in schematic form in Fig. 7.

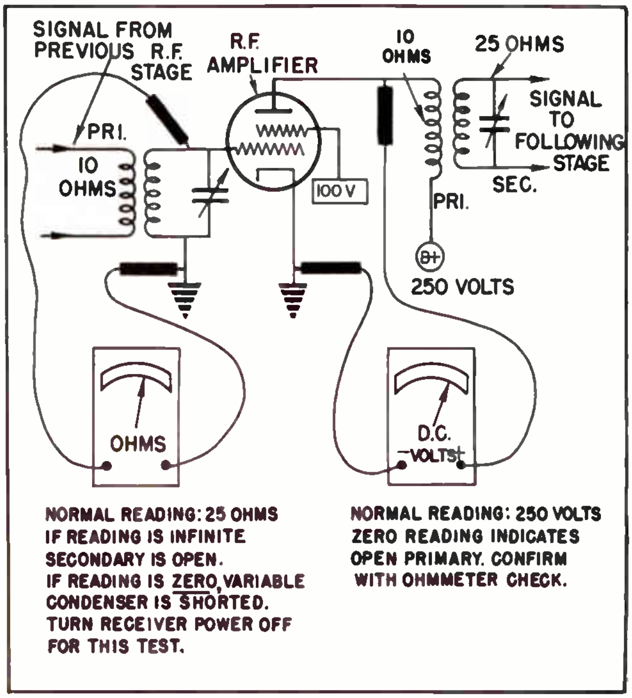

Fig.7. Voltmeter and Ohmmeter Tests on RF Coils in the TRF Receiver.

Section 7. PLATE AND SCREEN VOLTAGES

Plate and screen voltages in the RF Stages. From the illustration of Fig. 4, it can be seen that plate potential in the RF stages is supplied at 250 volts D-C from the rectified and filtered power supply. The ohmic resistances of the primary windings in the RF transformers are very low, and no appreciable voltage drops take place in these windings. Voltages at the plates of the RF amplifiers, therefore, should be almost exactly equal to that of B-plus, around 250 volts for this type of power supply. Screen grids, as was mentioned earlier, should read about 100 D-C volts with respect to ground.

The screen by-pass condenser, C-10 of Fig. 4, has already been discussed from the trouble-shooting point of view. It is significant that the absence of screen voltage in the RF stages, while B-plus is present throughout the rest of the receiver, indicates that the screen by-pass condenser, C-10, is shorted, or that R-2 of the voltage divider is open. We recall that either or both of these troubles may be present, since under common operating conditions a shorted screen by-pass condenser can cause resistor R-2 to burn itself open.

An open in R-3, on the other hand, will be indicated when the screens and plates of the

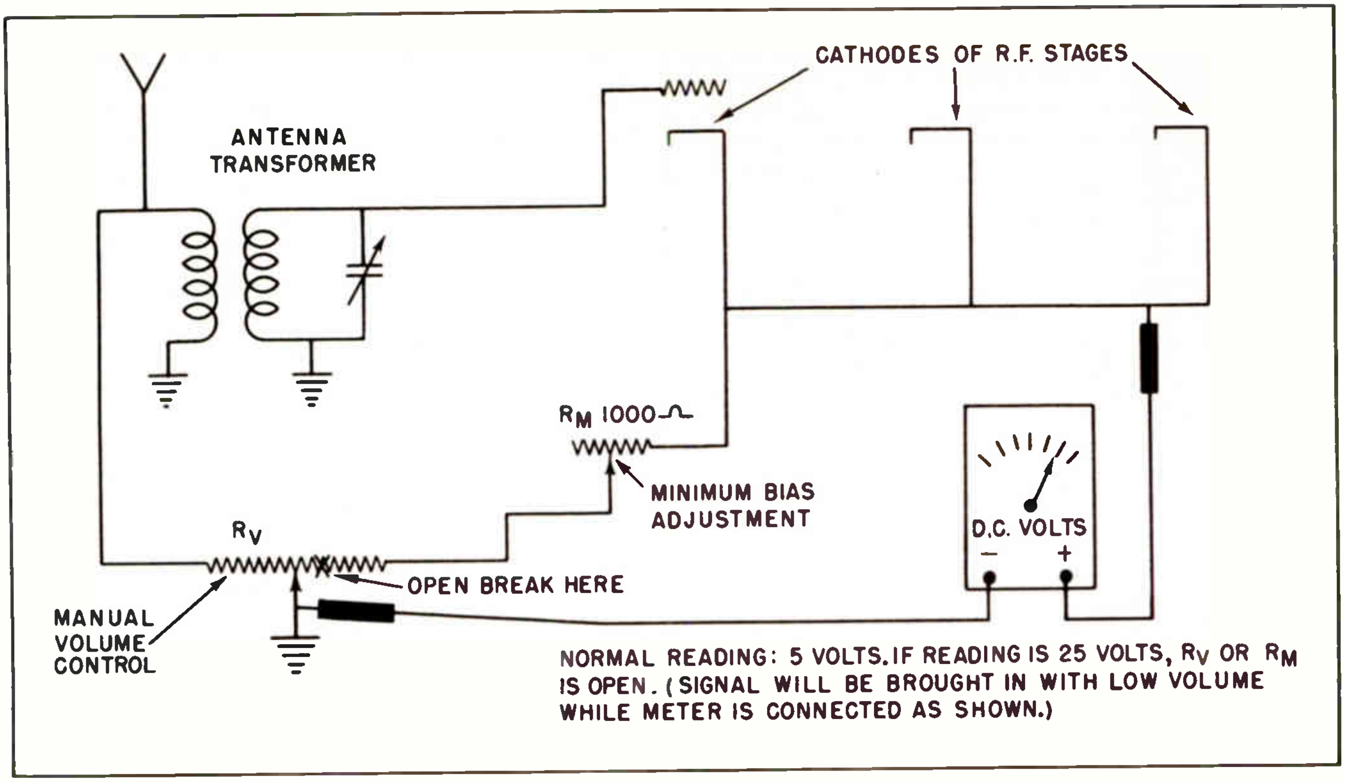

Fig. 8. Checking Manual Volume Control Troubles in the TRF Receiver.

amplifier tubes lack their potentials, but the output push-pull stages measure normal voltages.

Section 8. **BIAS VOLTAGE**

Bias voltage in the RF stages. Operating conditions for all of the RF stages are determined by the value of the bias voltage applied to these stages. Reference to Figs. 4 and 6 will show that cathode-bias is used, and that this cathode-bias is common to all the RF stages, and to them only. Two controls are involved in this biasing circuit; they are the minimum bias control (a screwdriver adjustment) and the manual volume control. The former is adjusted only at relatively long intervals, and once set, is left until need arises for a re-adjustment. The latter, the manual volume control, is manually operated by the user of the receiver each time he wants to change the volume level of the signal at the speaker.

This type of volume control in the TRF receiver is known as bilateral, since two separate circuits are involved in the manual adjustment for increasing or decreasing the signal value at the speaker. Study of the antenna primary circuit in Fig. 6 will reveal that there is a direct connection between the antenna and the left side of the manual volume control potentiometer. Its right side is connected through the minimum bias control to a point joining the cathodes of V-1, and V-2, and V-3, which are the RF amplifier stages of the receiver. The center tap of the manual volume control potentiometer is connected directly to ground.

The 1000 ohm minimum bias resistor establishes a minimum bias voltage for the three RF stages. Note that this resistance can be changed by adjusting the potentiometer. It is thus possible to alter to the required degree this minimum bias voltage. But once this resistance value is set, the minimum bias voltage remains fixed. Maximum value of the bias of these stages, however, is determined by the setting of the sliding tap on the manual volume control. Further, it may be noted that the total bias voltage developed in this circuit varies with the setting of the manual volume control.

Now notice the connection between the antenna and the left side of the manual volume control. It can be seen that as the variable tap of the manual volume control is moved to the right (in Fig. 6) the value of the bias voltage decreases, since less resistance lies between ground and the RF cathodes. This increases the gain of these stages. At the same time, maximum resistance is placed between the antenna and ground, permitting the full antenna voltage to be applied to the grid of the first RF amplifier. Thus the combined action of moving the sliding tap of the manual volume control toward the right is to increase the value of signal by two separate means.

Now, if we move the sliding tap of the manual volume control toward the left (again in Fig. 6) we see that there is maximum resistance between the RF cathodes and ground. This increases the bias voltage to these stages and decreases their gain. At the same time, we now observe that the antenna signal is shorted out to ground by a minimum of resistance between the antenna and ground. This too, lowers the signal strength. This bi-lateral electrical action is referred to as an "antenna-shunt" type of volume control.

This analysis brings us to some simple and interesting observations regarding trouble in the manual volume control circuit. If the manual volume control is open at a point, let us say, about half-way through its end-to-end resistance (See Fig. 8), we note that while the sliding tap is to the left of the break the RF cathodes will stop conducting due to the absence of a path for cathode electrons. The signal will be completely lost under this condition.

Now, if the manual volume control sliding tap is moved to the right of the open break, the signal will be brought in as normally. The result will be that while there will be no signal during the lower part of the manual volume control range, the signal will appear suddenly, and in rather strong volume, when the manual control is turned clockwise. This peculiar action of the manual volume control, as described, will at once throw suspicion upon the manual volume control continuity. This can be readily verified by the test suggested in Fig. 8.

Note that this test includes two possible troubles, one of which is an open manual volume control. The other is an open break in the minimum bias control. To distinguish between these two possibilities, note that (1) an open in the minimum bias control will not account for the peculiar action of the signal suddenly re-appearing when the manual volume control is advanced; and (2) the continuity of these potentiometers can readily be measured separately by the ohmmeter. Stated in other words, an open in either the manual volume control or the minimum bias control will account for the high 25 volt) cathode potential, but only an open in the manual volume control will betray itself by the sudden cutting-in of the signal as this control is manually advanced.

Section 9. THE AUDIO SECTION

Let us now direct our attention to the third and remaining portion of the circuits of a TRF receiver -- the audio section. This section, for convenience, is here taken to mean all of the stages following the third RF stage. The audio section begins with the detector and includes the driver and the push-pull stages, together with the speaker.

Fig. 9 reproduces the schematic circuit of the audio section of the TRF receiver shown in Fig. 4. Here the audio section is shown by itself, except for the inclusion of the biasing and heater connections to the push-pull stages.

Let us study the functions of the components shown in this section of the receiver.

T-4, the final RF transformer, couples the RF modulated signal from the last RF stage to the detector stage. Its secondary is tuned by means of C-4, a unit of the ganged variable condenser.

The 25,000 ohm detector biasing resistor, R-5, develops the class-B bias necessary for operating this stage as a detector. This is equivalent to saying that the operating point on the characteristic curve of this tube is approximately at cut-off. If R-5 were to open, the detector would conduct no current and the signal would be lost in the stage. A D-C voltmeter would indicate this condition by reading about 25 volts between the cathode of V-4, (the detector) and ground. Normal voltage here should be about ten volts.

The radio-phonograph switch in this cathode circuit is a simple means of selecting the one of the two functions which is desired. A phonograph pick-up, driven by an independently connected motor, is connected to the switch as shown. In using the radio, the user closes this shorting switch. This places the cathode directly in the biasing circuit and shorts out the phonograph signal. When the switch is open, however, the signal from the phonograph pick-up is placed in series with the biasing circuit and the

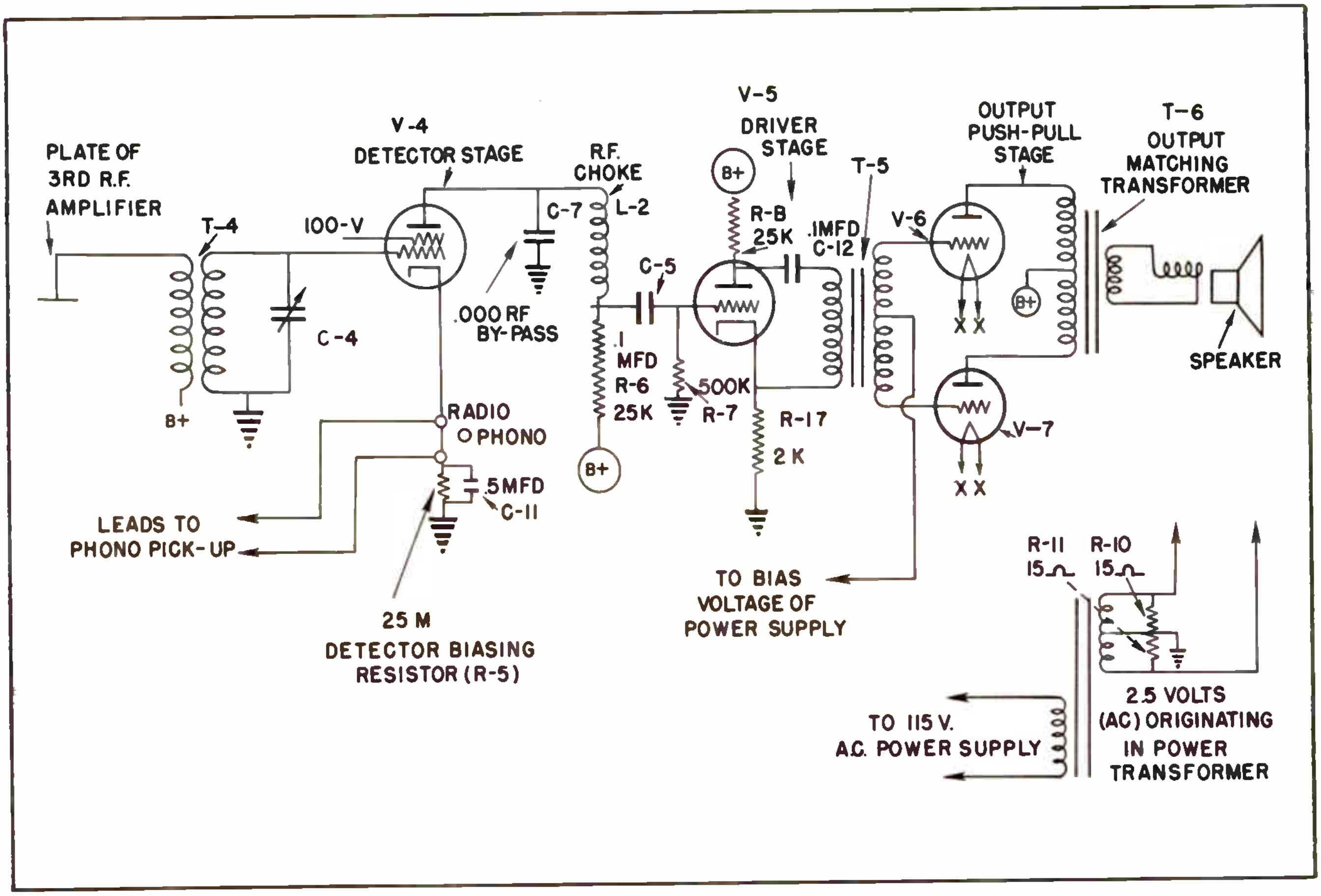

Fig.9. The Audio Section.

phono signal is now in the form of a variable bias (changing at phonograph signal frequency) on the cathode of this stage. The gain of the detector and driver stages, as in the case of a pure radio signal, builds up these signals and sends them to the output stages for conversion to sound energy at the speaker.

C-7 is a radio-frequency by-pass condenser, and leads the now unneeded RF component of the signal to ground. The plate output of the detector stage, because this stage operates at its cut-off point, consists of a rectified form of the RF. C-7, whose value is small, offers practically no reactance to the fast-changing radio frequency component. But the audio component, also a part of the output of this stage, meets high reactance in C-7 because the audio is relatively slowly changing. L-2 and C-7 thus form an RF filter system which permits passage of the audio signal to the following grid (through capacitor C-5), while diverting the RF component to ground.

The plate load resistor of the detector stage, R-6, is the true load of this circuit. You will recognize this as a linear plate detector, one of the fundamental amplitude-demodulators which provide a measure of gain as well as a means of extracting the audio component from the RF carrier. If R-6 opens the signal will be lost in this stage and the plate of this tube will display no B-plus potential. When measured on the ordinary 1000-ohm-per-volt D-C voltmeter, this voltage should read approximately 50 to 75 volts. Zero plate voltage here will indicate that the plate load is open. An excessively low plate voltage will indicate that the plate load has greatly increased in resistance. This is not an uncommon fault in plate load resistors.

C-5, the audio coupling condenser, is simply a means of getting the audio signal over to the grid of the driver stage, without taking along with it the high D-C potential from the plate of the detector. Since the signal is in A-C form, condenser C-5 passes it readily to the grid of the driver. The D-C component of the detector plate voltage, however, is effectively barred from passage across C-5 by its non-conducting dielectric. This leaves the grid bias of the driver undisturbed and permits it to operate as designed.

If C-5 is open, the signal will drop considerably in volume, although it could be brought in if the manual volume control is advanced to maximum. To verify the suspicion of an open in C-5, shunt it with an equivalent condenser.

If C-5 were to short out, the grid of the driver stage would be brought at once to saturation, the signal would be badly distorted, and somewhat lower in volume than normal. To verify this suspicion, measure the voltage at the grid of the driver. It should not be positive to any degree. Normally, its voltage is slightly negative, or zero, with respect to ground. In case a positive voltage of any value is found on this grid, C-5 may be suspected of a short or of leakage. In either case it should be replaced.

The grid-leak resistor R-7 serves as a return path for excess electrons from the grid of the driver to ground. If open, R-7 would cause the driver stage to block because the leakage path for excess electrons would be absent and the grid of this stage would become free-hanging. Shunting a resistor of equivalent value across R-7 and noting the results, will verify the suspicion of an open break in this resistor.

R-8, the plate load resistor of the driver stage, (like its counterpart R-6 in the detector stage), serves to provide an amplified voltage drop at signal frequency for delivery to the output stage. Like R-6, R-8 (if open) will also cause the signal to be lost. Plate voltage in the driver stage is a good indicator of the condition of R-8, a value of 50 to 75 volts D-C being normal.

C-12, the coupling condenser in the plate circuit of the driver stage, sends the voltage changes developed in the plate load to the transformer T-5 primary. In order to avoid signal distortion in this transformer due to the tendency of its core to saturate on strong signals, C-12 permits only the A-C component of the voltage to pass to the transformer primary. If C-12 is open, most of the signal would be lost here. To confirm an open in C-12, shunt it with a condenser of equivalent capacity and voltage rating. A short or leakage in C-12 would result in shorting out the plate voltage of this stage through the transformer primary and the cathode circuit. This would lower the value of B-plus considerably throughout the receiver, cut the signal down to practically zero, and possibly burn open the plate load resistor, R-8, of this stage.

The secondary of T-5 is center-tapped to the biasing circuit and provides the two push-pull stage grids with signal voltages which are equal in amplitude but 180° out of phase with each other. This, as we already know from a study of push-pull circuits, is a requirement in the operation of this kind of circuit. Note that the bias voltage for both of the push-pull grids is fed through the center-tap. If either half of this transformer secondary were to open, the grid to which it is connected would lose its signal as well as its bias voltage.

While the signal would be intact on the opposite grid, the loss of bias voltage on either grid would result in the immediate saturation of the output transformer core due to excessive current flowing in one-half of its primary. This would show up as definite distortion in the signal, and can be confirmed by removing first one, and then the other, of the output push-pull tubes from their sockets. If the signal clears up when one tube is removed, look for an open break in the grid winding of that tube. This can be done, with power in the receiver turned off, by the aid of an ohmmeter. Ohmic resistance across each half of the secondary of T-5 should be about 200-400 ohms.

The output push-pull transformer T-6 is a means of matching the low impedance of the speaker voice coil to the high impedances of the two push-pull tubes. Its center is tapped to B-plus, which provides the two push-pull plates with operating potentials.

If either half of this winding is open, the tube connected to it will not conduct. The speaker volume will drop to almost half its normal value, and all signals will sound slightly muffled. These consequences follow logically from the failure of the system, when one-half of the transformer primary is open, to accomplish the full purpose of a push-pull amplifier. This purpose can be stated as two-fold: To effect the cancelling out of the even harmonics, resulting in better tone; and the increase of power output. Where only half of the push-pull system is operating, as would be the case if one-half of the transformer primary were open, then the performance would be equivalent to a single stage, instead of push-pull.

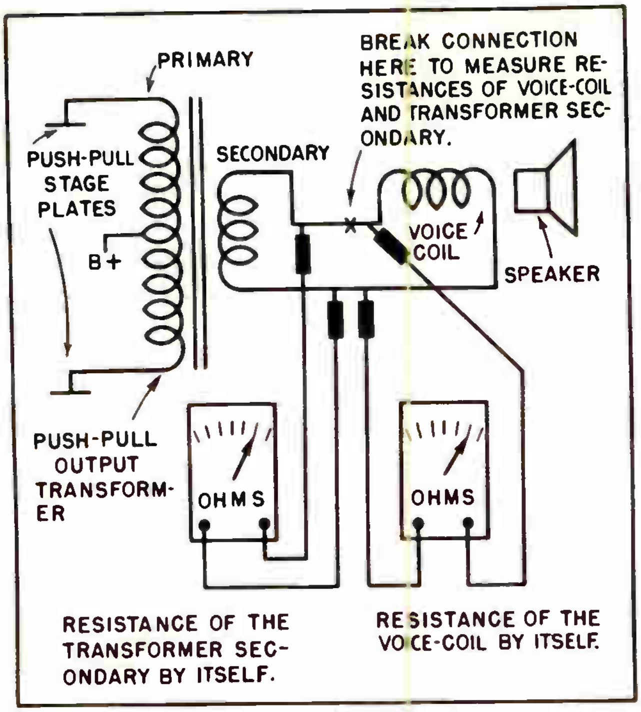

Fig.10. Distinguishing Between Speaker and Transformer Trouble in the Audio Section.

Such open breaks in the transformer windings can be readily checked with an ohmmeter, which should read about 200-400 ohms across each half of this primary winding.

The secondary is of low impedance, matching that of the low impedance voice coil. When open, this secondary will fail to deliver any electrical impulses whatever to the voice coil, and the natural result will be that there will be no sound of any kind at the speaker. To verify this suspicion, break open the connection between the secondary of the transformer and the voice coil, as shown in Fig. 10. Now each of the two windings may be reliably measured apart from each other, to determine their condition. The results of this technique will tell us at once whether corrections must be made in the speaker or in the output push-pull transformer.

Section 10. THE AC-DC POWER SUPPLY IN THE TRF RECEIVER

It has been pointed out that the characteristics of a TRF receiver refer only to the signal circuits. The chief difference between the TRF and the superheterodyne is that the TRF employs circuits tuned at any given dial setting to the frequency of the signal being received, while the superheterodyne mixes the received frequency with a local oscillator frequency to obtain a constant I-F difference frequency.

The power supplies for the TRF and the superheterodyne may be exactly the same, however, since the operation of the amplifier tubes may be assumed as long as proper plate, screen, and heater voltages are applied to them. The TRF receiver previously discussed was powered by a full-wave rectifier system. For the larger TRF receivers of this type, this power supply is typical. However, there is no real reason why the TRF cannot be powered by a half-wave rectifier system. In fact, if actual numbers are considered, it will be discovered that the majority of receivers, whether TRF or superheterodyne, are powered by half-wave rectifiers.

The reason for this is obvious. With a half-wave rectifier there need be no power transformer. Thus, the weight, space and cost of the AC-DC power supply may be kept at a minimum.

The development of low-priced, compact, and light-weight table-model receivers had to wait for an important development, however. This development was the invention and large-scale production of the high-capacity small-size, electrolytic capacitors.

In the full-wave rectifier system included in the purely A-C power supply, as in the circuit of Fig. 4, the filter capacitors were of comparatively low capacity. This was due to the fact that at the time of manufacture, electrolytic capacitors were not available. The 2 or 4 mfd capacitors used for filter condensers were large, heavy, and costly. Besides, in order to attain a minimum hum in the plate and screen supply circuits, the filter choke had to be of high inductance, often 30 henrys or more. This added to the weight, space, and cost of these receivers.

These condensers were at once applied to the TRF receiver, and a typical table-model TRF receiver containing them is illustrated schematically in Fig. 11. This circuit is typical of an AC-DC receiver employing TRF tuned circuits. Note there are only four tubes, including the rectifier.

The ballast, which may look like a tube, is only a convenient way of containing the voltage dropping resistors (for dropping line voltage to the value required by tube heaters). In working with a receiver of this type, containing a "ballast tube" exercise extreme caution in handling the ballast -- it becomes exceedingly hot.

Note also that this table-model receiver contains a grid-leak type of detector. This is shown by the resistor-condenser parallel combination in the control grid circuit of the 6C6 tube. This does not infer that only A-C receivers use plate detectors and only AC-DC sets use grid-leak detectors. A generous sprinkling of both types of detectors are used in both types of sets. Common values for the grid leak resistor and condenser are 2 megohms and .00025 mfd, respectively.

Another point of interest in this AC-DC TRF is that it contains only two tuned circuits. The object, of course, is compactness. While the number of amplifiers are thus reduced, the gain of each of them is high through the use of pentodes, and signals are brought in with satisfactory strength. Selectivity (separating one station from another), however, suffers in this compact type of receiver. In fact, it was due primarily to the lack of selectivity in this type of receiver that the superheterodyne signal circuit was introduced. As soon as certain technical problems of design were solved, and patents on new superheterodyne circuits were released, the small size superheterodyne was produced in quantity, eliminating the short-comings of the TRF receiver.

Section 11. SIGNAL TRACING AND ALIGNMENT IN THE TRF RECEIVER

These two subjects, tracing signals through the TRF circuits, and alignment of their resonant components, may be treated as one, since the test equipment and procedures for each are identical. Before describing these procedures, let us emphasize an important consideration.

In the TRF receiver, all of the tuned circuits are resonant to the same radio frequency. The only other frequency involved in the TRF is the audio signal itself, which is recovered in the detector stage.

Alignment of the TRF, and signal tracing through its circuits, can be seen as a simple

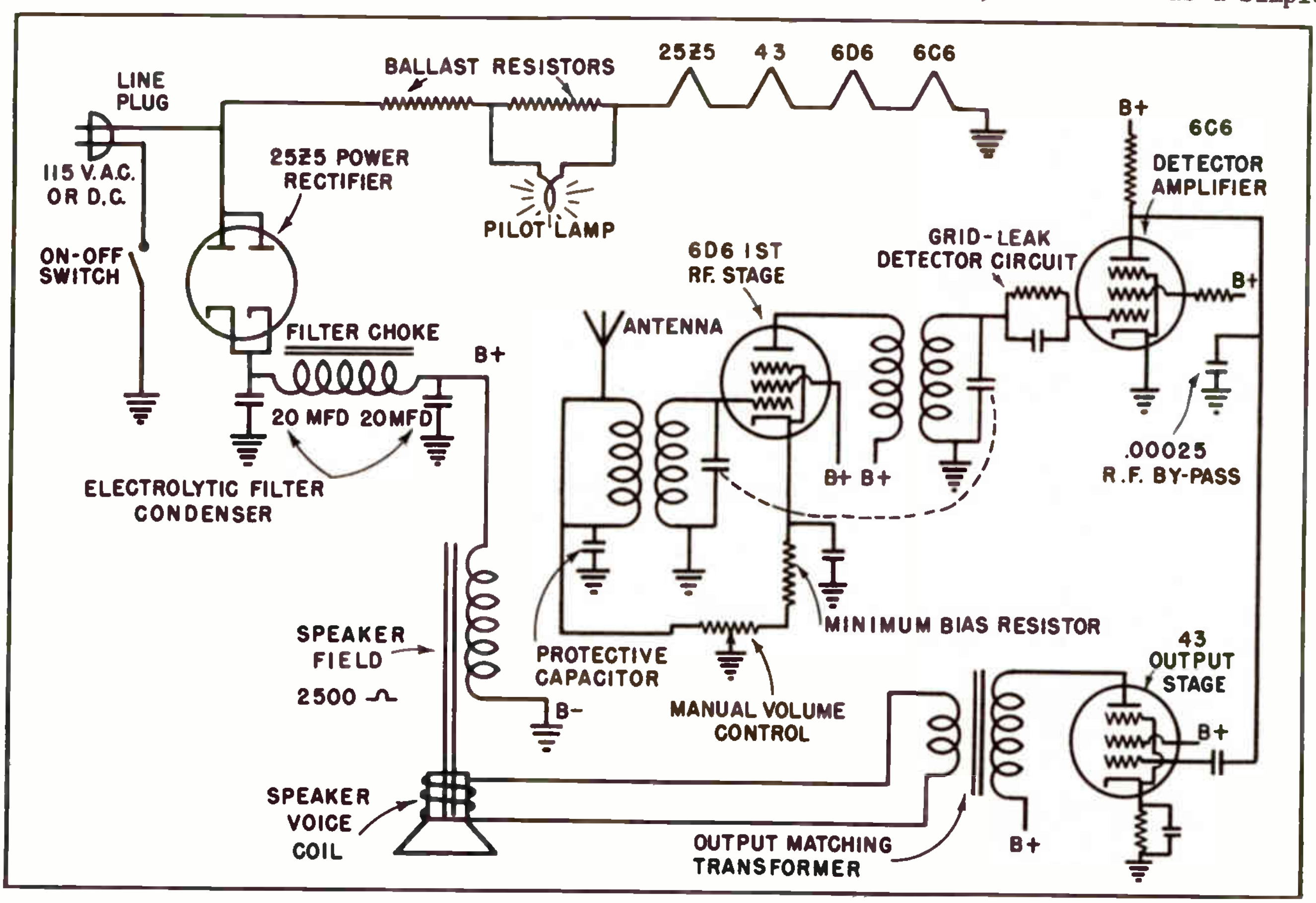

Fig.11. Full Schematic Diagram of the Typical Table Model, 4-Tube TRF Receiver.

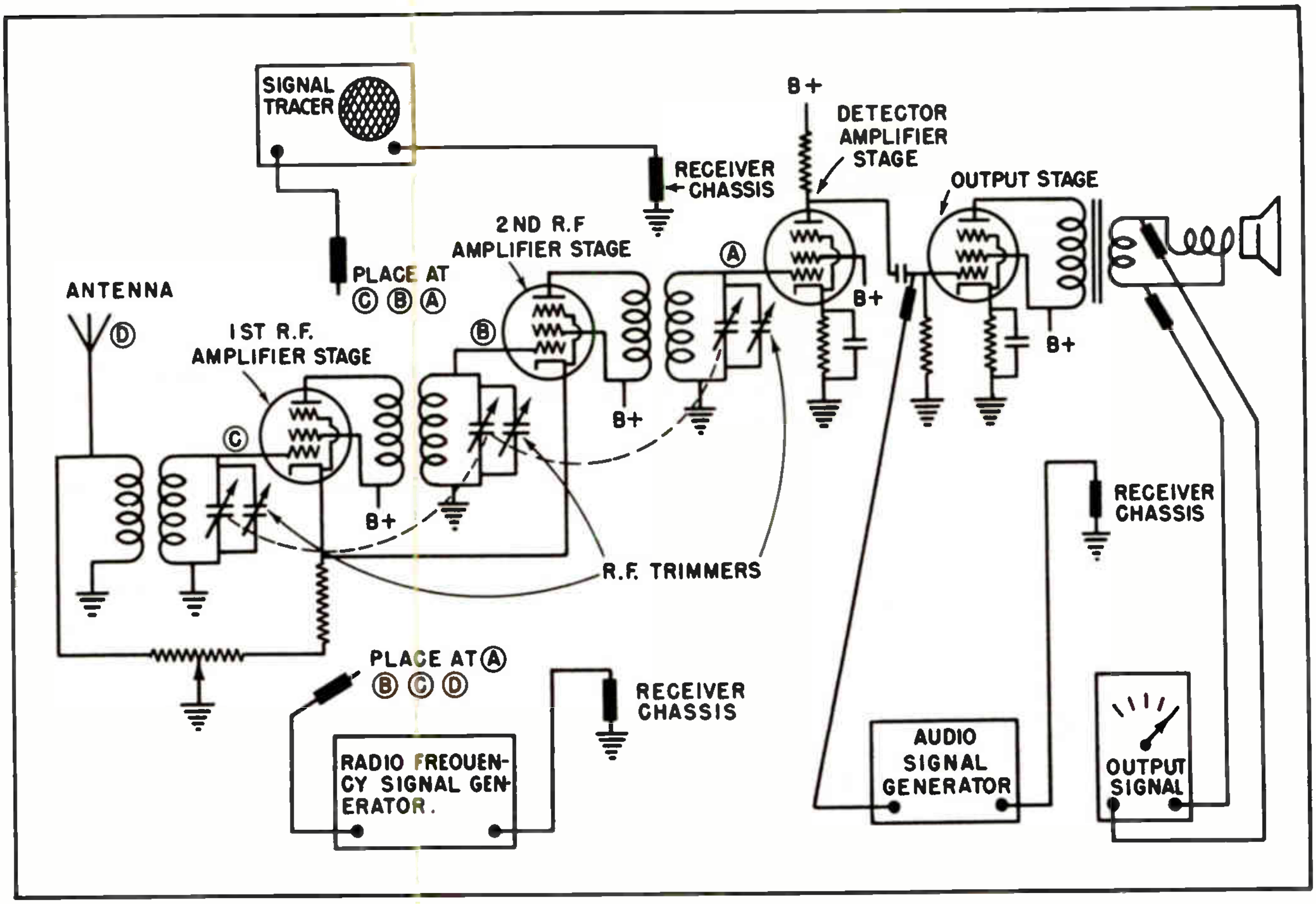

Fig.12. Signal Tracing and Aligning the TRF Receiver.

matter of adjusting each tuned circuit to the same frequency and testing the results.

Fig. 12 shows the alignment and signal tracing setup and the test equipment used.

The first step in the TRF alignment procedure, which also tests the output stage and speaker for normal operation, is to apply an audio signal to the grid of the output stage. While no alignment adjustment is made here, this step is necessary to test the final circuits of the receiver so that we may proceed in the confidence that a signal, once introduced at the output stage grid, will reach the speaker.

The next step is to apply a modulated radio frequency, at 1500 k.c. to the grid of the detector. The radio frequency signal generator is now set at this value and the test probe applied to point (A) of Fig. 12. Turn the receiver station selector to 1500 k.c. to pick up the modulation tone of the signal generator. Now make this tone as loud as possible, and make the output meter read as high as possible, by adjusting the trimmer condenser at point (A). (If the output meter is driven off its scale, reduce the output at the RF signal generator.)

The third step is to move the signal generator test probe to the point represented by (B) in Fig. 12. Repeat the previous procedure; that is, adjust the trimmer condenser at this point until the signal at the speaker is loudest, and the meter reads maximum.

The fourth step is to move the signal generator to the point represented by (C). Again repeat the adjustment on the trimmer condenser of this grid circuit, to maximize both the loudness of the tone at the speaker, and the output meter reading.

In the fifth and final step, move the signal generator test probe to the antenna of the receiver, marked (D). Starting with the last RF trimmer (in the grid of the detector stage), re-adjust each of them, progressing toward the first one in the first RF amplifier stage. Look for maximum reading on the output meter at the same time as the loudest tone is heard in the speaker.

Theoretically, this concludes the alignment procedure of the TRF receiver. Check the results by removing the test equipment connections and trying for station reception. If the signals are loud enough, if no whistling or howling occurs, and if stations can be reasonably separated from each other, then we may assume that the receiver is satisfactorily aligned.

Now referring to the signal tracing procedure, we may reason as follows: If during the alignment procedure a point is reached where the signal is lost, we may suspect that stage, circuit, or component of operational failure.

As an example, let us suppose that the alignment procedure is carried to point (B) and that a signal introduced here is recorded by the output meter and the speaker. This tells us that all circuits following this point must be in working order. Let us now suppose that when the test signal is applied to (C), we get no response from the output meter or the loudspeaker. We may correctly assume that the exact trouble lies somewhere between points (B) and (C). Ohmmeter and voltmeter tests of the coils, condensers, tubes, resistors, and wiring will readily reveal the exact trouble.

Signal tracing may be approached from a similar, but somewhat different point of view by the use of the signal tracer. Remembering that the signal tracer is essentially an untuned detector followed by an audio amplifier, it is evident that wherever we place the signal tracer test probe, if a signal is present at that point, the speaker of the signal tracer will respond with the modulation note.

In practice, the signal generator is applied to the antenna, and the signal tracer test probe is moved from (C) to (B) to (A), monitoring the signal at each point. The sudden disappearance of the signal between any two points will indicate that trouble lies between these two points. A detailed search in this limited area with voltmeter and ohmmeter will reveal the exact trouble.

Alignment may also be accomplished by the use of the signal tracer, if the trimmer condensers are each adjusted for maximum response in the signal tracer speaker. It must be noted, however, that the signal tracer will respond only to signals in the circuits which precede the pickup point of the signal tracer. In this way, the best order in which to adjust the trimmers are from the first, to the second, to the third, as we leave the antenna and progress toward the final circuits of the receiver.

An important final suggestion with reference to signal tracing and aligning the tuned circuits in a TRF receiver is this: Often, when the technician makes initial check of the receiver, the tubes are removed from their sockets. Almost all of the RF tubes in a TRF receiver are well shielded, to reduce the possibility of unwanted oscillations in the tuned circuits. The technician may neglect to replace the shields after replacing the tubes. This error must be avoided, for the alignment procedure will be notably unsuccessful if the tube shields are not replaced.

The symptoms of low signal volume, combined with whistling and howling, can often be traced to the absence of a tube-shield. This interference with signal reception may not affect the low end of the tuning dial, but it will become very strong at the high end. Where the tube shields are replaced, and whistling and howling are still present, it may be necessary to slightly detune at least one of the RF trimmers to eliminate the whistling. This should be done at a point on the dial where whistling interference occurs, as a conclusive proof that the correction is effective.

(Notes for Reference on Page Following)

NOTES FOR REFERENCE

A TRF receiver can be distinguished by the absence of the following: converter tube, I-F transformers, a cut-plate variable condenser section.

A TRF receiver may have either a half-wave power supply, or a full-wave power supply. The full-wave systems are heavy and bulky. The half-wave systems are used in the table-models.

In most of the console type TRF receivers, electrolytic filter capacitors are seldom found. Electrolytics are present in table-model TRF receivers.

TRF trouble-shooting is simplified by the fact that all of the tuned circuits are tuned to the same frequency at any given dial setting. The TRF receiver does not contain an oscillator, a mixer, nor I-F transformers.

The disadvantages of the TRF circuit compared to the superheterodyne are that the TRF is less selective and provides less gain per stage. It is for these reasons that the TRF receiver has largely been replaced by the superheterodyne receiver.

The advantages of the TRF receiver in comparison with the superheterodyne are that the TRF permits a wider band of frequencies to pass through its tuned circuit arrangement (making for better tone); and that the TRF -- unlike the superhet -- is not subject to image frequency interference. This is because the TRF contains no local oscillator.

Understanding TRF troubles is a pre-requisite for trouble-shooting superheterodynes, FM, radar, and television equipment.

The letter (K) or the letter (M) following the value of a resistor multiplies that value by 1000. Thus 10M is 10,000. Likewise 50K is 50,000.

The letter K is used to indicate "1000 ohms". For example, 10K means 10,000 ohms. 270K means 270,000 ohms. When so used the word "ohm" and the symbol for "ohms" is not needed. The letter K alone, stands for both 1000 and for ohms.

The letter M has long been used interchangeably with the letter K to represent "1000 ohms", some draftsmen using one form, others using the other. In recent years there has been a tendency among technical men to use the letter M to represent 1,000,000 ohms. Thus, 10M would mean 10 megohms, or 10,000,000 ohms. 15M would mean 15 megohms.

When used on schematic diagrams these two abbreviations are intended to shorten the number of digits, and make the drawing simple. At the same time, most such drawings have an index which indicates exactly what the two letters are intended to represent. If there is any possibility of confusion in a particular case always look for an explanation on the drawing. It is usually there, or should be.

NOTES

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THE SUPERHETERODYNE RECEIVER

Contents: Introduction - Recognizing the Superheterodyne Radio Receiver - Remote Cut-Off and Sharp Cut-Off Tubes - Stage Purposes and Operational Tests in the Superheterodyne - The Output Stage - The Driver Stage - The Second Detector Stage - The I-F Stage - The Mixer Stage - The Separate Mixer Stage - The Separate Oscillator - The RF Stage - Trouble-Shooting and Alignment - Power Supplies in Superheterodynes - Special Superheterodyne Circuits - Notes for Reference.

Section 1. INTRODUCTION

In previous lessons we have mentioned there are two separate and distinct ways of handling a radio-borne signal in the receiver. The first method, employed by the TRF receiver, involves the amplification of the signal by all of the tuned circuits *at the frequency of the RF carrier.* The second method is to accept the transmitted signal in one or two circuits tuned to the RF carrier frequency, then convert that frequency to another -- somewhat lower intermediate frequency. This second method is typical of the one employed in all modern superheterodyne receivers.

Much of the discussion in this lesson will constitute a review of the subjects previously covered. These will include the stages, functions, and peculiarities of the superheterodyne receiver -- from the trouble-shooting viewpoint -- with the object of including under one heading the salient characteristics of the superheterodyne receiver and the circuits peculiar to that type of receiver. Also included in this lesson will be several subjects which have been mentioned briefly in other lessons, subjects which nevertheless require detailed treatment. Historical changes in circuit design will be discussed. Some of these were brought about by improvement in modern

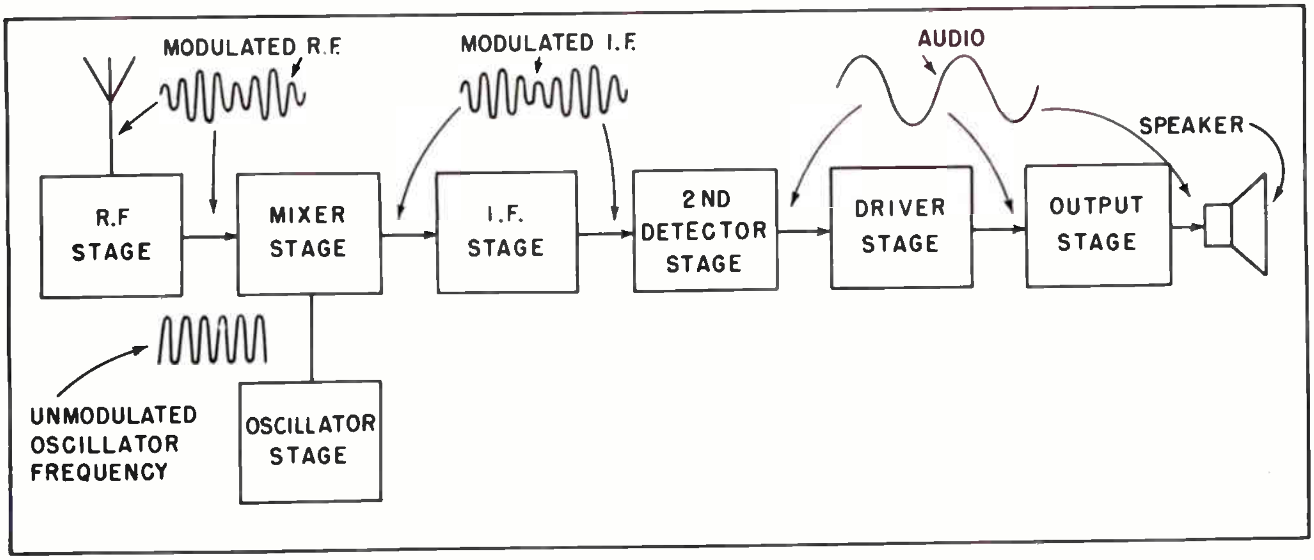

Fig.1. Block Diagram of the Superheterodyne Receiver.

manufacturing techniques. Others, by the need for separating the ever-increasing number of transmitters on the air. These circuit changes will all be pointed out and duly emphasized. Our purpose now is to further simplify the job of radio and television trouble-shooting by showing the underlying reasons behind the many changes in modern radio and television receiver circuits.

Section 2. RECOGNIZING THE SUPERHETERODYNE RADIO RECEIVER

An initial step, of utmost importance in trouble-shooting any kind of radio or television receiver, is to distinguish beyond all doubt the type to which it belongs. By this simple step many *impossible* troubles can be immediately ruled out of the analysis. If the type of receiver is known beyond doubt, we can rule out those troubles which are inconsistent with that type receiver. This method of reasoning is at the heart of all quick and accurate radio and television trouble-shooting. This scientific principle saves time and effort, as well as confusion, which could result from a vain attempt of a technician to locate and test a component part which is not even present in the type of receiver under analysis.

Before studying the features which distinguish the superheterodyne receiver from the TRF, another important consideration should be borne in mind. This involves the power supply of a receiver which is not important so much for what it tells us about a receiver signal circuit, as for what *it fails to tell us.*

Both a TRF receiver and a superheterodyne receiver may have any of four different power supplies. These are: the AC-DC, the straight A-C, the automobile type, and the portable power supply. But the type of power supply included in a receiver under analysis is in no way a positive indication of the nature of its signal circuits.

While it is true that portable and automobile receivers, being of more recent development, virtually always contain superheterodyne signal circuits, there is no technical reason why they cannot contain TRF circuits. Since any type of receiver can contain any type of power supply, let us then conclude that the nature of the power supply is not a reliable guide in determining the nature of the signal circuits of a receiver.

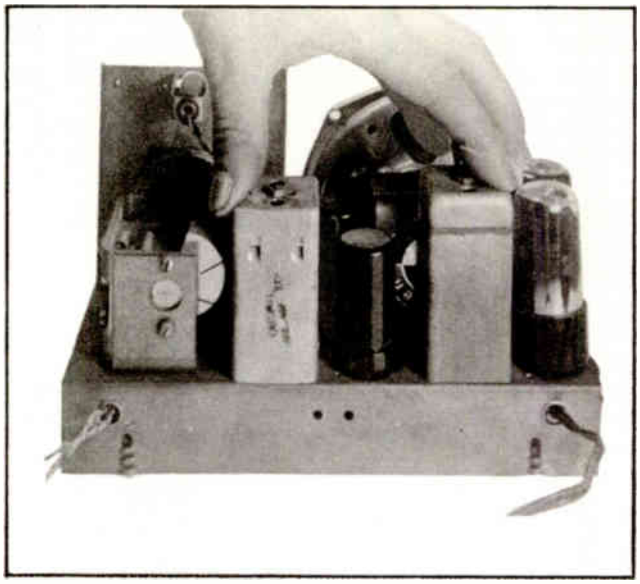

Fig.2. I-F Transformers Identify the Superheterodyne Radio Receiver

Now let us review briefly the action which takes place in the handling of an incoming signal by a superheterodyne receiver with an eye toward the special components required. Once we have identified these components, we have at once placed the receiver in its class and can positively recognize it as a superheterodyne type of signal circuit. Trouble-shooting the receiver, then, becomes a matter of organizing our analysis around the superheterodyne character of its design.

Fig. 1 reproduces the block diagram of a superheterodyne receiver, and includes the wave-forms into and out of each stage. The signal, transmitted from a distant point, is picked up at the receiver antenna in the form of A-C voltage changes of very low amplitude. The audio component, carried in the form of amplitude modulation, is represented by a changing amplitude in received signal strength while the signal frequency remains constant. An initial tuned circuit in the RF stage of this receiver resonates at the frequency of the incoming signal. This resonance is adjustable by the manual tuning dial, and constitutes the station selector of the receiver. Mechanically coupled to this station selector knob is another condenser, also variable, which adjusts the local oscillator frequency to maintain a constant *difference* from that of the incoming signal. This difference, called the Intermediate Frequency, is produced in the *non-linear* mixer stage and is fed from there to the plate load of this stage. The plate load of the mixer stage is the primary winding of the first I-F transformer, which is tuned to the difference frequency originating in the mixer stage. All this is merely restating things we have covered in previous lessons.

Pausing a moment at this point, let us see what has happened thus far. The incoming signal, carrying the modulation of voice or music, or the pattern of a picture for the picture tube, has been tuned and amplified in the RF stage. It is fed to the mixer, into which the local oscillator frequency is likewise injected. The mixer stage, through the agency of the first I-F transformer primary, produces a new frequency whose numerical value is equal to the difference between the oscillator and incoming signal frequencies, and which bears the modulation of the incoming signal.

The I-F transformer is simply a means of tuning and coupling the difference frequency, with its modulation, to the I-F amplifier. This amplifier, a pentode of the high-gain type, increases the signal strength and passes it further along to the primary of the second I-F transformer. Here again the tuning process is repeated. It should be emphasized that tuning and amplification in the I-F stages of the superheterodyne are accomplished at the I-F frequency, and *not* at the frequency of the RF carrier signal.

The second I-F secondary accepts the induced signal and places it as a voltage change across the network consisting of the diode detector and the manual and automatic volume control resistors. Here the fast-changing I-F component is filtered off to ground through an appropriately small RF by-pass condenser, and the audio component is retained as a constantly varying voltage drop across the manual volume control.

Adjustment of the signal volume is done manually by advancing or retarding the manual volume control. Electrically, this is a potentiometer, usually with a resistance of about half a megohm. It is placed between the diode detector and the driver grid, accepting an audio signal from the former and passing it on, at the proper volume level, to the latter.

From the driver grid on to the loudspeaker -- and this includes the entire audio section starting with the driver grid -- the superheterodyne and TRF receivers are strikingly similar. The driver stage provides enough *voltage* gain to energize the output stage grid. The output stage, in turn, provides enough *power* gain to energize the loudspeaker or sufficient voltage to control the grid of the picture tube.

The output stage of either the superheterodyne or the TRF receiver may contain push-pull stages, together with interstage transformer or phase-inverter, where the output is to drive a speaker.

In the light of this comparison between a TRF receiver and a superheterodyne, what are the distinguishing features of these two distinctly different types of receiver signal circuits?

First: If a receiver contains an oscillator tube, or an oscillator-mixer tube, it must be a superheterodyne. In case of doubt regarding any tube, reference to the tube manual will indicate the exact function of the tube.

Second: If a receiver contains a pair of I-F transformers (See Fig. 2) it must be a superheterodyne receiver.

Third: If a receiver contains a ganged variable condenser, one of whose sections is physically smaller than any other, it is a superheterodyne receiver. (See Fig. 3.) The converse of this is not necessarily true, for in the older superheterodyne receivers, all of the sections of a ganged variable condenser are of the same physical size. The oscillator section, however, is found upon examination to contain a "padder" condenser in series with it, which serves to reduce its capacity.

Fourth: Both the sound and the video channels of all television receivers operate on the superheterodyne principles.

These four identifying marks are dependable either when they occur singly, or together. (In most cases, they will occur together.) However, when at least one of these identifying features is recognized, the receiver may be classed as a superheterodyne without further confirmation. The technician, in handling the set, will soon notice the other features characteristic of the superheterodyne receiver.

The reason why several separate identifying marks are mentioned in recognizing the superheterodyne receiver is interesting, since it illustrates the wide variety of manufacturing and design practices. For

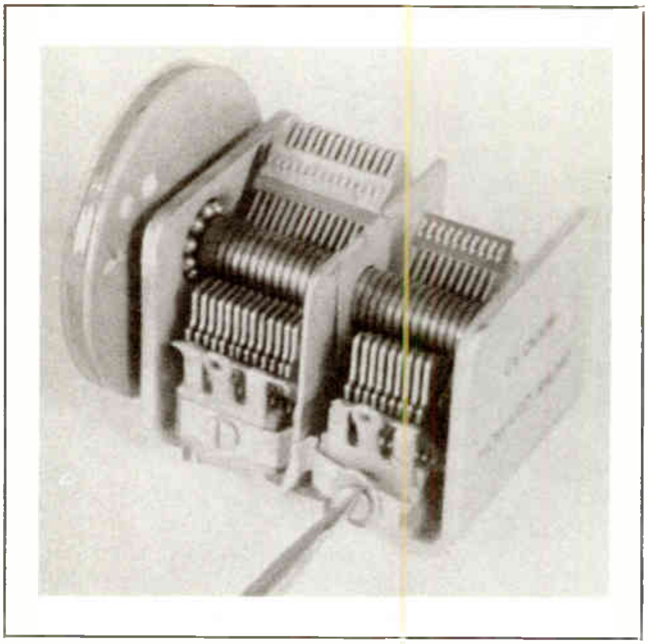

Fig.3. One Section of the Superheterodyne Ganged Tuning Condenser Assembly is Physically Smaller Than the Other.

instance, some manufacturers, in their equipment, use a triode oscillator and a pentode mixer. In the tube manual, neither of these is *stressed* as a superheterodyne component. The technician may fail to notice that a triode, usually an audio component, may *also* be effectively employed as an oscillator. He would assume, then, that since the triode is not specified as an oscillator, the receiver must be a TRF. This would be an erroneous conclusion, to be sure, and in order to avoid this error, *another* feature of the superheterodyne receiver should be sought, such as the I-F transformers, or the differently-sized variable ganged condenser sections.

Another example would be if the receiver contained a three-ganged variable condenser, all sections of which are the same physical size. This would be a TRF receiver unless it is known that one of the condenser sections has a padder in series. But it may take extra time and effort to trace out the circuit and look for the padder. Quicker identification can be made by referring either to the presence of an oscillator tube or the I-F transformers. If any of these are present, then the padder condenser in series with the oscillator section of the ganged variable condenser may be assumed without further checking.

Since the signal circuit of a receiver must be of *either* the TRF *or* the superheterodyne class, it cannot belong to both classes. We may logically conclude, then, that if a receiver is known to be a superheterodyne, it cannot be a TRF. The contrary is likewise true. If it is *not* a superheterodyne, it *must* be a TRF. The trained technician will be able to identify a receiver at a glance, and will know the type of signal circuit, as well as the type of power supply it contains, long before he has taken the chassis from the cabinet. This is as true of television receivers as of radio receivers. Then, having already made this identification, the trained technician will know just about what kind of troubles to expect, and what not to look for.

Section 3. REMOTE CUT-OFF AND SHARP CUT-OFF TUBES

In separate lessons on superheterodyne circuits, frequent reference was made to RF and I-F amplifier tubes as *remote*, or *sharp*, cut-off types. The cut-off characteristics of amplifier tubes become significant when we are dealing with the superheterodyne receiver, which is almost always provided with automatic volume control (AVC).

In the *sharp cut-off* type of pentode or tetrode amplifier tube, which is the "ordinary" type, the control grid is wound with uniform spacing between its loops. This is

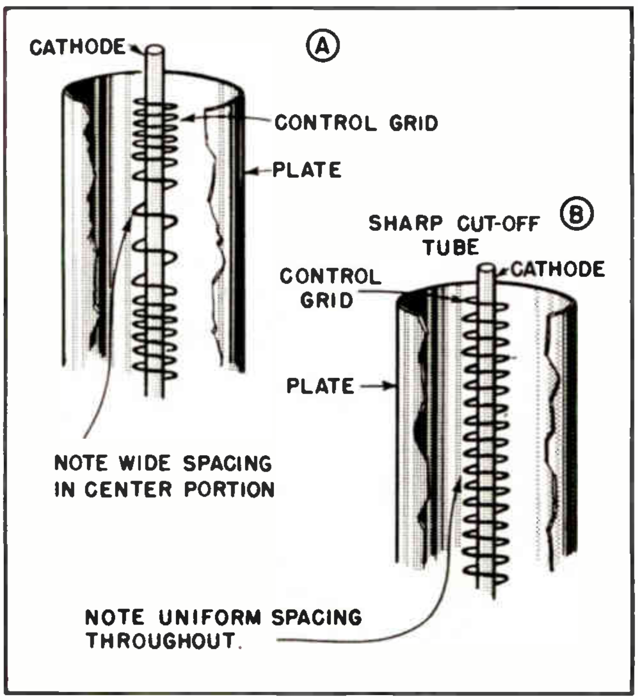

Fig.4. Remote Cut-Off and Sharp Cut-Off Tube Construction.

illustrated in Fig. 4-B. While for many purposes, including that of the pentode detector, this construction is satisfactory, it falls short of requirements in some applications.

Fig. 4-A shows the manner in which the control grid loops are wound within the *remote cut-off*, or *variable mu*, tube. Notice that the spacing is wide in the center portion of the loops, while the end portions are spaced rather close together.

The change from sharp cut-off amplifier tubes to remote cut-off characteristics is an historical step forward in the design of radio tubes. It was brought about by the development of the diode detector as a replacement of the pentode detector. This alteration in circuits obviated the need for high-gain detector tubes with sharp cut-off characteristics. These same high gain pentodes had been previously applied to radio frequency amplifiers in the TRF receiver.

At the time when there were comparatively few radio transmitting stations on the air, the sharp cut-off tubes served their purpose rather well. However, as new stations were being placed on the broadcast band, it was found that two stations whose frequencies differed by twenty or thirty kilocycles would interfere with each other, since they were both presumably broadcasting with strong power and (in a given community) were fairly close together. This type of interference between two broadcasting stations is known as "cross-modulation", and essentially amounts to one signal riding through the tuned stages of the receiver on the other signal. The results are obvious -- two stations coming in at the same time render both of them unintelligible.

It was found that the reason for this cross-modulation lay in the sharp cut-off characteristics of the pentode RF amplifiers. Reference to Fig. 5 will show that in the sharp cut-off tube, the sharp bend of the knee of the curve at high negative bias makes it possible for a strong and numerically adjacent transmitter to vary the self-bias of a stage through the comparatively narrow limits of the "knee" of this curve. Moreover, this varying bias, small though it may be, is accomplished at the modulation (or audio) frequency of the interfering station. Besides, since this phenomenon takes place only in the first RF amplifier stage (where tuning is broad), any injection of an interfering signal at this stage must

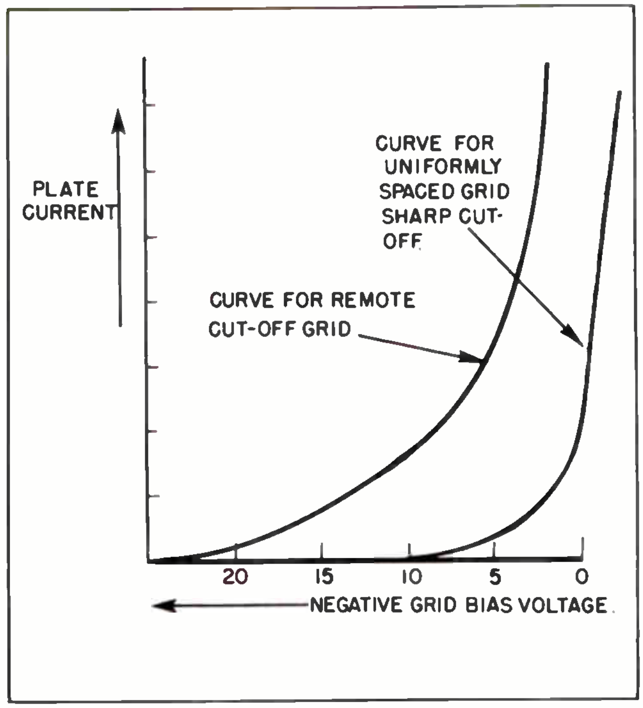

Fig.5. Plate-Current vs. Grid-Voltage Curves for Sharp Cut-Off and Remote Cut-Off.

be followed by a great deal of gain in the following stages. The consequence is a signal interfering with that to which the receiver is tuned. The remedy for this type of interference was to stretch out the "knee" of the curve. This was done with the remote cut-off amplifier tube.

As illustrated in Fig. 4-A, the remote cut-off, or variable-mu, amplifier tube will perform the desirable function of stretching out the "knee" of the characteristic curve of the tube. This is accomplished in the following way:

When weak signals are applied to the stage provided with a "variable-mu" tube, while the bias voltage is high, the emission of electrons from those areas of the cathode surrounded by the closely spaced grid loops is very low, virtually cut off to zero. The center portion of the cathode, however, which is surrounded by relatively open grid loop spacing is not so much affected by the high bias. It will therefore continue to emit its current in almost the normal amount and the electrons will pass through the wider spaces. When the signal drives the control grid still more negative, the only effective portion of the cathode that produces plate current changes is that *within* the openly-spaced grid loops. This

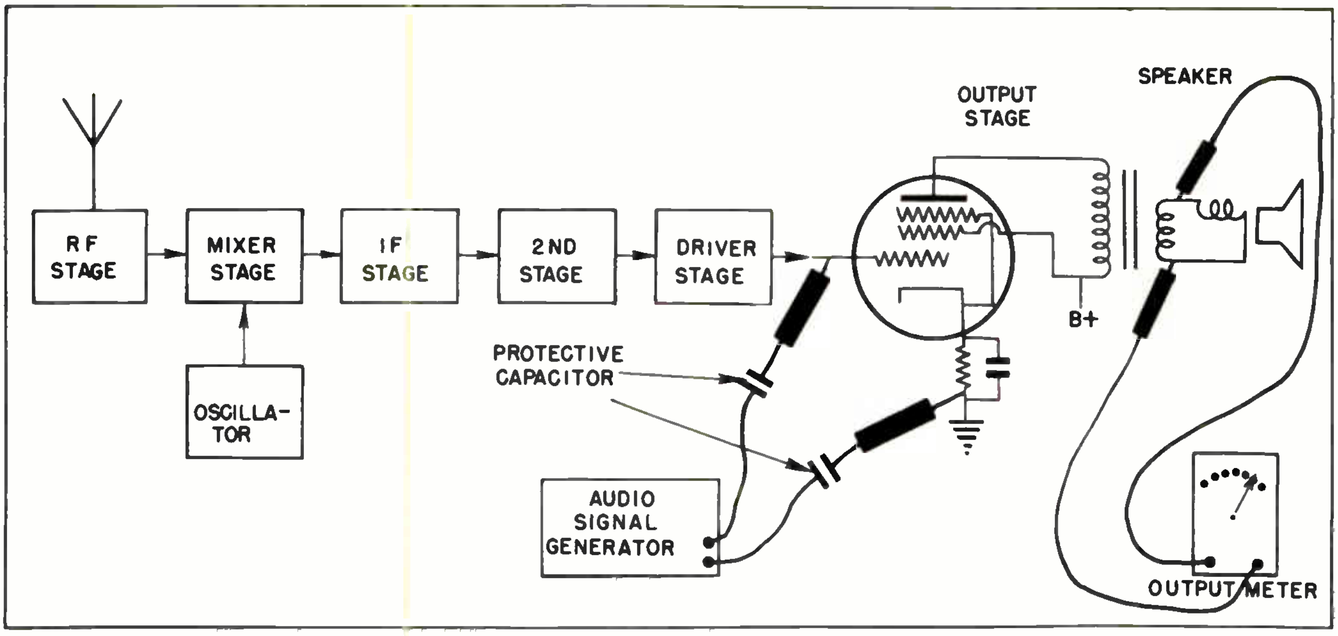

Fig.6. Checking the Output Stage During the Stage-by-Stage Tests of a Superheterodyne Receiver.

means that this tube becomes harder to cut off with an increasing bias. It may be added that this type of tube is almost immune to complete cut-off no matter what grid voltage is applied.

With this property, the remote cut-off tube has successfully reduced cross-modulation. But its services have been extended to minimize another disadvantage inherent in the sharp cut-off tube. This is a type of distortion known as *modulation distortion.* In a TRF receiver this distortion of the audio signal generally takes place in a sharp cut-off last RF amplifier. In a superheterodyne, the sharp cut-off last I-F amplifier is generally the offender.

Examination of the curves in Fig. 5 shows the reason for modulation distortion. Where the "knee" of the curve is excessively bent, the positive half-cycles of the carrier frequency will be amplified without distortion. The negative half-cycles, handled by the non-linear portion of the curve, will be flattened out considerably by the small changes in plate current per unit change in grid voltage.

This amounts to an undesirable detection process on a signal that is not yet meant for detection. Moreover, a detector should have a *resistive*, and therefore *untuned* load, for proper demodulation of a radio frequency carrier. The result of this premature detecting action in the sharp cut-off tube is to actually distort the audio component of the signal, sometimes to a serious degree. Here again stretching out the "knee" of the curve, accomplished by the remote cut-off tube, serves to minimize this effect in the last RF or I-F amplifier stage.

There is yet another important purpose served by the remote cut-off tube as applied to the superheterodyne receiver containing automatic volume control.

Since the sharp cut-off tube is considered as a constant-mu tube, any AVC bias voltage applied to its grid will quickly bring the stage to near cut-off, without affecting its gain characteristics. In the variable-mu, or remote cut-off tube, however, the effect of an increase in AVC bias voltage will not bring the tube to cut-off, but will smoothly reduce its gain characteristics. As we can see, this will avoid both the evils of modulation distortion and that of cross-modulation in any stage controlled by AVC voltage.

Fig. 4-B and Fig. 5 illustrate the physical arrangement, and electrical response curve, respectively, of the sharp cut-off amplifier tube.

Section 4. STAGE PURPOSES AND OPERATIONAL TESTS IN THE SUPERHETERODYNE

The function of each stage in a superheterodyne receiver may well be discussed along with an operational check for each stage. For in understanding the function of a stage, we may better evaluate what it *does* in direct comparison with what -- under normal conditions -- *it ought to do.*

Let us begin, as the experienced radio and television technician begins, the actual trouble-shooting of a defective superheterodyne receiver. We will first test all tubes carefully for shorts, emission, and leakage on a dependable tube-checker. Replace those which are found to be at fault. Test the receiver for signal reception. In many cases, the replacement of a defective tube will eliminate the trouble.

If the receiver does not operate after checking tubes and replacing those found to be faulty, then the process of stage-by-stage analysis begins.

Section 5. THE OUTPUT STAGE

In Fig. 6 is shown a complete block diagram of a typical superheterodyne receiver, but with the output stage shown in detail.

The purpose of the final output stage is to accept from the driver stage an amplified form of the audio signal (originally brought from the transmitting station on the RF carrier) and amplify it enough to energize a loudspeaker. In view of this function, the test for this stage is to introduce a typical audio signal on its control grid, as shown in the illustration, and listen for the tone in the loudspeaker. The output meter, as shown, will read maximum when the tone sounds the loudest. If the tone is absent or unreasonably quiet, and the meter reads zero or very low, the problem of locating the exact fault is approached by the use of ohmmeter and voltmeter on the components of this stage, including the output transformer and the loudspeaker.

Significant in this stage test are the following:

1. The manual volume control, since it is located in an *earlier* stage, will not affect the loudness of the tone at the speaker.

2. Keep the loudness control *on the audio signal generator* reasonably advanced for a conclusive test.

3. The output tube should have been previously tested.

Section 6. THE DRIVER STAGE

The next stage to be tested is the driver stage. Its function is to accept from the manual volume control a comparatively weak audio signal, amplify its voltage with a gain of ten or twenty, and deliver it to the signal grid of the output stage. Testing equipment for the driver stage is consequently set up as in Fig. 7. An audio signal is introduced at the high side of the manual volume control and the output meter

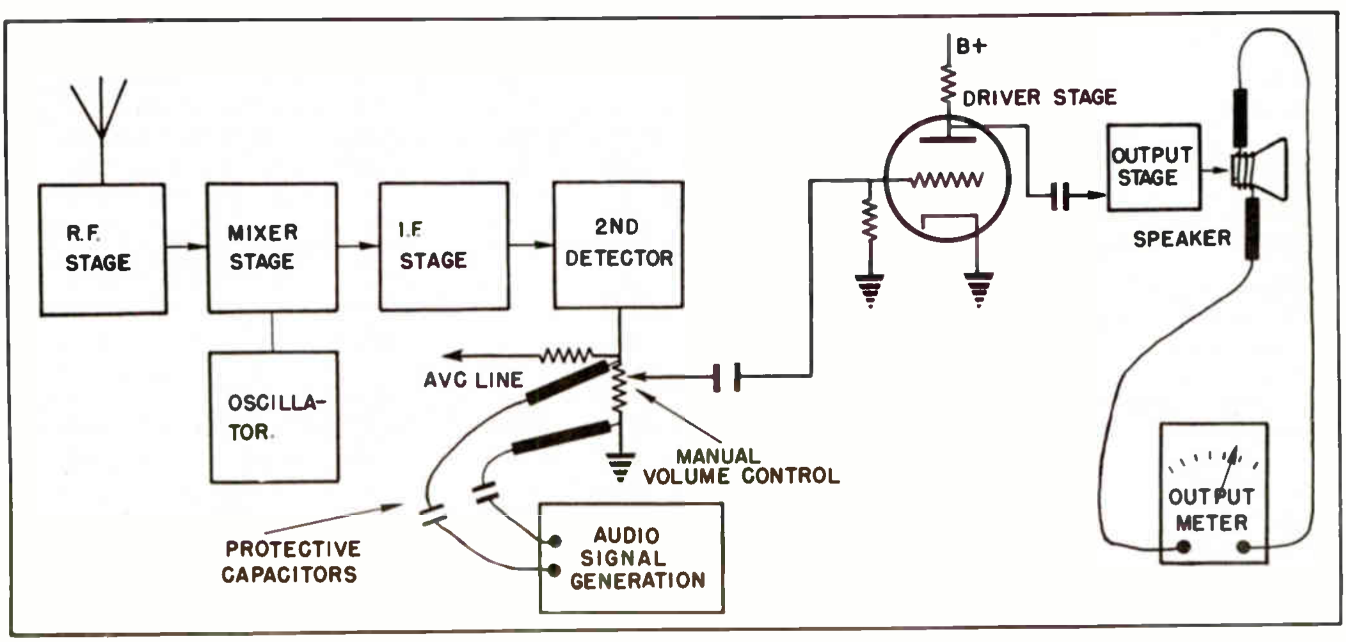

Fig.7. Testing the Driver Stage of the Superheterodyne Receiver.

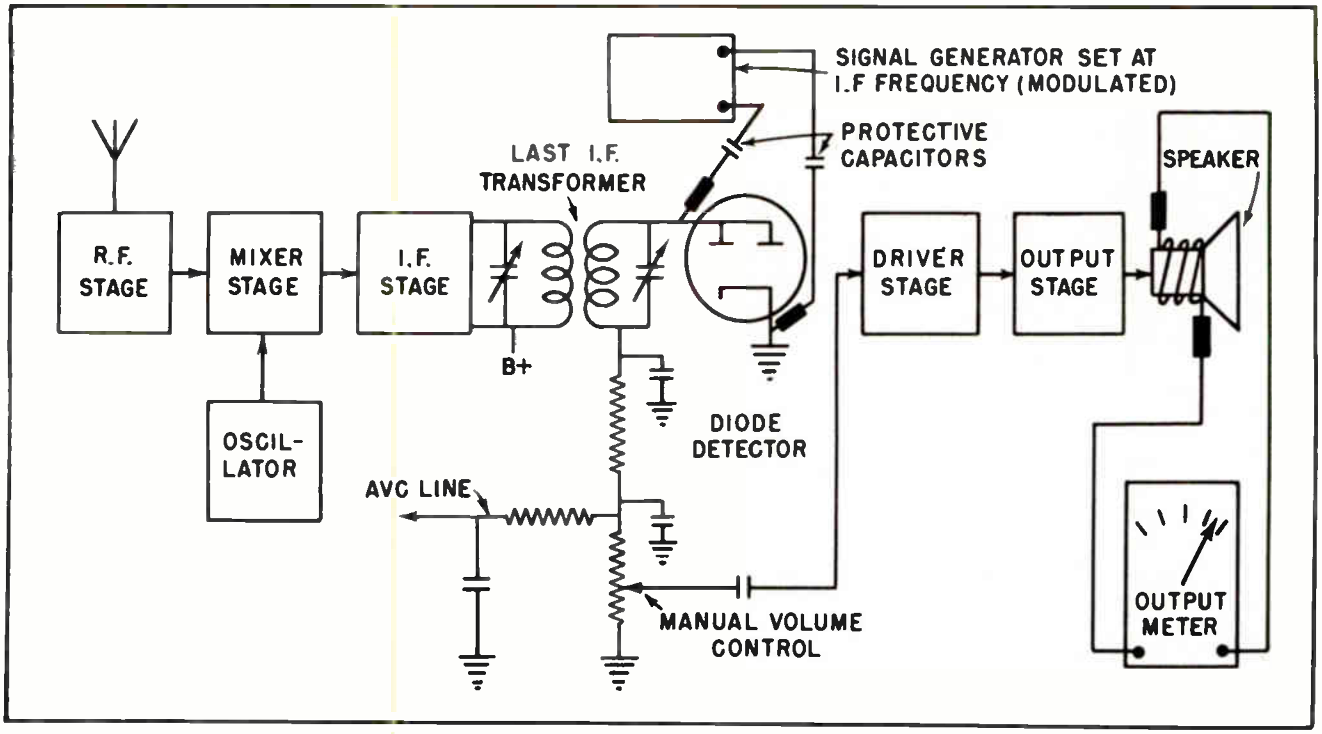

Fig. 8. Checking the Second Detector of the Superheterodyne Receiver. Note That the Signal Generator is Now Set at a Modulated I-F Frequency.

is attached across the speaker voice coil. The audio tone should be clearly heard at the speaker, and the output meter should respond with a maximum reading. As the diagram shows, this test also includes the operation of the manual volume control and the volume control condenser, which immediately follows it. If no signal is heard, and the output meter deflection is very low or zero, then the trouble must be located exactly by the use of an ohmmeter and a voltmeter applied to the components of this stage.

Significant in this stage test are:

1. The signal will be affected by the manual volume control.
2. The signal should be louder (and the meter deflection greater) than in the previous test for the output stage. This is because we may expect that a driver stage, properly operating, will supply considerable *voltage gain* to the applied signal.
3. The driver tube should have been previously tested.

Section 7. **THE SECOND DETECTOR STAGE**

After the audio stages have been tested (and these include the driver, the output stage, and all of their associated circuits) we are ready to make an operational check on the second detector stage.

The purpose of the second detector is to accept an I-F signal, with its audio modulation, from the last I-F stage; to separate the audio and I-F components; then to pass the former to the driver grid through the manual volume control, while the latter is sent to ground. A second detector stage which accomplishes these duties is considered in good working order, and can consequently be tested for operation by the method suggested in Fig. 8. Here the schematic diagram of this stage is shown in detail, while the rest of the stages are indicated in block form.

This is the first stage, in the trouble-shooting procedure, where a high-frequency test signal is introduced instead of an audio test signal. In most cases, where the audio and RF signal generator are not combined in one unit, the audio signal generator will have to be replaced by an RF generator. This is attached as shown in Fig. 8, and the meter is left across the voice coil of the speaker, as before.

Determine the I-F frequency of the receiver, and set the RF signal generator to this value. Apply this signal, modulated, to the diode plates of the second detector. Advance the volume control to maximum. The modulated tone, originating in the signal generator, should be heard at the speaker at the same time as the output meter shows a deflection. With an insulated screw-driver, adjust the two trimmer condensers (across the primary and secondary of the last I-F transformer) for maximum meter reading and loudest tone at the speaker. If the tone is reasonably loud and the meter shows a noticeable deflection, then the second detector stage is indicated as in working order.

If the tone is extremely quiet, or altogether absent, and if the meter reads little or zero, the exact trouble is in this stage and must be sought out in detail with the aid of the ohmmeter and voltmeter.

Significant in this stage test are:

1. The loudness of the signal will be affected by the manual volume control of the receiver.
2. Since we are now using another signal generator, a new standard of loudness, and output meter deflection, must be set. Advance the output amplitude control on the RF signal generator, so that the meter reads about 1/4 of the scale. Do not change the position of this control throughout the rest of the procedure, unless the output meter is driven off of its scale. This setting establishes a new comparison value to indicate the gain through the preceding stages of the receiver.
3. The tube containing the diode plates should have been previously tested on a tube-checker.

Section 8. **THE I-F STAGE**

The next stage to be tested is the I-F stage, which includes the first I-F transformer, the I-F amplifier, and the last I-F transformer. The purpose of these combined components, lumped together as the I-F section, is to select and amplify the I-F modulated signal from the mixer stage, and present it, in highly amplified form, to the second detector stage. The operational test of this section of the superheterodyne receiver, then, is the process of introducing a modulated I-F signal at the mixer plate, and looking for its appearance at the diode detector plates. Since the detector, the driver, and the output stages have been previously tested, *this modulated I-F signal should be heard at the loudspeaker.* Fig. 9

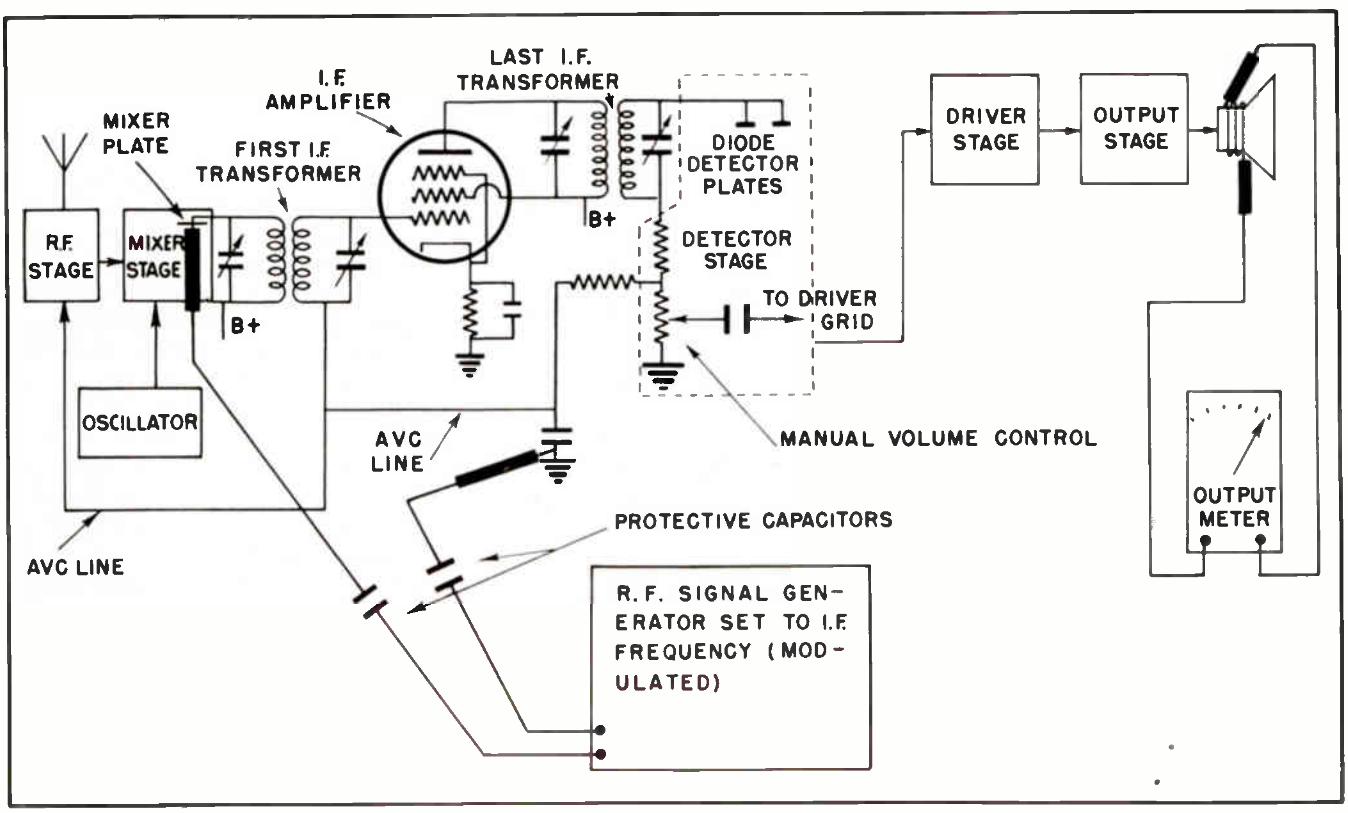

Fig.9. Operational Check for the I-F Section of the Superheterodyne Receiver.

shows how the equipment is connected for this test. Here the I-F section is shown in schematic detail while the remainder of the receiver is represented in block form.

In this test, the previously determined I-F frequency of the receiver, with audio modulation, is introduced at the mixer plate through the protective capacitor. If this stage is in working order, the modulation tone of the signal generator should be heard at the loudspeaker at the same time the output meter deflects. During this test, adjust the trimmers across the *first* I-F transformer primary and secondary windings for loudest tone and maximum deflection of the output meter. (Note: Use an insulated screw-driver for these adjustments.) If the signal comes through with a volume greater than in the previous test (of the second detector stage), and if this is also indicated by an *increase* in the reading of the output meter, the I-F section of the receiver may be assumed in good working order.

However, if the signal is unreasonably quiet, and the output meter reads a low value or zero, then the trouble is due to a fault in the I-F section of this receiver. In this case, the technician would lay aside his stage-testing equipment and search out the exact fault in this section by the use of the voltmeter and ohmmeter.

Significant in this stage test are:

1. The manual volume control will affect the loudness at the speaker.

2. The previous setting of the output amplitude on the signal generator, and the meter readings from that test, may now be used as a standard of comparison. If the meter is driven off scale by excessive output voltage, reduce the strength of the signal generator output. This action, however, indicates a properly operating I-F section, for it shows that considerable gain has taken place between the input and the output of the I-F section.

3. The adjustment of the I-F trimming condensers during this, and the previous, stage tests will mean that not only have the I-F tuned components been found in good working order, but that their adjustment insures against their having "drifted" in the past. Any small change in their resonant frequencies can be corrected with practically no effort during these tests.

4. The I-F amplifier tube should have been previously tested on a tube-checker.

Section 9. **THE MIXER STAGE**

In its most common form, the mixer stage is found in electrical combination with the oscillator stage, and in almost all commercially produced receivers both the mixer and oscillator functions take place within the same glass tube envelope.

From the stage-testing, and trouble-shooting, point of view, therefore, a test that fully investigates the mixer must also take the oscillator stage into consideration.

Fig. 10 is the block diagram of the superheterodyne receiver with the schematic circuit details shown for the combined oscillator-mixer stage. Since this type of conversion circuit is the most common, we shall outline its function and operational check procedure first.

The purpose of the oscillator-mixer stage is to convert the incoming radio-borne signal over to an I-F frequency which bears the same audio modulation as the received carrier. Since the oscillator feature is also included in this stage, it has the additional function of producing the local frequency used to heterodyne with the incoming frequency to derive their difference. This difference in frequency, of course, is the I-F frequency.

To test the operation of this combined oscillator-mixer stage, therefore, a modulated RF signal created by the signal generator and introduced at the signal grid of the stage should mix with the local oscillator frequency within the electron stream of the tube and their resultant difference should be picked up in the mixer plate circuit. The test set-up in Fig. 10 will accurately provide this test. Now, since the succeeding stages have all been tested, if the I-F difference is presented to the first I-F transformer primary, it should be carried through the remainder of the receiver and be heard at the speaker, while the output meter across the voice coil shows a measure of deflection.

Comparison may now be made with the standard of loudness as heard by the ear, and the meter reading, during the previous (I-F stage) test. Without changing the output strength of the radio frequency signal generator, set its frequency to 1000 k.c.

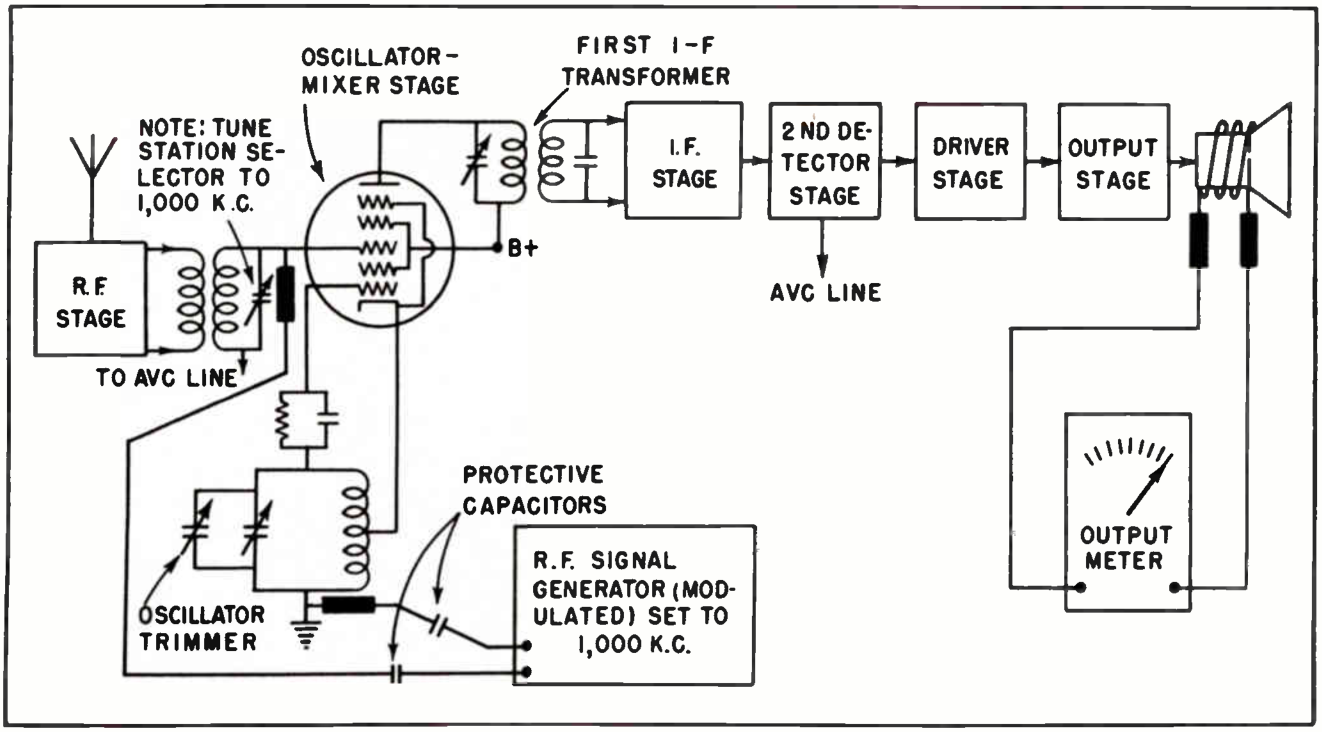

Fig.10. Checking the Mixer Stage for Performance. Note That the Signal Generator is Now Supplying a Modulated RF Frequency.

and tune the receiver station selector to the same value. The signal from the generator should be picked up by the RF tuned circuits, sent through the oscillator-mixer stage, and should appear at the speaker (and the output meter) in increased strength.

This increase in signal strength as compared to the previous stage check is due to the gain of the mixer stage. The meter should read a high value, and the ear should also be able to distinguish this increase. (Not too much gain in this stage should be expected, however, for gain in the mixer stage is only incidental to the conversion process.) If there is no perceptible increase or if there is a decrease in the response at the speaker and the meter, then trouble in the oscillator-mixer stage is indicated.

However, before attempting to shoot a component failure in this stage, another possibility should be investigated. This is the likelihood that the oscillator capacity (shown in Fig. 10) may have "drifted" in value. To compensate for any such drift, adjust the oscillator trimmer condenser so that the loudest signal at the speaker, and the highest meter deflection, take place. This act re-aligns a "drifted" oscillator capacity; or, if the oscillator has *not* drifted, this act establishes that important fact.

If an adjustment of the oscillator trimmer capacitor only serves to *lessen* the speaker response, then return it to its original position and assume the oscillator-mixer stage to be in good working order.

Significant in this stage test are:

1. This test includes the performance of the oscillator, as well as of the mixer, functions of the stage. If the oscillator had not been in working order, there would be no conversion in the stage and the signal would not move to the following stages. In like manner, if the oscillator were in good order, but a fault occurred in the mixer components, that also would account for the signal being lost in that stage.

2. The alignment of the oscillator trimmer capacitor is an easy and natural part of this test, and can be made with practically no extra expenditure in time or effort. It assures the technician that the oscillator will "track" properly, and that the trouble he is seeking may be merely one of mis-adjustment rather than one of component failure.

3. The oscillator-mixer tube should have been tested on a tube-checker, *and* -- this is of the utmost importance in this

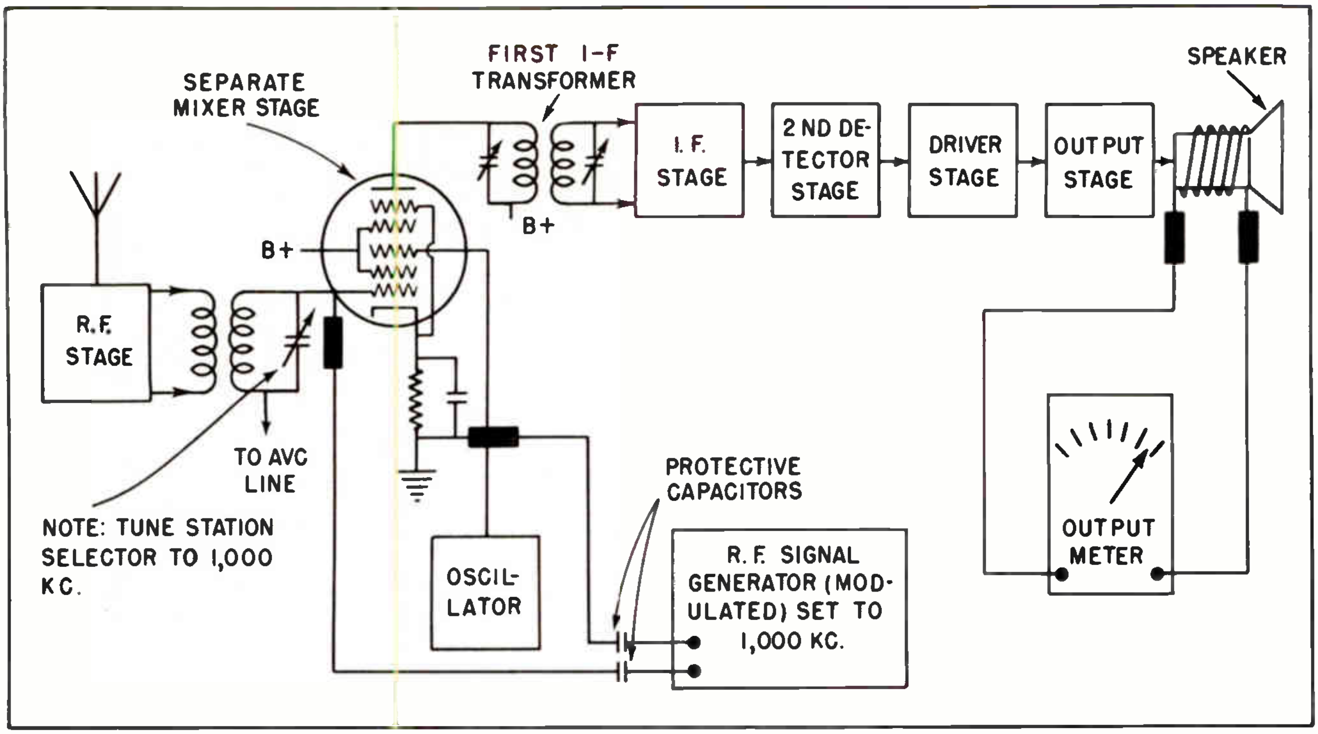

Fig. 11. Checking a Separate Mixer Stage.

stage -- *it should be replaced for trial by another oscillator-mixer tube known to be good.* This replacement should be made even if the tube-checker indicates that the tube is "good".

4. If this test for the oscillator-mixer stage fails, then the technician will lay aside his stage-testing equipment and proceed to check the stage in detail with an ohmmeter and voltmeter.

Section 10. **THE SEPARATE MIXER STAGE**

If the receiver contains separate stages for the mixer and oscillator, then the stage test is almost identical in nature with the one outlined above. The schematic of a separate mixer stage is shown in Fig. 11, together with block diagram representation of the remainder of the set.

Here the oscillator and mixer functions are accomplished in two different stages. This leaves for the separate mixer stage only the function of effecting the conversion from modulated RF frequency to modulated I-F frequency, with the heterodyning frequency being produced by the separate oscillator stage.

As Fig. 11 indicates, the test equipment is the same as in the previous test. Note that the introduction of the generated signal, in contrast to that of the previous test, is at grid No. 1, rather than at grid No. 3. (Grid No. 1 is usually the top-cap in the separate mixer tube.) In both cases, however, note that the signal is introduced at the RF grid.

The effective results should be the same, since the failure of either the separate oscillator or the separate mixer will prevent the signal from getting beyond the mixer stage. On the other hand, if both of these separate stages are in good order, then the signal will be properly handled and sent on its way toward the I-F stage for eventual delivery to the loudspeaker.

If this test fails, then trouble may be expected in either of the two stages. Since the oscillator stage is usually easier to check than the mixer, its operation should next be verified by the simple test presently to be outlined.

If the oscillator performance is proven to be satisfactory, then the technician would logically return to the mixer stage with voltmeter and ohmmeter and investigate its circuits in detail. If the oscillator stage is found to be non-operative, then the mixer stage may be assumed good and the technician's attention can be devoted to shooting the oscillator trouble.

Section 11. **THE SEPARATE OSCILLATOR**

This test for the oscillator may be done with a D-C voltmeter, preferably one of the ordinary D'Arsonval 1000-ohm-per-volt type, because of special considerations.

As in Fig. 12, place the voltmeter across the grid leak resistor of the oscillator stage. If it reads a negative value of one volt or more, then the oscillator stage may be assumed good. If it reads zero, or any positive value, then the oscillator stage may be assumed at fault. The reason for using an ordinary voltmeter for this test becomes clear when we take into consideration one of the more common types of troubles to which the oscillator stage is subject. This is an open grid leak resistor. With an ordinary voltmeter, if the grid resistor should be open, and is thus the cause of failure in this stage, then the meter resistance will take the place of the open grid resistor during the time that it is across it. The meter will read a negative voltage in this case, due to grid current, but the signal will again disappear when the meter is removed. There is no better confirmation for this type of trouble in an oscillator stage.

If the meter reads zero or any positive value, however, then other components should be checked. If the meter reads negative and still the receiver does not produce a signal (after all other stages have been tested) then trouble in the *mixer* stage is conclusively indicated.

Significant in this stage test are:

1. By the simple application of the ordinary type of voltmeter, oscillator stage performance is ascertained.

2. No signal generator need be applied to this stage for a conclusive test.

3. The output meter used on other stage tests is not used during this test.

4. This test checks only the performance of a separate oscillator. It may indicate trouble in the mixer stage only by the process of elimination, that is, by showing that the trouble *does not* lie in the oscillator.

5. This test assumes that the oscillator tube has been reliably tested previously, either by a tube-checker or by replacement with an oscillator tube known to be in working condition.

Section 12. **THE RF STAGE**

If the oscillator, mixer, I-F, second detector, driver, and output stages have been

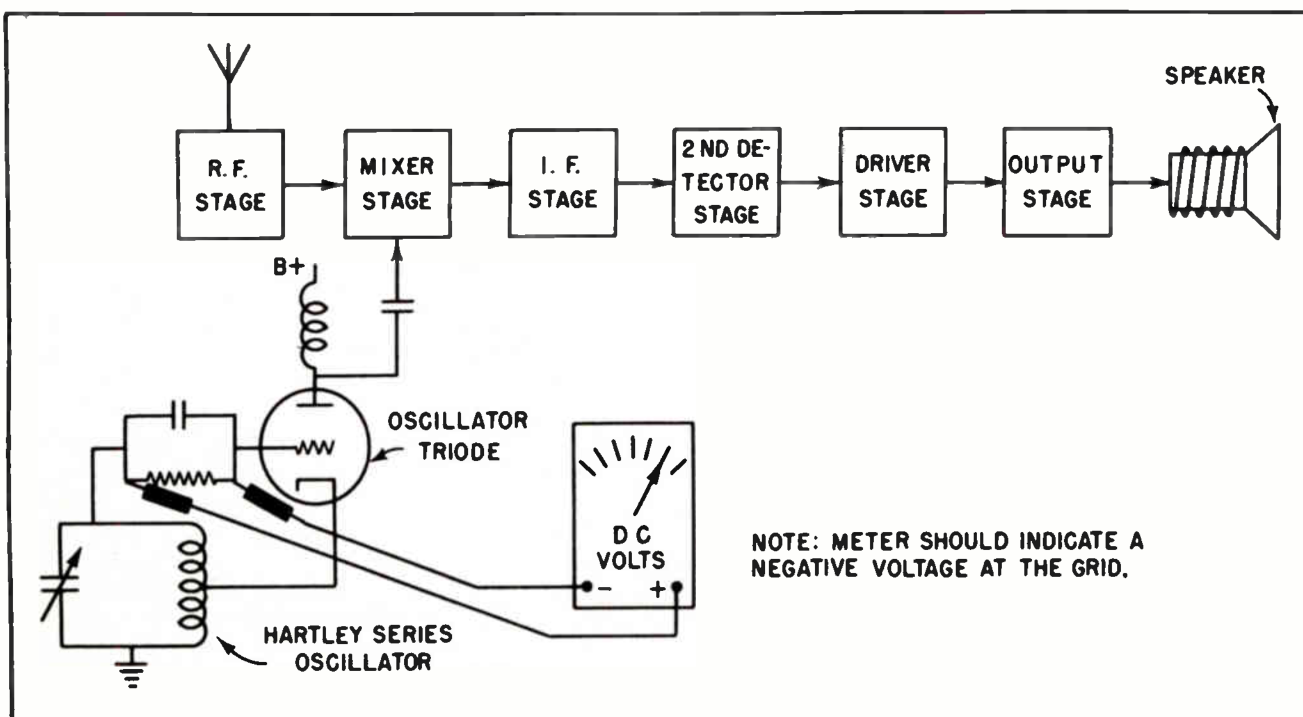

Fig. 12. Checking a Separate Oscillator Stage. The Only Instrument Required is a Voltmeter.

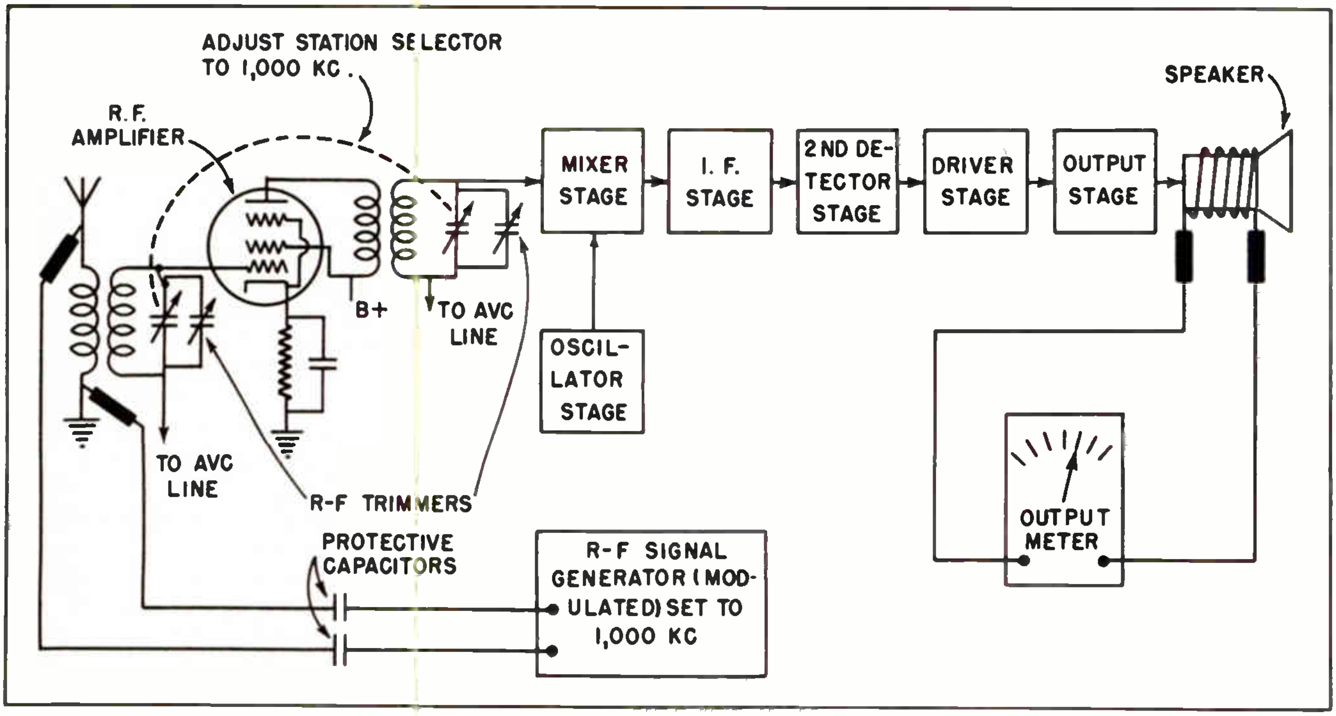

Fig. 13. Operational Check for the RF Section of the Superheterodyne Receiver. This Will Also Test the Entire Receiver.

tested and found good, and still the *receiver is not operating*, then only one stage remains in which the trouble can be. That is the RF stage.

Fig. 13 shows how the test equipment is connected in order to check the RF stage. The output meter is left connected across the speaker voice-coil, and the modulated RF signal is now introduced at the antenna. If all other stages have been tested and found good, and if the RF stage is in operating condition, then the modulation tone from the signal generator should be heard in strong volume at the speaker while the output meter responds with a high reading.

During this test, adjust the two RF trimming capacitors shown in Fig. 13, for loudest signal at the speaker and maximum deflection of the output meter.

If this test fails; that is if the speaker response is either absent or very low, then the RF stage may be assumed at fault, and a detailed search should be made to determine the exact failure.

Note that if this test shows the RF stage to be in operating condition by the expected loud tone at the speaker, *the entire receiver must be in working order*. The failure to receive a transmitted signal may therefore be laid to some other reason, such as the stations not being on the air at the time, or the normal location of the receiver may be in a spot shielded from radio signals.

Note also that if the RF and all other stages pass their individual operational tests, then the power supply of the receiver may also be assumed operative. For if the power supply were at fault, then none of the stages would respond to tests.

Significant in this stage test are:

1. Testing the RF stage of a receiver may not be necessary. If the receiver does not operate properly, and all other stages are known to be operative, then if a trouble is in the set, that trouble must lie in the RF stage.

2. However, in order to eliminate the possibility of poor reception due to external causes, the stage test may be made as outlined.

3. The RF amplifier tube should be previously checked on a tube-checker.

4. Adjusting the RF trimming capacitors during this stage test may make the test well worthwhile, for in many cases complaints are directed toward *poor operation*

of a receiver rather than the *complete lack of operation.* Where the RF trimmers have "drifted", the re-adjustment during this stage test can bring the entire receiver up to a point of best performance.

Section 13. TROUBLE-SHOOTING AND ALIGNMENT

You will notice that the stage-by-stage trouble-shooting tests have gone hand-in-hand with the alignment procedure of the superheterodyne receiver. This is, of course, no accident. Trouble-shooting a radio or television receiver should and must include the adjustment of all of the adjustable circuits. This specifically applies to resonant circuits with variable components.

In many cases, the radio and television technician will find that the only real trouble with a receiver is the mis-adjustment, or drifting, of a tuned circuit. It is also quite reasonable to assume that where a receiver has been in use for a prolonged period of time, a drift in one tuned circuit will usually be accompanied by a drift in one or two others. Singly, these drifts may not amount to much, but together they may spell the difference between satisfactory operation of a receiver and highly unsatisfactory performance.

The *general symptoms* of drifting or mis-adjustment of tuned circuits in a radio or television receiver are usually:

1. The inability of the receiver to pick up any station in normal volume.

2. That some stations may be received in the normal way, but some others may not come in at all.

3. That there may be emphatic distortion of an audio signal or a television picture, either on all stations or on only one or two.

4. That there may be cross-talk and other forms of interference between stations, either by the image phenomena or by non-sufficiently narrow tuned circuits.

5. That there may be audio or picture distortion due to resonant circuits being tuned too sharply.

These and other general symptoms of misaligned tuned circuits in the superheterodyne radio and television receiver can normally be quickly corrected by an alignment procedure such as the one described above. In addition, where a stage is operating with fair efficiency, but not quite up to par, the procedure will indicate this fact in establishing gain characteristics of the separately tested stages.

Section 14. POWER SUPPLIES IN SUPERHETERODYNES

As mentioned previously, and continually emphasized in other lessons, the superheterodyne may be powered by one of four different voltage sources. These are: the AC-DC, the straight A-C, the automobile power supply, and the portable power supply.

We have pointed out that the power supply of a receiver is no sure indicator of the type of signal circuit it contains, for the TRF receiver may likewise be powered by any one of these four different power sources.

In trouble-shooting the superheterodyne receiver power supply, therefore, no special reference need be made to the type of signal circuit involved. The general check of a power supply in any kind of receiver may simply consist of measurement of the "A" and "B" voltages at points in the receiver normally supplied with them. For any type of receiver, "A" voltages may be checked across the heaters (or filaments) of the tubes, while "B" voltage can be readily measured at the screen-grid of the output amplifier stage. The actual values of heater voltages, as measured, may be compared to the heater rating of each tube (as indicated by the tube manual). The values of "B" voltages will be determined by the nature of the rectifier system in the receiver. Thus, in AC-DC and portable receivers, using half-wave rectifiers, full B-plus is normally around 100 volts; while in A-C and automobile power supplies, since they involve full-wave rectification, B-plus may reach values of 250 volts or more.

In those portable receivers which employ batteries only, thus differing from the 3-way portable, "B" voltage, as measured at the "B" battery *under load,* are either 67 1/2 or 90 volts. In these receivers, "A" batteries are rated at one of the following: 1.5, 4.5, 6, 7.5, and 9 volts, depending upon the wiring plan of the filament circuit. It is important to recognize the battery ratings, since the application of a high "A" battery voltage to a circuit *designed for low voltage will result in the burning out of one or more of the tube heaters.*

If the trouble in a superheterodyne receiver can be traced to its power supply, it is seldom necessary to check the stages of the set. Make the repairs as needed in the power supply, and test the entire receiver on a station signal. The exception to this rule may be a stage-by-stage alignment procedure, after power supply repairs have been made, and the set tested. This, of course, involves only the tuned stages, and a separate check of the detector and audio section would be unnecessary.

Section 15. SPECIAL SUPERHETERODYNE CIRCUITS

In the light of its electrical behavior, we look upon the superheterodyne receiver as containing certain special circuits which are not and cannot be a part of a TRF receiver. Because they are peculiar to the superheterodyne, they must be taken into consideration in trouble-shooting this receiver. These circuits may be enumerated as follows:

Automatic Volume Control. While AVC has been incorporated in a few of the later TRF receivers, it is today a special superheterodyne feature. Its purpose is to maintain a constant volume at the speaker without regard to the strength of the signal at the antenna. It is operated by the diode plate current in the second detector stage, which causes a voltage drop in the diode load so as to increase the bias on the I-F and RF signal grids in proportion to the signal strength at the antenna. Thus a strong antenna signal will bring the amplifier stages to a condition of low gain, while a weak antenna signal will render the receiver more sensitive by reducing the bias in the tuned stages. AVC may be of the "regular" type, or, in certain "quality" receivers, of the delayed type (DAVC). Common troubles in AVC circuits, of either type, are open AVC resistors, and shorted or open AVC audio-by-pass capacitors.

Diode Detectors. In the superheterodyne receiver, the second detector stage is usually operated by means of a single or double diode. This set of tube elements are usually included in a single envelope with the driver triode elements. Since the diode has more linear rectification characteristics than the triode or pentode detector which it has superseded, and since receiver gain is supplied mostly by the high-gain I-F amplifier stages, to the diode falls naturally the task of demodulation. It is particularly suitable for this job, since it can, at the same time, accomplish the production of AVC voltage for the receiver, and, in some cases, energize a tuning-eye indicator. Besides, since it is a part of a tube which also contains the triode driver, and has a cathode in common with the driver, it takes up no more space in a receiver than any single tube. In some of the larger sets, one diode is used for AVC and detection, while the other is used for automatic frequency control.

Intermediate Frequency Stages. The superheterodyne receiver operates on the principle of conversion from the frequency of the incoming carrier signal to a different -- somewhat lower -- intermediate frequency. A complete set of tuned circuits tuned only to the I-F is the outstanding feature of the superheterodyne receiver, for it is this special feature which enables the receiver to separate stations numerically close to each other in frequency, and do it with high gain. In modern radio receivers, the I-F stages are usually tuned to 455 k.c., 456 k.c. or 465 k.c. In most television receivers the I-F is normally set at approximately 21 megacycles, while in radar receivers the I-F may be more than twice this value. Troubles in the I-F stages are multitudinous, but may be readily attacked by first isolating the defective stage (through a stage-by-stage check) and then using the voltmeter and ohmmeter to locate the exact fault in the defective stage.

The Oscillator-Mixer. It is this characteristic of the superheterodyne which makes it possible for a constant-frequency signal to be delivered to the I-F stages. In this stage the conversion process takes place, altering the carrier frequency, with its audio modulation, to the I-F frequency bearing the same modulation. Where the oscillator and mixer functions are combined in the same tube, checking its troubles is a matter of taking critical voltage and ohmage readings throughout its circuits, and comparing them to standard data for the stage. It is in this stage, too, that a trouble peculiar to the superheterodyne may be produced; namely, image frequency interference. Corrections for the whistling, howling, and cross-talk due to image interference are outlined in detail in other lessons of this series. Worthy of mention here is that image interference cannot take place in the TRF receiver, which contains no mixer stage.

Loop Antennas. The development of high gain RF and I-F amplifier tubes has made it more convenient to use a radio receiver, since higher overall gain eliminates the need, in most cases, for an outside antenna. The loop antenna, mounted within the cabinet of the receiver, takes the place of the outside antenna in areas which have relatively strong transmitted signal intensity. This, of course, includes the centers of dense population, such as the metropolitan areas of cities, and takes in the majority of the nation's radio audience. The loop antenna, either of the single- or double-wound type, provides the inductance component for the first RF tuned circuit in the receiver, while at the same time, presenting a broad cross-sectional area for signal wave pick-up. Troubles in loop antennas, therefore, are easy to check with the simple expedient of an ohmmeter, with which wire continuity can be ascertained. An open loop antenna is usually indicated by receiver "growling", with a decided drop in signal strength at the speaker. Moreover, the "growling" is tunable across the dial, being stronger at some dial settings than at others.

NOTES FOR REFERENCE

Recognizing a superheterodyne receiver is an important step in trouble-shooting. Identification may be made on the basis of the tubes used, the variable condenser gang, and the presence of I-F transformers.

The superheterodyne principle is part and parcel of every modern receiver, and includes AM and FM radio, television, and radar receivers.

In the superheterodyne receiver the I-F and RF amplifier tubes are of the *remote cut-off*, or *variable-mu*, type. This feature minimizes such interference as is due to cross-modulation and modulation distortion.

The variable-mu tube lends itself to smooth action of the AVC system, and provides well-regulated control of static interference and signal stability.

In trouble-shooting the superheterodyne receiver, make an accurate check of all of the tubes first.

Do not try to bring a signal through an inoperative superheterodyne receiver by making coarse adjustments on the tuned circuit trimmers. If these trimmers are adjusted without a signal generator, they should be adjusted only very slightly (not more than an eighth of a turn). If the superheterodyne receiver is completely inoperative, the trouble is probably *not* due to a mis-aligned tuned circuit. However, if the trimmers are turned too much, the receiver, in addition to containing its original trouble, may now be seriously mis-aligned.

NOTES

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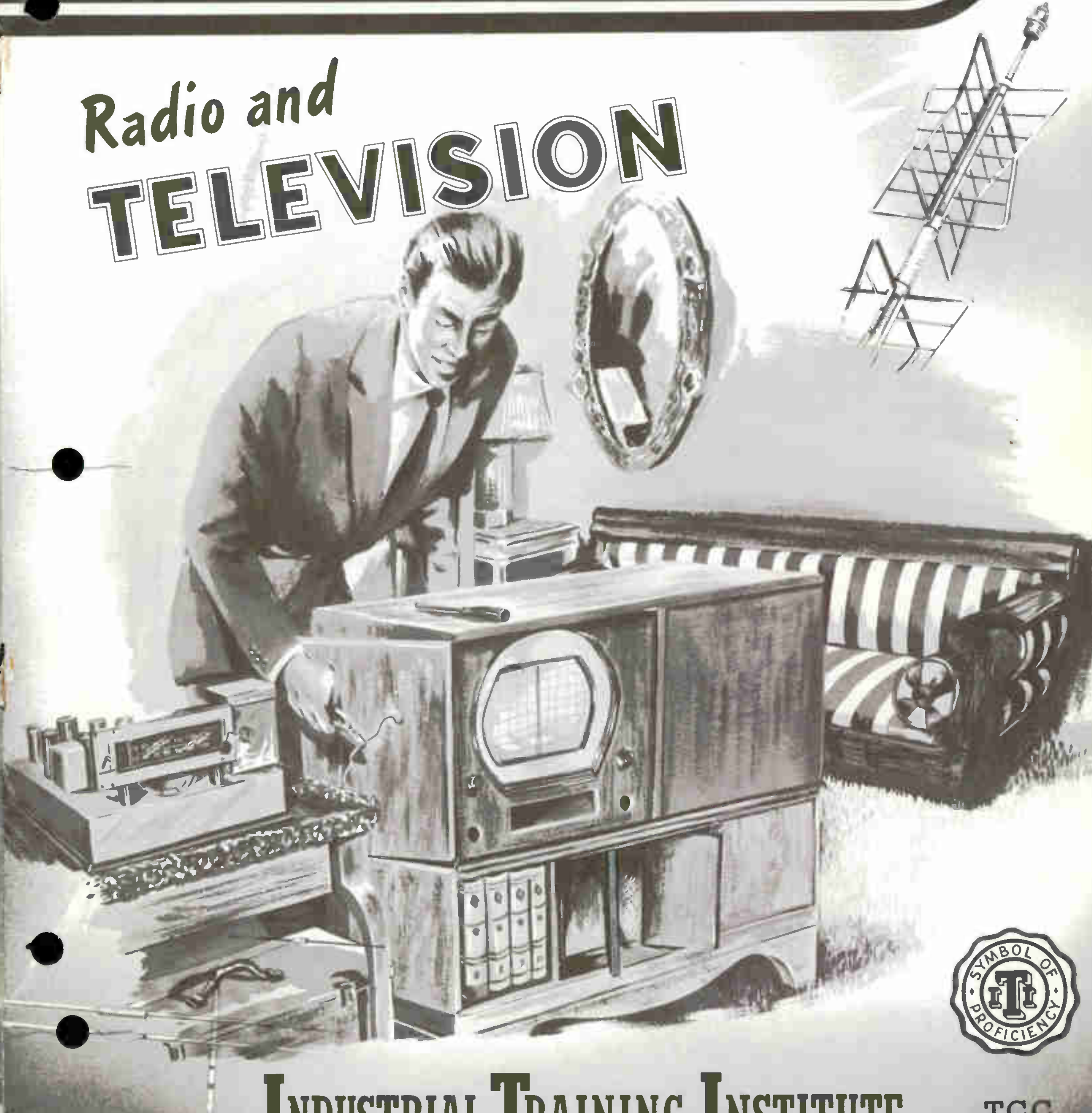

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TECHNICAL TRAINING SERVICE

RADIO TELEVISION

AC-DC AND PORTABLE RECEIVERS

Contents: Introduction - The AC-DC Receiver - Receiver Completely Silent - Hum Interference - Motor-Boating - Whistling - Signal Distortion - Signal Clear but Below Normal Volume - Three-Way Portable Receivers - Identifying the Three-Way Portable - Checking the 3-Way Portable Power Supply - The Straight Battery Portable - Notes for Reference.

Section 1. INTRODUCTION

Before getting into the more complicated circuits found in television receivers, there are some radio circuits we should learn first. This lesson will investigate the special trouble-shooting problems connected with the small radio receiver, and might just as well have been titled, "Table-Model Receivers". For it is within these small, table-model sets that the AC-DC or the portable (battery) power supplies are to be found. (See Fig. 1.)

Notwithstanding the fact that all small receivers have something in common, namely their size and price range, there are striking differences between the various classes in this group. They may be divided into the following classes:

(1) The AC-DC Receiver.

(2) The 3-Way Portable Receiver.

(3) The Straight Battery Portable Receiver.

In AC-DC receivers we have a class that will operate from any 115-volt, 60 cycle, commercial A-C or D-C power source.

In the 3-way portable, we have a class that will operate from *either* an A-C or D-C power source, *or* from a battery power supply contained within the cabinet.

In the straight portable, we see a class that will operate *only* from a battery power supply contained within the cabinet.

In common with each other, the classes of this group constitute the entire family of small radio receivers. They are inexpensive, compact, light in weight, and as a consequence of these advantages, they are extremely popular. Customers of the radio and television repairman are constantly bringing these receivers to the shop for service.

One class -- the AC-DC receiver -- stands out from the others in that its popularity far exceeds that of all the others combined. The AC-DC receiver may unquestionably be termed the "most popular set in the world". (See Fig. 1.) With due regard to its popularity, let us give it first place in our

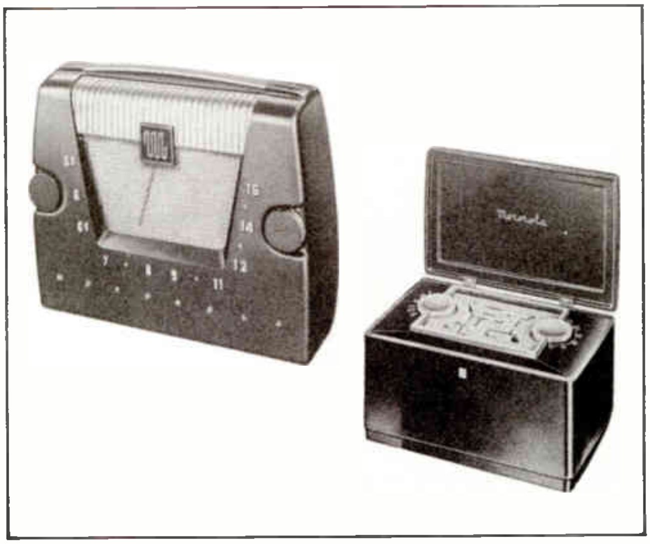

Fig.1. Typical Small Radio Receivers. These Sets are Extremely Popular.

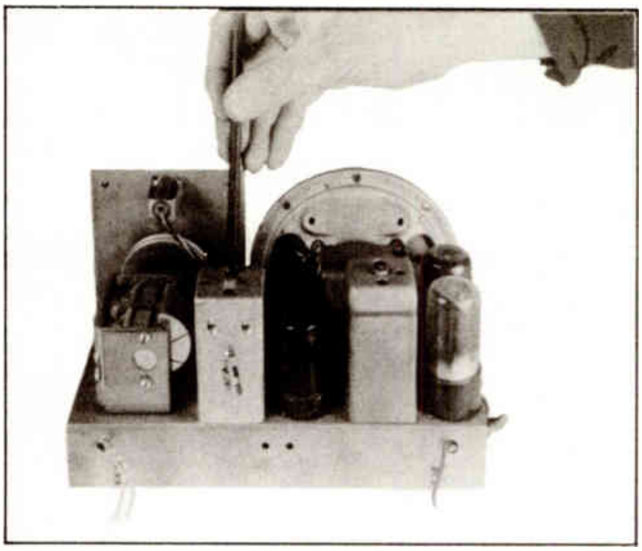

Fig. 2. Chassis View of the AC-DC Receiver.

study of table-model receivers. The AC-DC principle is being applied with increasing frequency to television receivers.

Section 2. THE AC-DC RECEIVER

There is much for the radio and television technician to be thankful for in the AC-DC radio receiver. It contains one of the most simple types of power supply. It contains a simplified form of the superheterodyne signal circuit. It seldom -- except in rare and special cases -- contains push-pull stages. It contains nothing that is not absolutely essential for satisfactory performance at broadcast frequencies. When one masters the simple rudiments of its circuits, shooting trouble in the AC-DC receiver boils down to quick and accurate analysis of its symptoms. These symptoms, in the AC-DC receiver, fairly scream for attention from the repairman. In most cases, except for freak troubles, all the technician need do is observe the symptoms by sight or sound, then apply his knowledge of the circuit toward a scientific and reasonable explanation of what may be the cause of these symptoms.

Fig. 3 is a circuit diagram of the typical AC-DC superheterodyne receiver power supply. Standard voltages are indicated, as are the more important resistances.

Let us now suppose that someone brings in a small receiver and simply says: "This set suddenly stopped playing. What's the matter with it?" It is obvious that without trying out the set, or making at least a few tests on it, even the most expert technician would hesitate to make an immediate reply. What, exactly, would we do in order to determine the exact fault of this receiver?

Let us first identify the receiver. We notice that, on removal from the cabinet, the chassis is small and contains no provision for batteries. This rules out the portable power supply. We also note that the chassis contains no power transformer. This rules out the A-C power supply. The cabinet is obviously not that of a car radio so we have but one possibility left -- the AC-DC power supply. We confirm this by looking for -- and finding -- a complement of tubes whose heater ratings vary anywhere from 12.6 volts to 50 volts. This clinches our decision that we are dealing with an AC-DC power supply.

What about the signal circuit? Are we dealing with a superheterodyne receiver, or a TRF signal circuit? We glance at the variable condenser gang and see that one of the sections is physically smaller than the other. We conclude that the signal circuit must therefore be a superheterodyne. Besides, in previously looking at the tubes, we have noticed that one of them is an oscillator-mixer. Furthermore, the shield cans of the I-F transformers confirm the identification.

We have now positively identified the receiver as an AC-DC superheterodyne, and can organize our analysis of its trouble around what we have determined to be the character of both the signal circuit and the power supply of the receiver. It can be honestly said that most troubles in electronic equipment spring from defective tubes. The first procedure is to make a routine check of all the tubes of the receiver, testing them carefully on a tube-checker, for shorts, opens, emission and leakage. Let us suppose that all of the tubes check good. At least we now conclude that the trouble *probably* is not due to any tube defect. (We will return to this point later.)

The next step would be to try the receiver out, in order to determine its symptoms. We plug the receiver into a suitable power receptacle, and turn the set on. After allowing time for warm up, we notice these symptoms:

(1) The tubes and pilot lamp do not light.

(2) There is no sound of any kind from the speaker.

(3) B-plus voltage in the receiver, as we measure it with a D-C voltmeter, is found to be zero.

(4) A-C voltages across the tube heaters are completely absent.

Let us again ask ourselves, "What is the trouble? Do we now have enough information about the receiver to enable us to say that such-and-such a component must be defective? Or, at least, that such-and-such a *circuit* must *contain* the trouble?

We may decidedly answer these questions at this time. We are now supplied with enough data to specifically state that the trouble in this receiver is an open circuit somewhere in the 60-cycle supply wiring. This may include the power plug, the power cord, the on-off switch, and all of the connecting wires from heater to heater in the series of tubes.

When one considers the multitude of possible troubles in an AC-DC receiver, and then sees how most of these are ruled out by observation and analysis in a specific case such as we are considering, it is remarkable that the trouble can be so quickly narrowed down to only a few probabilities. In the case under consideration, we would test the suspected components one by one, doing the *easiest* tests first, until the defective component is found.

After narrowing down the *probabilities* to the supply voltage circuit, we would test, in order, the following components:

A. The Power Plug. See if both leads are firmly fastened to the plug prongs.

B. The Power Cord. See if there is continuity between each of the power plug prongs and the other end of the cord within the receiver.

C. The On-Off Switch. Test continuity across it with the switch turned to the *on* position.

D. If the trouble does not lie in any of the components mentioned, make a point-to-point continuity check of all the wires in the tube heater series circuit.

In many cases the open will be found in the power plug. Small receivers are often moved about from one room in a house to another. Those who use these receivers, instead of carefully removing the power plug from the wall receptacle, usually remove it by grasping the cord, and jerking the plug from the receptacle. This, of course, is no crime -- but it does serve to eventually tear away the connections within the power plug. Sooner or later, under this treatment, the circuit will be opened and will result in the symptoms described.

The example given above is not meant to illustrate the frequency with which this type of trouble occurs in an AC-DC receiver. There is a much more important conclusion to be drawn from the case. This is the method employed in trouble-shooting the set.

This method may be stated in the following terms:

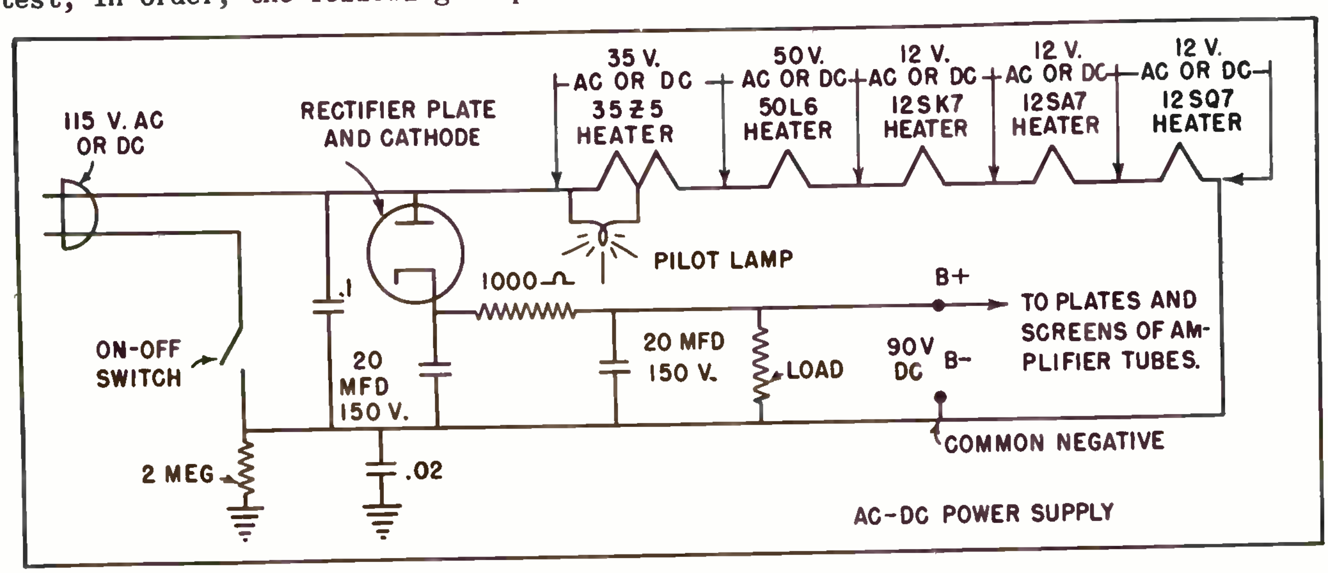

Fig.3. Standard Power Supply Circuit in the AC-DC Receiver. Note Pilot Lamp Connections.

(1) Identify the receiver power supply.

(2) Identify its signal circuit.

(3) Test its tubes carefully on a tube-checker. Replace tubes as necessary.

(4) Try out the set. Notice its symptoms. Notice if it hums, if the signal is distorted, or quiet, or absent; see how it tunes across the dial. Operate the manual volume control and observe results. In other words, note any abnormal action.

(5) Take several voltage readings. Important ones are the value of B-plus, heater voltages, supply voltage as it is introduced into the chassis of the receiver.

On the basis of the previous five steps, analyze the trouble. This means ruling out any possibility that is inconsistent with the type of power supply, the kind of signal circuit, the visible and audible symptoms, and the voltage readings as measured.

Make a list, either mentally or on paper, of the remaining possible troubles. We may now call this list the probable troubles, and may proceed to check them one by one until we find the exact trouble. When this trouble is found, correct it by appropriate means, such as replacement or adjustment; finally, test the correction.

You will recall there is another approach to trouble-shooting a radio receiver. If the power supply is tested and found to be in order, then a signal generator and output meter may be connected to the receiver and then a stage-by-stage check of the signal path may be made. This method is outlined in detail in other lessons.

Note that signal tracing through a set can be done only when the power supply is in working condition, and that it will tell us only the stage in which the trouble lies. Once the defective stage is determined, the technician's job will be to analyze this stage by comparing its voltage and resistance readings with a set of data standard for that stage in the type of receiver under observation.

In the small receiver, it is seldom necessary to trace a signal through it to determine the defective stage. However, occasionally when the symptoms it displays are abnormally hidden and confused there is no better method of locating the trouble than by tracing a signal through it.

In dealing with AC-DC superheterodyne receivers, we will quickly realize that regardless of the manufacturer or model, these circuits are as alike as peas in a pod. The differences between them are of relative unimportance, such as the types of tubes used (octal, loktal, or miniature), and the occasional presence of an R-F pre-amplifier stage. Once in a great while the rectifier tube will be replaced by the dry-disc selenium rectifier. Otherwise, they form a standard family of identical members that are so much alike that they may be treated as one single type.

With this in mind, we may logically infer that if the breakdown of a certain component in an AC-DC superheterodyne receiver causes a certain set of symptoms, then the presence of these symptoms in another AC-DC superheterodyne receiver will indicate that its corresponding component has broken down. If the circuits of the two receivers are the same, then the inference is logical and correct. On the basis of this fact, we may (after identifying the receiver) consider the symptoms first, and then work backwards from these symptoms to their common cause.

The general symptoms of an AC-DC radio receiver of the superheterodyne type may be divided into several groups, which will be considered separately.

Section 3. RECEIVER COMPLETELY SILENT

If an AC-DC receiver produces no sound of any kind at the speaker, notice if the tubes and pilot lamp are lighted when power is applied. If not, check all tubes with an ohmmeter for heater continuity, with special care on the *three* heater connections of the rectifier tube. If an open tube heater is found, replace the tube and test the set. (This is the most common trouble in AC-DC receivers.) If no tube heater is found to be open, check the power source, the power plug, the power cord, and the on-off switch. If these are found good, make a point-to-point continuity check throughout the series heater connecting wires.

If the tubes and pilot lamp light when power is applied, however, measure the value of B-plus. This is most easily measured between the *screen-grid* of the output tube and the *negative* side of the filter con-

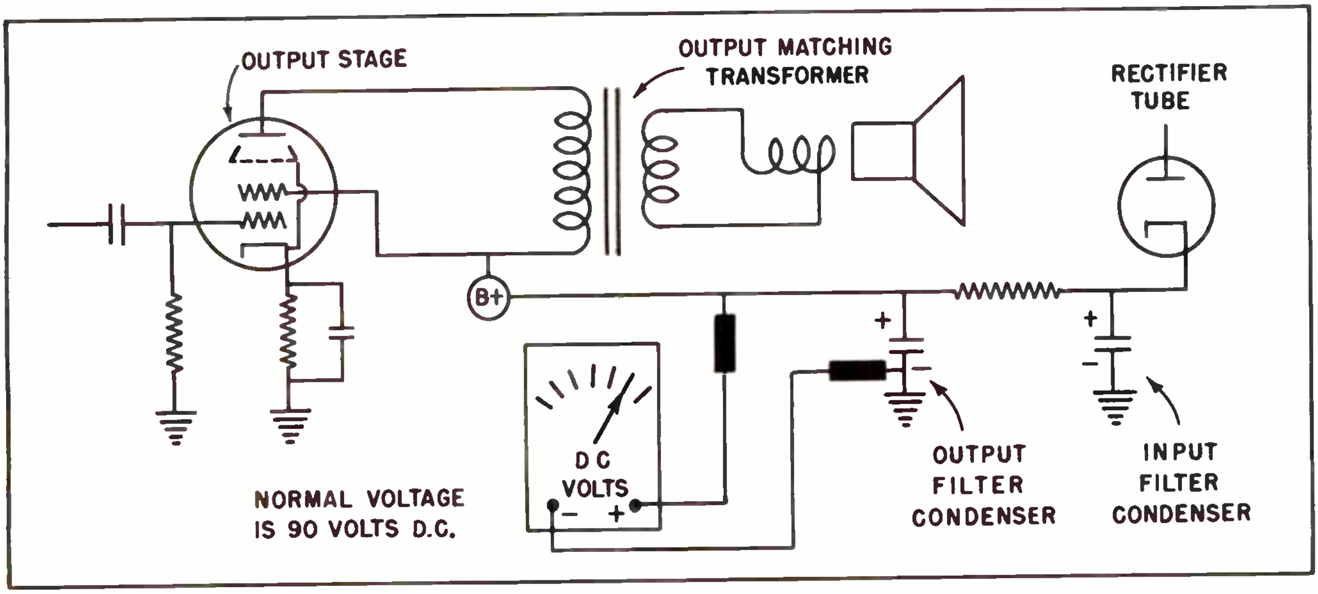

Fig. 4. Convenient Check Points for Measuring B-Plus in the AC-DC Set.

densers, as in Fig. 4. If B-plus is present, check the primary and secondary of the output transformer, and the speaker-voice-coil for continuity with an ohmmeter.

If the tubes light but B-plus is absent throughout the receiver, determine whether the receiver is operating from an A-C or a D-C source. If from A-C, test the tubes on a tube-checker and look for a bad rectifier tube. If from D-C, reverse the power plug in the wall receptacle, and then, if necessary, proceed as in the case of A-C.

Special Note on the Rectifier Tube. If the rectifier tube in an AC-DC receiver lights up when power is applied, but shows no emission on the tube-checker, look for a short circuit across the B-supply with an ohmmeter. If a short is found, remove the cause of the short-circuit before inserting a new rectifier tube. The reason for this precaution is that if the tube has been damaged by a short across the B-supply, such a short will also damage the new rectifier tube and should therefore be removed. It will be found that in most cases, removing the short will also remove the original trouble in the receiver.

Section 4. **HUM INTERFERENCE**

When the 60-cycle supply line hum is present in the AC-DC receiver, it may take several forms. First, it may be a loud hum not controllable by the manual volume control. In this case, proceed as follows:

Check the tubes carefully on a tube checker for emission, shorts, and leakage. Replace defective tubes as needed. Test the set again. If the hum is still present, notice the nature of the signal. If it sounds "hoarse" (as if the speaker has a "cold"), measure the value of B-plus between the screen grid of the output tube and the negative side of the filter condensers, as in Fig. 4. If B-plus is lower than 60 volts, shunt the *input filter condenser*, which is found between the rectifier cathode and common ground) with a condenser of equivalent rating, observing the polarity signs. With the test condenser bridging the old input filter, observe the results. A low value of B-plus, and a 60-cycle hum making the signals sound hoarse, almost always means a deteriorated (dried out) input filter condenser. Shunting the suspected condenser will usually confirm the suspicion. Correction is to remove the old input filter and replace it with a new one of the same capacity and voltage ratings.

If the hum is not adjustable by the manual volume control, and does *not* make the signals sound hoarse, the value of B-plus will probably measure the standard 90 volts. Check this with the voltmeter. Next, even after the output tube has been tested and found "good", replace it with a new one, and note the results. (In many cases, this type of hum interference is due to internal leakage in the output tube, a condition which the tube-checker may not indicate.) If this procedure does not remove the hum, the output filter condenser may be suspected of deterioration. To confirm this, shunt it with its equivalent in mfd and voltage ratings, and observe the results. If the hum disappears in this last step, remove the old condenser and install a new one. (Both the input and output are *electrolytic capacitors* and their polarity must be observed.)

If the loudness of the hum *is* adjustable by the manual volume control, a completely new family of troubles is indicated. First, read the value of B-plus to make certain that the power supply is functioning properly. Then try reversing the power plug in the wall receptacle, and test the results. Next examine the grid circuit of the driver stage to see if the grid lead wire has been moved close to a lead carrying the 60-cycle power voltage. If so, spread them apart, and test the set.

If the hum has not been removed, check the connections to the loop antenna, as well as the continuity of the secondary winding in the loop antenna. The secondary winding may be identified by its connections to the signal grid of the oscillator mixer stage at one end, and to the AVC line at the other. (One *primary* lead will go to chassis, while the other goes to an external clip.) In this case, that of an open loop antenna secondary, it will be noticed that the hum is adjustable by the volume control. It will also be evident that the hum will vary somewhat as the station selector is moved across the dial. These are important features to observe in trouble-shooting a 60-cycle hum in the AC-DC receiver, for they serve to distinguish between the hum due to power supply or output stage faults on the one hand, and R-F and I-F faults on the other.

Section 5. **MOTOR-BOATING**

In the AC-DC receiver power supply, motor-boating at various frequencies is encountered. The most common form of motor-boating is the put-put-put effect that really sounds like a motorboat crossing a lake. The frequency of this "slow" motor-boating is usually about 10 to 25 cycles per second.

A medium speed of motor-boating would be about 50 or 60 cycles per second. This approximates the frequency of the 60-cycle line hum, but should not be confused with it. The two may be distinguished from each other by the *smooth* drone of the 60-cycle line frequency, in contrast to the sharp, *staccato* character of the motor-boating sound.

Fast motor-boating may have a frequency of upwards of 100 cycles per second, and hence may sound like a *squeal*. In this respect it is distinguished from R-F or I-F *whistles*, by the fact that these whistles are smooth -- almost musical in character, while fast motor-boating sounds like a *rough* howl, or screech.

The most common cause of motor-boating in an AC-DC receiver is an *open* output filter condenser. The motor-boating is usually of low frequency and is *violent*, with remnants of the audio signal evident in the background. To verify the suspicion of an open output filter condenser, shunt it with an equivalent electrolytic, observing the polarity. This is readily accomplished by connecting the positive lead of the test condenser to the screen grid of the output tube, and the negative lead to common negative of the receiver. (Common negative, as previously indicated, can always be found at the negative side of either filter condenser.) (See Fig. 5.)

If the motor-boating disappears after this procedure, replace the old filter condenser, and test the set.

If the motor-boating continues after this procedure, mis-aligned I-F tuned circuits may be suspected. The remedy is to first *slightly* adjust all of the I-F trimmer condensers, (do not turn any of them beyond *one-eighth* of a turn,) until the motor-boating disappears.

It may be found that the motor-boating can be eliminated by this step, *but at the expense of volume in the receiver.* If the volume drops too low, then align the I-F stages with the use of a signal generator and output meter, as described in previous lessons.

Motor-boating due to mis-aligned I-F stages generally takes on a fast frequency, although medium and slow motor-boating are also associated with this cause. When motor-boating of any frequency is due to mis-adjusted I-F stages, it will be evident that not only the frequency of motor-boating, but its loudness as well, can be changed with the manual volume control. In the case of motor-boating due to an open output filter

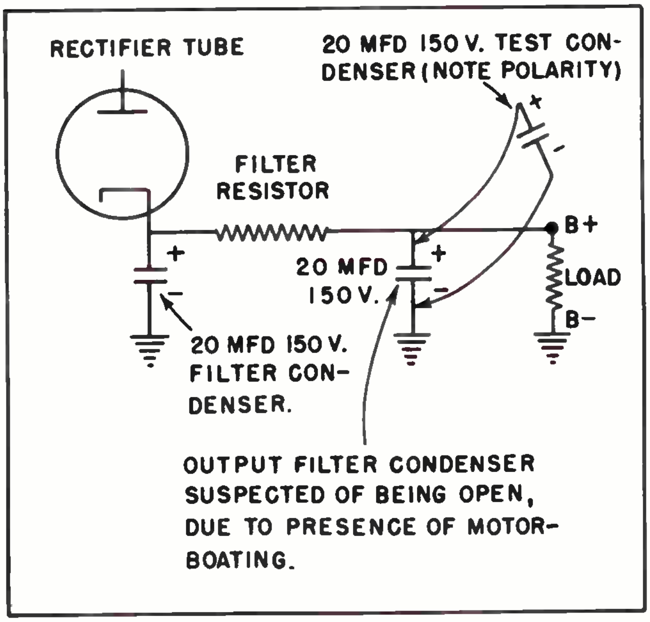

Fig.5. Test for an Open or Deteriorated Output Filter Condenser by Bridging with an Equivalent.

condenser, the frequency and loudness will not be affected by the adjustment of the manual volume control. These are important considerations since they dependably distinguish between widely divergent reasons for similar types of motor-boating.

Section 6. WHISTLING

In an AC-DC receiver, whistling may be due to various reasons. The power supply is a common cause, the trouble being due to a partial (but serious) defect in the output filter condenser. Note that the preceding discussion on motor-boating traced one of its causes to an open output filter condenser. It is noteworthy that the output filter condenser may have one of many different *degrees* of imperfection. It may be completely open, meaning that it contains no capacity. Or, it can be partially open, meaning that while it does have some capacity, it does not have all it was made to have. It may be rated at 20 mfd, but due to age and deterioration, it may now only contain 5 mfd. This is a serious drop in the capacity required by a filter.

Where a completely open output filter may cause violent motor-boating, a partially deteriorated filter condenser may cause *whistling*, especially when the manual volume control is rather advanced and the station selector is moved across the dial. Actually, the whistling encountered when the output filter condenser is partially open, is due to oscillations in either the R-F or I-F tuned stages. However, this may not be because the stages themselves are at fault. (Although this may also be a cause for whistling.) The fact that the filtering is imperfect at B-plus makes it possible for voltage changes in one stage to be fed back to previous stages. This principle, as we know, is the basis for oscillation. Here, however, such oscillation is undesirable, and the output filter condenser is specifically installed at B-plus to prevent this feed-back by opposing the voltage changes at B-plus.

A partial deterioration of the output filter, which reduces its capacity somewhat, will render it ineffective against feedback voltages, and thus will permit oscillations and their resultant whistling.

The remedy for this type of whistling is to shunt the output filter condenser with an equivalent and note the results, as in Fig. 5. Where this fails to eliminate the undesirable effect of whistling, check the following in the order mentioned:

Adjust the I-F trimming condensers (no more than an eighth of a turn) and notice if the whistling has disappeared.

Make sure that all tubes requiring external shields are supplied with them, and that the shields are well grounded. This especially refers to I-F and R-F amplifier tubes.

If the whistling takes place only at one point on the tuning dial, the trouble is not in the receiver. It is due to image interference by a nearby transmitter, or to another superheterodyne receiver operating in very close proximity. The correction for the former is to add pre-amplifier stages to the receiver where possible, or re-orient the loop or outside antenna. The remedy for the latter is to increase the distance between the two receivers. If the interfering receiver belongs to a neighbor, it is to his interest to co-operate in separating the two receivers as much as possible, for if his receiver oscillator causes a whistle in another set, then the action is mutual, and he too will notice a whistle at some place on his tuning dial.

Section 7. SIGNAL DISTORTION

An abnormally "tinny" or "flattened-out" tone in voice or music reproduction of a radio receiver of the AC-DC type may be readily traced to several causes, some of which are related to the power supply of this receiver.

Distortion due to power supply defects are, with the exception of hum interference, generally co-incident with low B-plus voltage at the rectifier cathode and throughout the rest of the receiver. Among the causes of distortion in the power supply are: low emission in the rectifier tube, confirmable by the tube checker; and partially leaking filter condensers, indicated by an ohmmeter check.

Other causes of signal distortion in AC-DC receivers are *not* accompanied by a drop in the value of B-plus. The voltage at B-plus, therefore, is a method of distinguishing between distortion due to power supply troubles and those due to troubles in other stages.

An AC-DC receiver displaying distortion should therefore be observed carefully to narrow down the probable cause. Besides measuring the B-plus voltage, the technician should notice the length of time elapsing between the application of power to the receiver and the onset of distortion. Where B-plus is below normal, check the items previously mentioned. Where B-plus is normal (around 90 volts, D-C) proceed in this manner:

If the receiver plays clearly during the first five minutes to half an hour, and *then* gradually starts to distort the signal, replace the output tube, even if it has checked "good" on the tube-checker. The fault in this case is a "gassy", or "ionized" output tube. Sometimes the tube checker will not indicate this condition, or will do so only after a prolonged warm-up period. After replacing the output tube, test the receiver for at least an hour.

If distortion sets in as soon as the signal is audible after applying power to the receiver, measure the D-C voltage at the grid of the output stage. This voltage should be either a few volts negative, or zero. Under no conditions should this voltage read a positive value. If, therefore, a positive voltage of any value is encountered on the grid of the output stage, a shorted or leaky audio coupling condenser to this stage is indicated.

To confirm this suspicion, clip the grid end of this condenser free of its tie point, and then measure the grid voltage again. The grid connection should not be positive with respect to ground. The free-hanging end of the condenser, however, would still be positive if it is shorted. This may be checked by reading the voltage at the free-hanging end of this condenser. If it is positive with respect to ground, it is either shorted or leaky and should be replaced in either case.

It should be noted here that the case of a gassy output tube, discussed in the previous paragraph, will also show a positive voltage on the grid of the output stage, with this important difference:

The positive voltage on this grid due to a gassy tube will only be present when the distortion sets in, which is at a time varying between 5 and 30 minutes *after* power has been applied to the set.

Where B-plus is normal but the grid shows no positive voltage at any time, signal distortion may be traced to the loudspeaker. Friction between the speaker voice-coil and the magnetic poles is the most common cause. Torn speaker cones and loose moorings at the cone may also be considered common. Where the speaker can be re-glued or re-centered, correction for speaker distortion may be tried. (See the lesson on Loud-Speakers.)

Where the speaker is beyond repair -- and this is up to the judgment of the repairman -- it should be completely replaced. In fact, due to the complications in repairing speakers and speaker cones, the technician should first of all seriously consider a replacement rather than a repair of a defective speaker. Then, if he decides that a repair would take more time than a replacement, he would be wise in choosing the latter.

If conclusive tests indicate that signal distortion is not due to any of these causes, then check the following in the order mentioned:

Read the voltage at the plate of the driver stage, and compare it with standard data for this stage. (It should be around 30 volts positive, with respect to common negative.) A low value will indicate that the plate load of this stage has greatly increased in value. This is confirmed by an ohmmeter check.

Place the negative lead of a D-C 1,000-ohm-per-volt voltmeter at the AVC line and

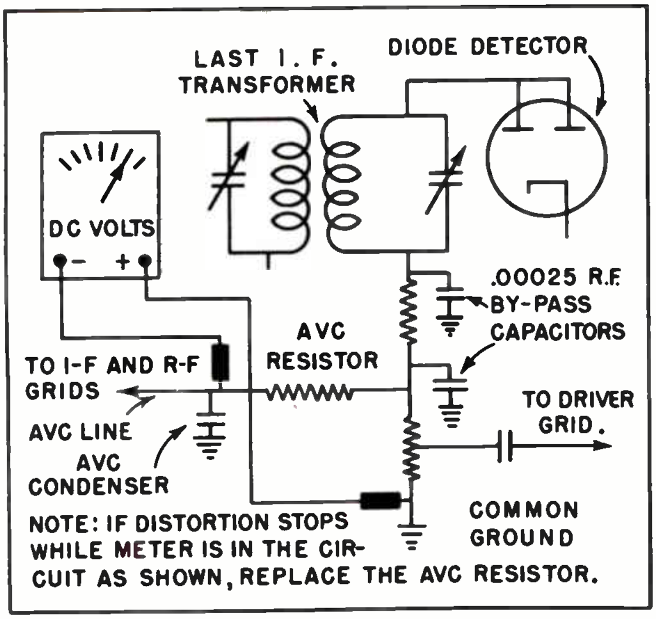

Fig.6. Testing for an Open AVC Resistor, with a 1000-Ohm-Per-Volt Meter.

the positive lead at common ground. If the distortion clears up while the meter is in the circuit, then replace the series resistor between the manual volume control and the control grid of the I-F amplifier stage. This test will mean that this resistor (known as the AVC resistor), is open. (See Fig. 6.)

If distortion takes place only at the low end of the volume control, then check the volume control condenser, leading from the center tap of the manual volume control to the driver grid, for a short-circuit.

Section 8. SIGNAL CLEAR BUT BELOW NORMAL VOLUME

If, after checking the tubes and replacing them as needed, the signal is found to be undistorted and tunable, but below normal volume, then two families of possibilities are equally likely. While neither of these is directly related to the power supply, as would be indicated by normal value of B-plus voltage, they may be discussed at this time.

The first group of possibilities is concerned with the mis-alignment of the I-F tuned stages. Long-period "drifts" in the resonant frequency of these stages are due to chemical and physical changes in the trimmer condenser plates and the dielectric between the plates. These may be due to temperature and humidity conditions prevailing in the locality where the receiver is in use. These drifts de-tune the I-F circuits by minute degrees over a period of time. There is no noticeably abrupt change taking place in signal strength at the speaker. But these drifts accumulate with time, so that at the end of a year or so, there is a marked divergence between the required and the actual resonant frequency of the I-F tuned circuits. The result is a lowered signal volume, especially noticeable on the weaker stations.

The remedy for this defect is to re-align the I-F tuned circuits, in accordance with the procedure given in the lesson on "The Superheterodyne Receiver." In place of the complete re-alignment with signal generator and output meter (but not quite so dependable) is a "touch-up" of all of the I-F trimmers using a normally received transmitter signal as a sample. In this simple procedure, the I-F trimmers, starting with the last and advancing toward the first, are turned *slightly* (no more than an eighth of a turn) for the loudest audible signal at the speaker. This method is effective in most cases, where previous handling of the I-F trimmers by the technician have not thrown them too far out of alignment.

In this connection, another trimmer may also be considered. This is the R-F trimmer, in parallel with the R-F section of the variable ganged condenser, upon whose structure it is usually mounted. If signals are weak primarily at the *high* end of the dial, adjust this trimmer for loudest signal, while the dial pointer is turned to a station around 1500 k.c.

The other family of troubles usually associated with low signal volume, while the signal is clear and tunable, are those relating to open audio coupling condensers. It is notable that these condensers show an *intermittent* character in their behavior, sometimes passing the signal through without loss and sometimes opening almost completely, thus barring all but a very small percentage of the signal. There are two condensers of this type -- the coupling condenser between the volume control and the driver grid, and that leading from the driver plate to the output stage grid. Either of these will, when open, cause the symptoms described. The correction for an open audio coupling condenser is to place an equivalent across it, and note the results. If the old condenser is open, then the presence of the test condenser in parallel with it should

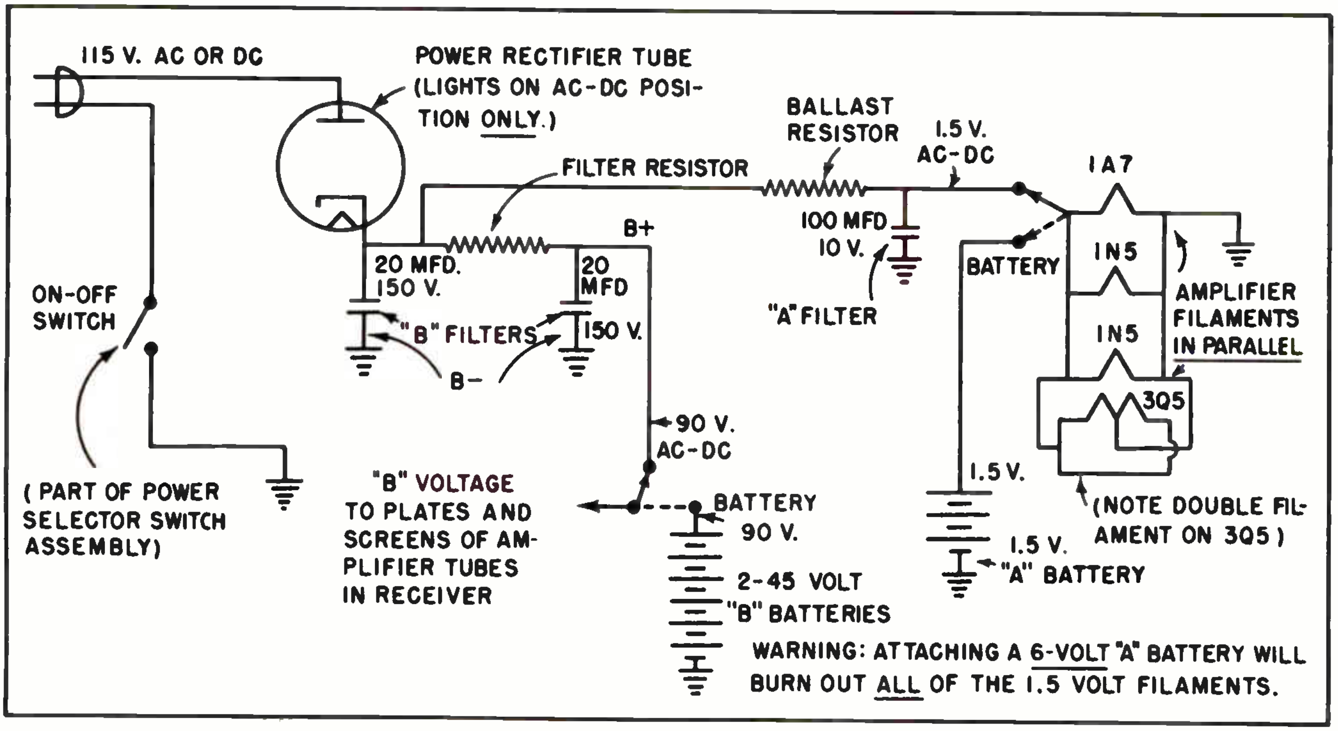

Fig.7. Illustrating the Parallel Connections of 1.5 Volt Filaments in the 3-Way Portable Using a 1.5 Volt "A" Battery.

bring the signal through in the normal manner. Try each of the two condensers separately, to ascertain whether the defect lies in the driver or in the output stage circuit. Replace whichever is defective. The chances are against both of them being defective at the same time.

Section 9. **THREE-WAY PORTABLE RECEIVERS**

Trouble-shooting the power supply of the three-way portable receiver may be conveniently divided into two parts: The AC-DC power supply circuits, and the battery power supply circuits. It is true that in some portions of the receiver, these two power supplies meet in circuits common to them both. However, we may further clarify their relationship by adding that *at no time are both supplies in operation at the same time.* This is reasonable, since the battery power supply is provided to activate the signal circuits only when commercial A-C or D-C power is unavailable.

Section 10. **IDENTIFYING THE THREE-WAY PORTABLE**

Positive identification may readily be made of the three-way portable receiver by the following features:

(1) It is contained in a portable case.

(2) It contains a set of batteries, and *also* a rectifier tube *or* a selenium rectifier.

(3) It contains tubes whose heater ratings are 1.5 volts.

These three features will leave no doubt as to the nature of the power supply of this receiver.

The power supply of the three-way portable may be checked by a voltmeter, with several considerations in mind. These are: What is the rated "B" battery voltage? And what is the rated "A" battery voltage?

Even if we are checking the operation of the 3-way portable from its commercial power point of view, the battery ratings are important. For it is by this means that we may accurately ascertain what voltages to expect in a given receiver under observation.

If the portable contains, in addition to the dry-disc or vacuum tube rectifier, *two* 45-volt "B" batteries, and *one* 1.5 volt "A" battery, then we may expect B-plus in the receiver, during A-C or D-C operation, to be 90 volts, and we also know that all of the amplifier filaments are wired in parallel with each other. (See Fig. 7.)

If the portable contains, in addition to the dry-disc *or* vacuum tube rectifier, *two*

45-volt "B" batteries and *one* 6-volt "A" battery, then we may expect B-plus to be 90 volts; we also know that the filaments of the four amplifier tubes are wired in series, as shown in Fig. 8.

Another combination of voltages in the 3-way portable is: *Two* 45-volt "B" batteries and *two* 4½-volt "A" batteries. We may therefore expect B-plus to be 90 volts. We will also find the amplifier tubes -- six of them -- are wired with their filaments in series.

The midget portable is an increasingly popular type. It contains one 67½-volt "B" battery, and two or more flashlight cells of the D-size, usually arranged in parallel. In addition to the battery combinations mentioned above, the 3-way portable may contain a single battery pack, whose voltages are equivalent to the above.

It should be emphasized that the 3-way portable contains one or the other form of these battery combinations, *in addition to* either a vacuum tube rectifier or a dry disc selenium rectifier. This is why it may be termed the 3-way portable, for it will operate on A-C commercial power, D-C commercial power, or its own battery power. Let us keep in mind that in the present discussion we are not concerned with battery operation, but are using the battery ratings only to indicate what voltages may be expected throughout the receiver.

Section 11. CHECKING THE 3-WAY PORTABLE POWER SUPPLY

We may begin a check of the three-way portable receiver first by testing the tubes on a tube-checker, replacing those which are found to be defective. Then test the receiver again for signal reception, for in many cases replacing the defective tubes will correct the trouble. If the receiver is still inoperative, we may start the analysis by checking the power supply.

Since battery ratings for different sets may differ by a considerable amount, the first step in checking the power supply would be to determine the exact voltages to be expected by referring to the battery requirements. Then, if the batteries are present in the receiver, test the receiver on battery operation. This is an important part of the analysis, as will soon be evident.

If the receiver operates properly on battery power, but not on commercial power, we may assume its signal circuits are in good condition and may at once suspect its AC-DC power supply. If the receiver operates

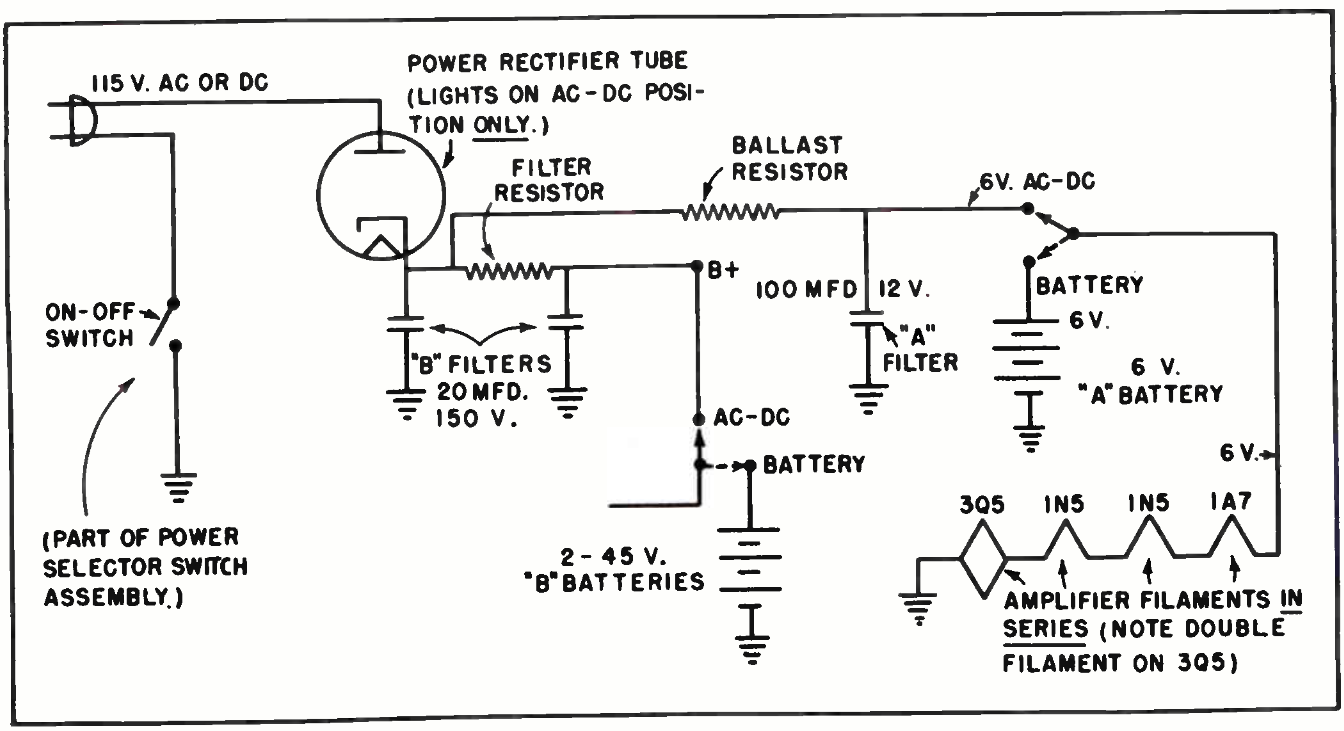

Fig.8. How the 1.5 Volt Filaments of the 3-Way Portable are Series-Connected When the "A" Battery is 6 Volts.

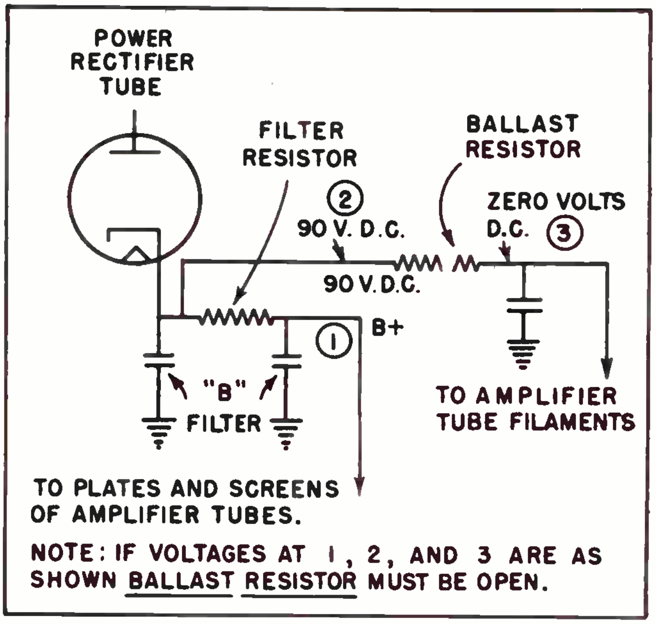

Fig.9. Comparing Voltages in the 3-Way Portable to Determine the Condition of the Ballast Resistor.

on neither battery power nor on its rectified power supply, we may suspect trouble is present in a signal circuit and is independent of the power supply.

To distinguish between these two possibilities, measure the battery voltages *under load*. If they are below normal output to a marked degree, while under load, replace them with good batteries and make the test again. Now, if the receiver operates properly on batteries known to be in good condition, and still does not operate on commercial power, we are ready to locate the exact trouble in the rectified power supply.

Check points for determining the exact fault in the rectified power supply are these:

1. The A-C voltage input, within the chassis of the receiver. This should be 115 volts, A-C or D-C, depending upon the commercial power characteristics of the locality in which the set is tested.

2. Between the screen-grid of the output stage and common negative of the filter condensers. This should be D-C voltage of the value indicated by the "B" battery rating of this receiver.

3. The filament voltages of all of the amplifier tubes. These should be *D-C*, and equal, in the case of each tube, to the filament rating as specified by the tube manual. (They are usually 1.5 volts, with the exception of a center-tapped output tube like the 3Q5, which is rated at either 1.5 volts or 3 volts, depending upon how its filament is connected into the circuit.)

Other indicators may be used to advantage. Notice if the rectifier tube lights up. Notice also if the speaker is completely silent, or whether it contains a hum, or any other sign of life.

Do not look for lighted amplifier tubes in the 3-Way portable. These tubes, with approximately 1.5 volts filament ratings, barely heat up to red heat. In a well-lighted room, it is almost impossible to see if they are actually lit. In a darkened room, it may just be possible to observe the red glow within these tubes. Since this method is too uncertain, it is best to ignore it. One thing can be done, however, to determine if the amplifier tubes are in order. If their filaments are known to be good by use of the tube-checker, and if they are being supplied with proper filament voltage, they can be assumed to be working. Moreover, in a series-connected string of 1.5-volt amplifier tubes, if any one of them is open, that one will show about 90 volts across its open heater while the set is on AC-DC. On battery operation, an open 1.5-volt filament will show a voltage approximately that of the "A" battery of the set.

In contrast to this, in a 3-way portable whose batteries supply only 1.5 volts for the filaments in parallel, all of the tube sockets will show this voltage, but each individual tube will have to be tested carefully for filament continuity. This, of course, is a part of the initial routine tube-checking procedure.

With the voltage readings taken as described at the test points, and the general symptoms of the receiver duly noted, we may begin analysis of the trouble in the AC-DC power supply of this 3-way portable receiver. Let us place certain related data in combination with each other.

If no sound of any kind is in the speaker, and B-plus voltage is completely absent, and the rectifier tube does not light up, we may readily suspect: - the power source, the power cord, the on-off switch, and the power wiring within the set. These should be tested separately in the order mentioned.

If the power rectifier lights up, but there is no sound of any kind in the speaker and B-plus is normal throughout the receiver, it would be wise to check the voltages across the amplifier tube filaments. (Note that we have previously tested the tubes and have either found them good or have replaced those which were defective.) With this combination of information, we suspect an open voltage dropping resistor (called a ballast) in series with the amplifier filaments. We then double-check this suspicion by noticing that at one end of this ballast B-plus is present, while the other end shows *no voltage whatever.* This means that the ballast, being open, prevents filament current from flowing to any of the amplifier tubes and thus renders the receiver completely silent. This suspicion would also be indicated when we find no voltages across the amplifier tube filaments. (See Fig. 9.)

If B-plus voltage is low, and only a hum is heard in the speaker, while all of the tubes check good, we may at once suspect an open or deteriorated input filter condenser. To verify this, place an equivalent filter condenser across the suspected one, and notice if the signal is brought in by this act. If so, a voltmeter reading B-plus will also be found to show a decided increase in this voltage at the same time that the signal is brought in.

If B-plus and filament voltages are normal, and the signal comes through with a loud hum then we have two suspects to track down. The first is the output filter condenser at B-plus, electrically found at the screen of the output stage. The second is the filament voltage filter, electrically located at the low-voltage end of the ballast. If either, or both, of these is open or deteriorated, their opposition to voltage changes is seriously reduced, resulting in the presence of the power line hum at the speaker.

Here again the *degree* of deterioration of either of these condensers will determine the nature of the symptoms. For a condenser only slightly below its mfd rating, the hum will be present, as described above. For a condenser with around half of its rated capacity, the signal will be accompanied by whistling. For a condenser completely dried out or electrically open, the result will be motor-boating at a comparatively low frequency.

If B-plus voltage and filament voltages are all correct, yet there is no sound whatever at the speaker, check continuity of the speaker voice coil, and of the primary and secondary of the output matching transformer. The simultaneous test for these three components is illustrated in Fig. 10.

In a receiver where all of the key voltages are normal, and yet the signal is either low in volume or altogether absent, a stage-by-stage check may be made with the use of the signal generator and the output meter. This method is equivalent to the alignment procedure for a superheterodyne receiver, and is highly dependable in locating a defective stage in a receiver whose power supply is known to be operative. Since most modern portable 3-way receivers are of the superheterodyne type, they lend themselves readily to trouble-shooting by the signal-tracing method. Once the defective stage is determined, a detailed search with the voltmeter and ohmmeter may be made, and readings compared with the manufacturer's wiring diagram or other standard data for the stage. Any discrepancy in the comparison will soon reveal the exact nature of the defect.

Section 12. THE STRAIGHT BATTERY PORTABLE

This type of receiver, which operates on batteries only, is complete in itself. Its batteries are contained within the portable cabinet, which also houses the loop antenna. (See Fig. 11.) Operating in exactly the same manner as the straight battery portable, is the 3-way portable while its power

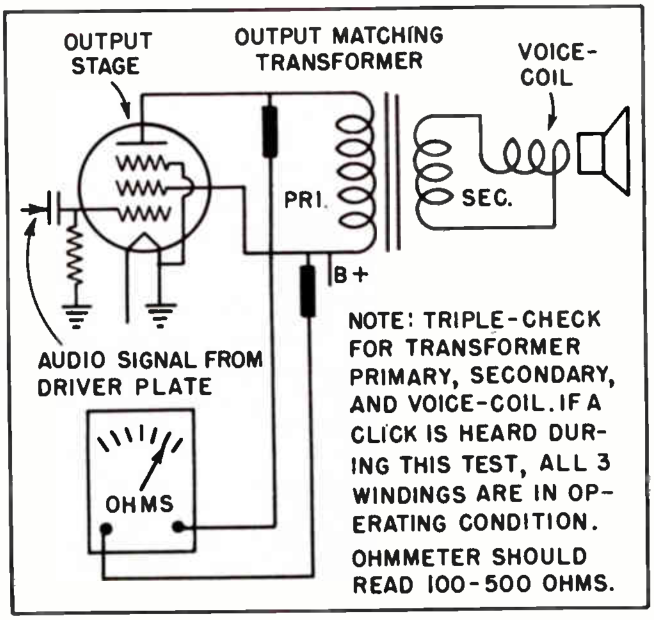

Fig. 10. Simple Test for All Three Windings in the Output Stage of a Receiver.

Fig. 11. Note the Absence of Power Cord in this Battery Portable.

selector switch is in the "battery" position. We may therefore discuss these identical receivers together, with respect to their power supplies.

If a 3-way portable receiver operates satisfactorily while plugged into the A-C or D-C commercial power outlet, but fails to operate on its batteries, then the cause is obviously in the batteries or in the wiring connections to them. These would include the soldered connections to the contacts of the power selector switch in such a receiver.

The most common cause of failure in a battery-operated receiver is worn-out batteries. There are a few tricks in checking batteries that are worth mentioning, for they may avoid confusion in trouble-shooting the battery-operated receiver.

The most important thing, after checking the tubes on the tube-checker, is to ascertain the condition of the batteries. This may be done with an ordinary voltmeter of medium sensitivity, around 1000-ohms-per-volt. *However, be sure to measure battery voltages while they are actually connected to their loads.* In the portable receiver, this simply entails turning on the power switch. If the "A" battery checks good but the "B" battery checks weak, the normal correction would be to replace the "B" battery. This is correct, but please notice an additional and related fact. If the "A" battery checks weak, or completely dead, *the "B" battery is not being loaded* and will probably check good even if it is weak. It may involve a delay of time and the expenditure of unnecessary effort, in order to determine that the "B" battery is also weak.

No reading of a "B" battery voltage is dependable unless it is properly loaded. Proper loading can only be achieved in the portable receiver when the "A" battery is known to be in good condition and the tube filament circuit is intact. In other words, it is useless to measure the voltage of the "A" or "B" batteries when they are not connected to the receiver. And it is useless to measure the "B" voltage unless it is properly loaded in the receiver.

Since the source of power in the straight portable (or the 3-way portable while in the "battery" position) are the batteries alone, there are certain troubles that simply cannot occur in this type of receiver. They are worthy of note.

Since no rectification is needed, there are no filter condensers, and there can be no form of 60-cycle hum resulting from deteriorated electrolytics.

The value of B-plus is dependent only upon the condition of the "B" battery, and not upon the state of the input filter condenser.

In a 3-way portable, the power rectifier is taken completely out of the circuit when in the "battery" position of the power selector switch. Do not look for a lighted rectifier tube while operating the set on batteries. It only lights while on the AC-DC position.

For the same reason, do not look for a rectifier of any kind in the straight battery receiver. It doesn't contain any, nor does it contain a filter choke, filter resistor, or filter condensers. Yet there are a few significant points about checking the straight battery power supply which point to trouble in *other* sections of the receiver.

Since there is no rectifier in this receiver, there can be no "residual" 60-cycle hum by which -- in any other set -- we recognize whether the receiver is "alive" or not. However, there is an indicator to tell us whether the set is "alive" or not. This is the background static which is heard when the manual volume control is advanced to maximum. In case the trouble lies in an audio stage, this background static would be entirely absent. If the trouble lies in either an R-F or an I-F stage, on the other hand, a considerable amount of background static will be audible.

If the tubes all check good, and the background static is audible in a fair degree, then replace the oscillator-mixer tube, even if it has previously been checked as "good". This is such a common trouble in the 1A7 and the 1R5 oscillator-mixer tubes that it is well worth the extra trouble of replacement. These tubes are peculiar in that they are critical, and a tube-checker may miss a defect in them. This defect may be serious enough, however, to prevent the set from playing.

If the symptoms are as described, and all key voltages check normal, then it is time to start a trouble-shooting procedure by the use of the signal generator and output meter, as described in the alignment procedure in the lesson on "The Superheterodyne Receiver." This procedure will locate the defective *stage* which, once identified, may be examined in detail for the exact fault.

NOTES FOR REFERENCE

The AC-DC receiver may be identified by the presence of several tubes whose heater ratings are 12.6 volts or higher and by the *absence* of a power transformer.

The 3-way portable receiver may be recognized by the presence of several tubes whose filament ratings are 1.5 volts each, *and* either a power rectifier tube *or* a dry-disc selenium rectifier.

The straight portable receiver, operating on batteries only, may be identified by the presence of tubes whose filament ratings are 1.5 volts each, and by the *absence* of any kind of a power rectifier or filter condensers.

The most common troubles encountered in the AC-DC receiver are: Open tube heaters, open or deteriorated filter condensers, open audio coupling condensers, open wiring in the power plug and cord, gassy or leaky tubes (especially the output and power rectifier tubes), and mis-alignment of the tubed stages.

The most common troubles in the 3-way portable receiver are: Open and shorted tubes, faulty filter condensers, mis-alignment of the tuned stages, open audio coupling condensers, defective power selector switch contacts, and worn-out batteries.

The most common troubles in straight portable receivers are: Worn-out batteries and defective tubes.

In checking the continuity of the tubes in an AC-DC receiver, make very certain that you check *all three* of the heater connections in the power rectifier. Examples are: 35Z5, 35W4, 35Y4. Each of these tubes has a tapped heater for the purpose of accommodating a 6-volt pilot lamp.

Take your time in radio and television trouble-shooting. Don't jump at conclusions until you have carefully confirmed your suspicions.

Look for only one trouble at a time in a receiver. More than one are possible, but not likely. Make the easiest, quickest checks first. *Any test that finds the trouble is a successful test.*

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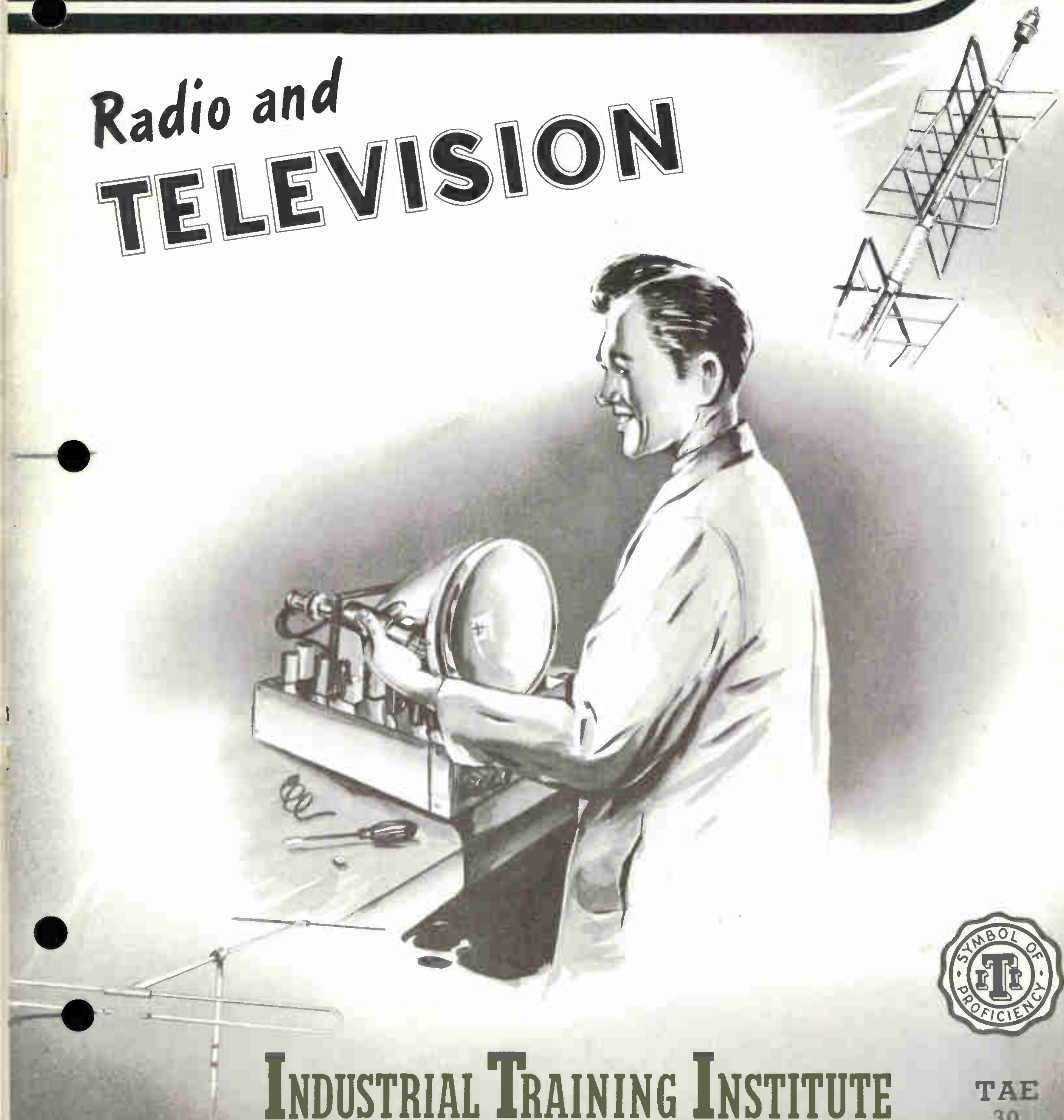

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RADIO TELEVISION

USING THE OSCILLOSCOPE

Contents: Introduction - Getting Acquainted with the Oscilloscope - Applications to Radio Receivers - Using the Oscilloscope as a Voltmeter - Measurement of High Frequency Voltages - Measuring Gain in the Radio Frequency Stages of a Receiver - Aligning Superhet Receiver and Setting I-F Band Width - Measuring High Voltages - Other Radio Receiver Tests - Notes for Reference.

Section 1. INTRODUCTION

This lesson is devoted to the use of the oscilloscope. It's most important applications to radio and television receiver circuits are stressed particularly. However, since there are many applications of this test unit to a wide variety of circuits, some important *precautions* should be obeyed. It is important to remember them in order to avoid accidents to the operator or damage to equipment.

Be careful in handling the voltages applied to the oscilloscope. Since this unit is often used for testing high voltages, the menace of these high voltages is ever-present. High-voltage testing, on the oscilloscope will be explained in later paragraphs where it will be evident that very careful handling and connections are required. So, be careful in handling the voltages applied to the oscilloscope; your caution may prevent severe electric shock. Carelessness could possibly kill you.

Do not apply a voltage to the oscilloscope that may damage it. Follow instructions for measuring high voltages and do not apply a high voltage *directly* to any connecting post on the 'scope. By "high voltage" we mean any value over 300 volts.

Do not try to repair or internally adjust the oscilloscope with the power on, and do not attempt to "short-out" the safety interlock switch connected to the panel of the 'scope. The internal voltages of this test unit are usually over one thousand volts. They are sufficiently dangerous to cause serious harm to personnel. Some 'scopes use several thousand volts.

Keep the spot on the 'scope in motion, or very dim. A bright spot standing still on the screen of the 'scope is almost certain to "burn" a hole in the fluorescent coating. If this occurs, that spot will always remain

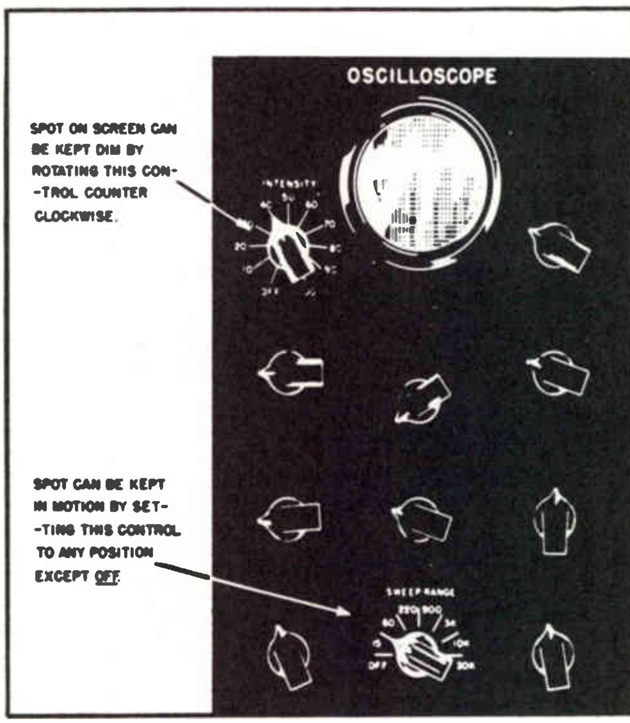

Fig.1. These Controls are used to Keep the Electron Spot Dim or in Motion.

dark and may later conceal the true wave-shape of a voltage whose form is to be examined. The spot formed by the electron beam can be dimmed by turning the Intensity Control in a counter-clockwise direction. The spot can be put in motion by selecting a Sweep Frequency of any value other than "Off". (See Fig. 1.)

When putting the 'scope into operation, stay with it until the trace appears. Sometimes when busy, we may turn the 'scope on, then walk away for a minute while it is warming up. If some other duty happens to divert us we may come back to the 'scope some minutes later to find that a stationary bright spot on the screen has already caused damage to the fluorescent coating.

Section 2. GETTING ACQUAINTED WITH THE OSCILLOSCOPE

Always bear the precautionary measures in mind. Now we will examine the method used for putting the 'scope in operation. In order to make this a practical example, let us assume that our objective is to examine the wave-pattern of the output of an audio sine-wave oscillator. We will use Fig. 2 to locate the 'scope controls.

Step 1. Plug the 'scope power line into the power receptacle.

Step 2. Apply power to the 'scope by turning the on-off switch (physically connected with the Intensity Control) to the "On" position; that is, clockwise. Note that after the "snap" of this control switch, the control knob will turn almost a full turn clockwise.

Step 3. Return this control knob back to its maximum counter-clockwise position just *before* it snaps to the "Off" position. This reduces the intensity to minimum but leaves power applied to the entire system.

Step 4. Wait until the 'scope warms up, usually about a minute or less. (Do not leave the 'scope to warm up by itself.)

Step 5. After the warm-up interval, slowly rotate the Intensity Control in a clockwise direction, watching for the appearance of the bright spot. When the spot appears, *keep it dim* by holding the Intensity Control at the proper point.

Step 6. Using the Sweep Range Knob, select a position other than "Off". The spot will now be repeatedly drawn from left to right at a speed corresponding to the selection made by the Sweep Range Control. The visual impression on the eye at this time will be a straight horizontal line midway between the upper and lower edge of the 'scope screen. The sweep is now moving the electron beam.

Step 7. Experiment with the Horizontal Gain Control, rotating it clockwise and counter-clockwise and noting the expansion and contraction of the sweep line. Adjust this control to make the sweep line approximately equal to the width of the viewing screen. This is the control marked "H-gain".

Step 8. Operate the Vertical Positioning Control, and notice how the sweep line rises and falls. Re-center the sweep line with this control.

Step 9. Operate the Horizontal Positioning Control. Note that with *only* the sweep voltage applied to the cathode-ray tube, the effect of this control is noted only in extreme positions.

Step 10. Being cautious of the voltage involved, connect the leads carrying the unknown voltage from the audio oscillator to the Vertical input, in the lower left-hand corner of the 'scope control panel. If the audio oscillator has a ground, connect this lead to the lower, or "G" binding post of the 'scope.

Connect the other lead from the audio oscillator to the "V" post on the 'scope. (It is a wise policy to disconnect power from the source of the unknown voltage while making these connections.) At this time, if the Vertical Gain Control is sufficiently advanced, a wave pattern is visible on the screen. If the only thing visible is a straight horizontal line, turn the "V-Gain" control clockwise enough to present a pattern with some reasonable amount of vertical dimension.

Step 11. The pattern now presented on the screen will seem jumpy and unstable. Now adjust the position of the Sweep Vernier Control, located just above the Sweep Range, until the pattern on the screen settles down to its slowest motion. When this is achieved, we are ready to "lock" the sweep frequency with a submultiple (such as 1/2, 1/4, etc.) of the unknown voltage.

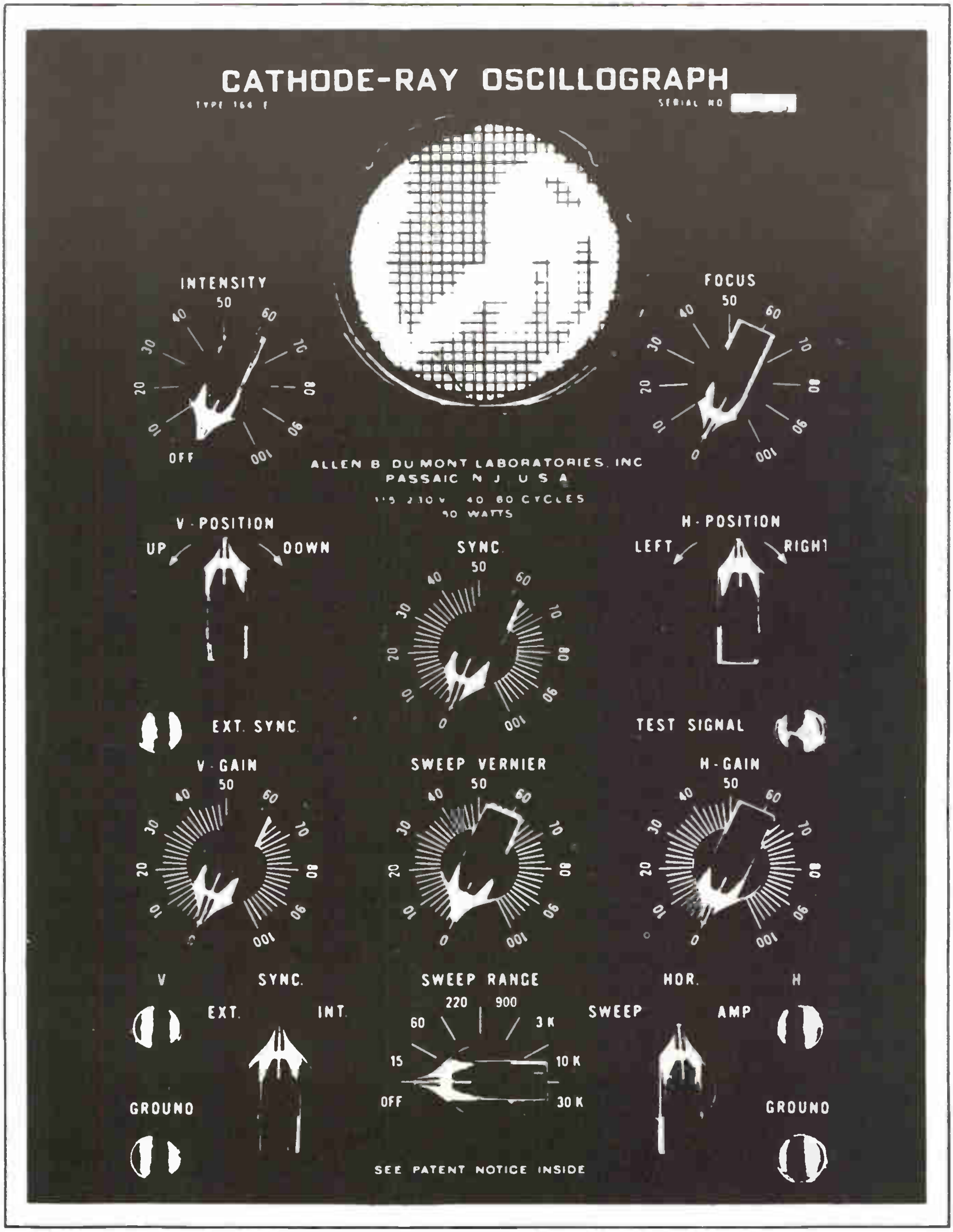

Fig. 2. Face Panel of 'Scope.

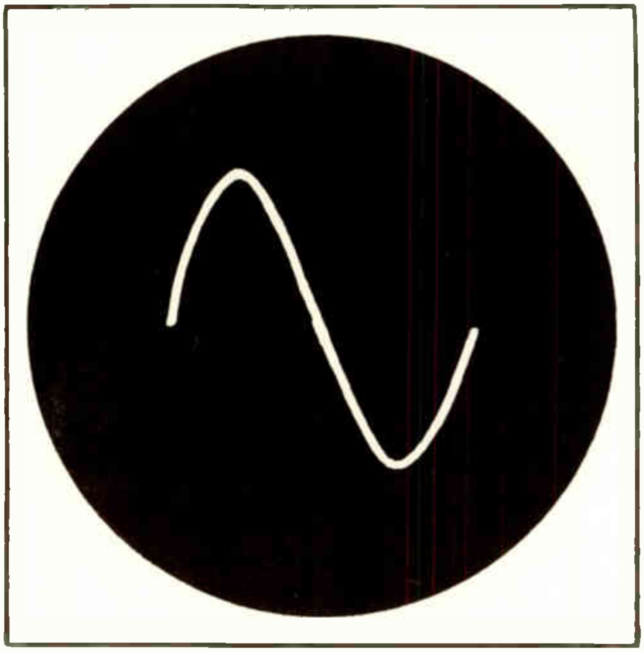

Fig.3. Sine Wave Pattern on the Screen.

Step 12. Adjust the "Sync" or Locking Control, located immediately below the screen, until the image stands perfectly still. The sweep voltage and the unknown voltage are now locked together for a stationary image.

Step 13. Adjust the Intensity Control for proper trace brilliance; then the Focus Control, in the upper right-hand corner, for the sharpest trace on the screen.

Final Step. The trace on the screen is now an exact duplicate of the audio oscillator output and is ready for examination. If it appears, as in Fig. 3, as an undistorted sine wave, the audio oscillator -- as well as any amplifier stage carrying this voltage -- can be said to be operating normally.

Section 3. APPLICATIONS TO RADIO RECEIVERS

Measuring the frequency response and checking for distortion in the audio section of a receiver constitute frequent uses of the oscilloscope.

When a radio receiver lacks full tone, or sounds "tinny" or distorted, the oscilloscope can be used to advantage in determining the frequency response of the audio frequency stages and at the same time will provide the technician with a detailed picture of any electrical distortion that may be present.

Fig. 4 illustrates the manner of connecting the necessary equipment together for this procedure. Notice the point of introducing the signal from the audio generator into the high side of the receiver volume control. This "high" side of the volume control can be identified readily in the radio receiver by selecting the one which is opposite to the side connected either to chassis or common ground. The advantage of introducing the audio signal at this point is to provide some measure of amplitude control over the test signal, and at the same time to serve as a test for volume control action as well.

After making the connections as shown in Fig. 4, apply power to the signal generator, to the receiver under test, and to the oscilloscope, allowing a warm-up period of at least several minutes.

Put the 'scope into operation as already explained, making certain that the spot on the screen is kept dim enough to prevent damage, yet bright enough to see.

Set the Sweep Range Control on the 'scope to 60, and adjust the Intensity, Focus, and Positioning controls for a straight horizontal line, well focused at the center of the screen.

Rotate the volume control of the receiver to its maximum clock-wise position. Set the Vertical Gain control on the 'scope to about 10.

Now, turning the audio signal generator, select an output frequency of 60 cycles and turn the output attenuator (or gain) control clockwise until the 'scope screen indicates vertical deflection to the extent of about one inch. Do not change these gain controls, either on the signal generator, the receiver or the oscilloscope, during the remainder of the test.

Next, rotate the Sweep Vernier until the pattern on the screen settles down to its slowest motion; at this time adjust the Sync control to secure a locked-in (stationary) 'scope pattern. The picture on the 'scope should resemble one of the patterns in Fig. 5, depending upon which submultiple of the signal frequency the Sweep Vernier has selected.

The picture on the screen is now ready for measurement. Count the number of spaces on the celluloid cross-hatched 'scope face-

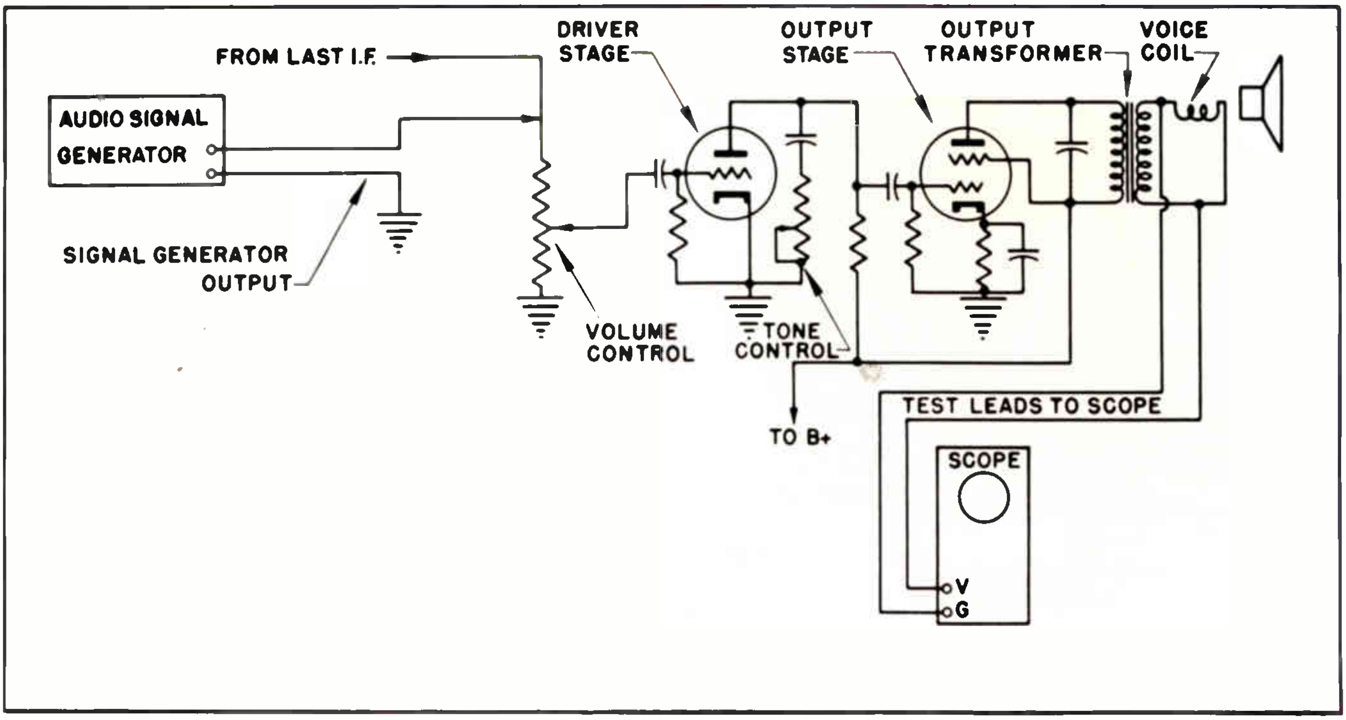

Fig.4. Connections for Measuring Frequency Response and Checking Distortion in an Audio Amplifier.

cover between the horizontal sweep line and the very top of the sine wave, and record this measurement. This measures the gain of the receiver audio section at the frequency used; that is, 60 cycles.

In order to ascertain the gain of the receiver audio section through the entire range of audio frequencies, our next step in this procedure is to set the signal generator to produce an audio signal at the top end of the audio range. For this purpose, a frequency of 15,000 cycles per second is satisfactory.

When the signal generator is changed to produce this 15,000 cycle output, it may be necessary to re-adjust the Sweep Range and Sweep Vernier controls to secure a stationary image on the screen. But do not change any of the gain controls, because we are about to make a comparison between the value of

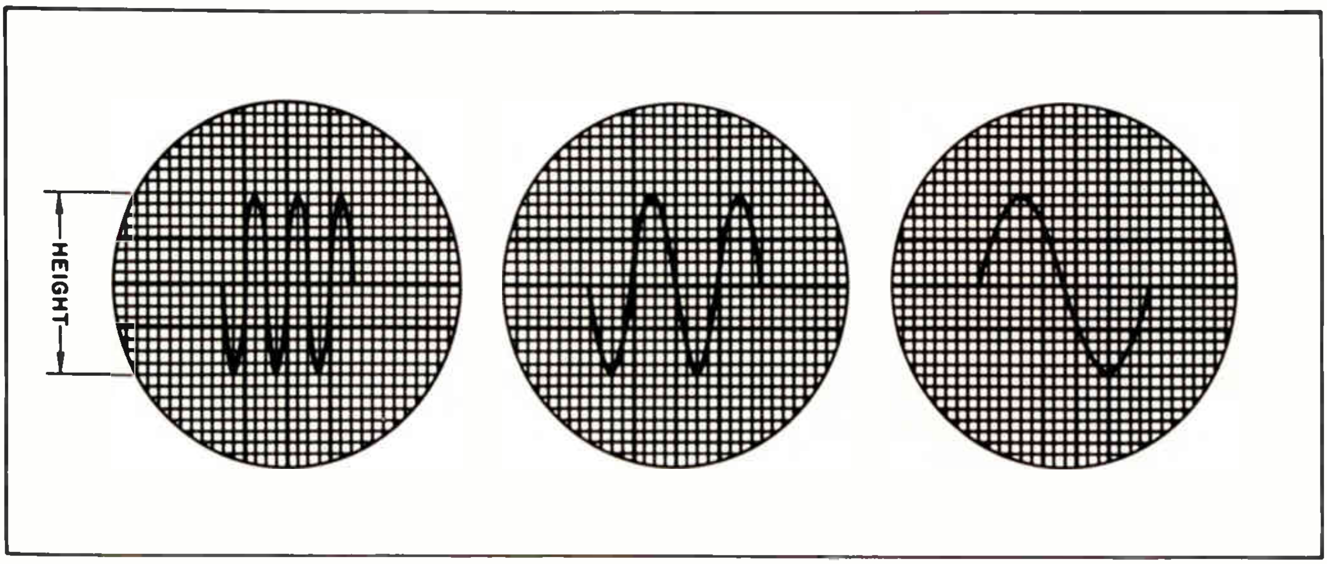

Fig.5. Three Possible Patterns on the 'Scope Screen when Measuring Frequency Response of an Audio Amplifier.

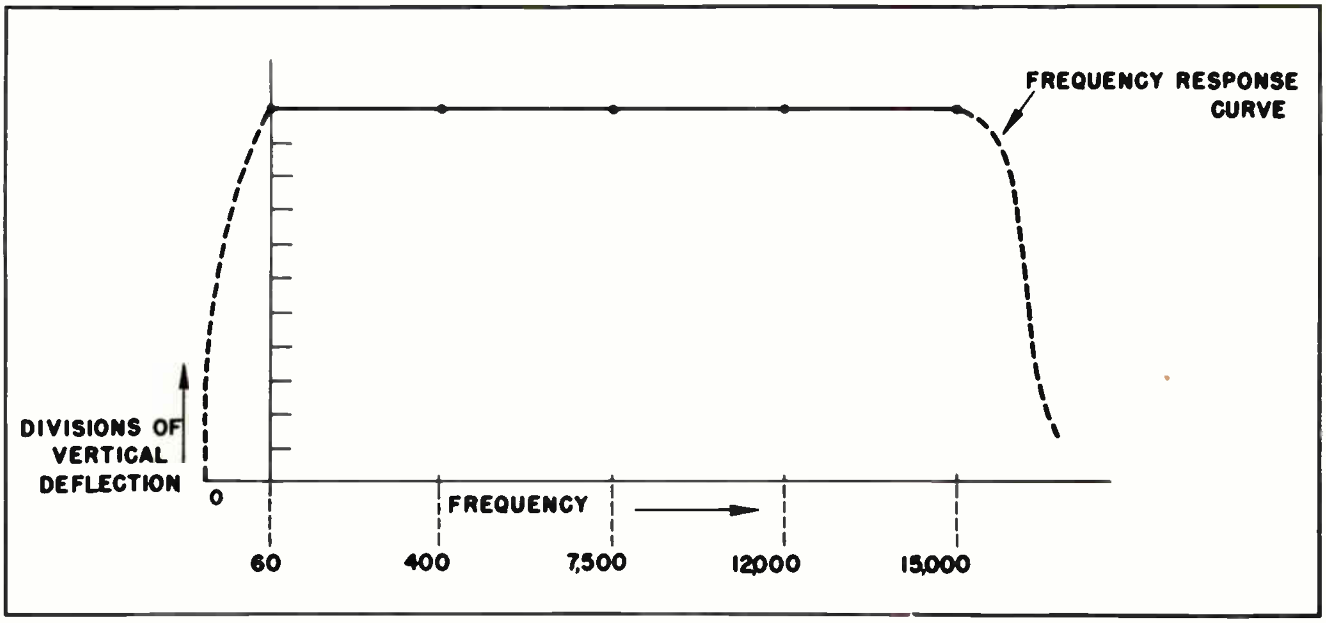

Fig. 6. Normal Frequency Response Curve for Properly Operating Audio Amplifier.

the gain at 60 cycles and the gain at 15,000 cycles. Note that we are interested primarily in the extent of vertical deflection, for this vertical deflection measures the gain at whatever frequency used.

As in the case of the 60 cycle frequency, count the number of divisions above the horizontal sweep line on the screen. Compare this deflection with the degree of deflection at the 60 cycle frequency.

We may go one step further by repeating the operation at mid-point in the audio frequency range, about 7,500 c/s (cycles per second). If we want to go even farther, we can also repeat the operation at the 400 c/s and the 12,000 c/s frequencies, making certain that we count the number of divisions of deflection in each case, and that we record these counts. We are now ready to analyze the results of this test.

Fig. 6 is a graph of frequencies plotted against vertical deflection on the 'scope screen, and shows the frequency response curve for a normally-operating audio section of a radio receiver. As can be seen from

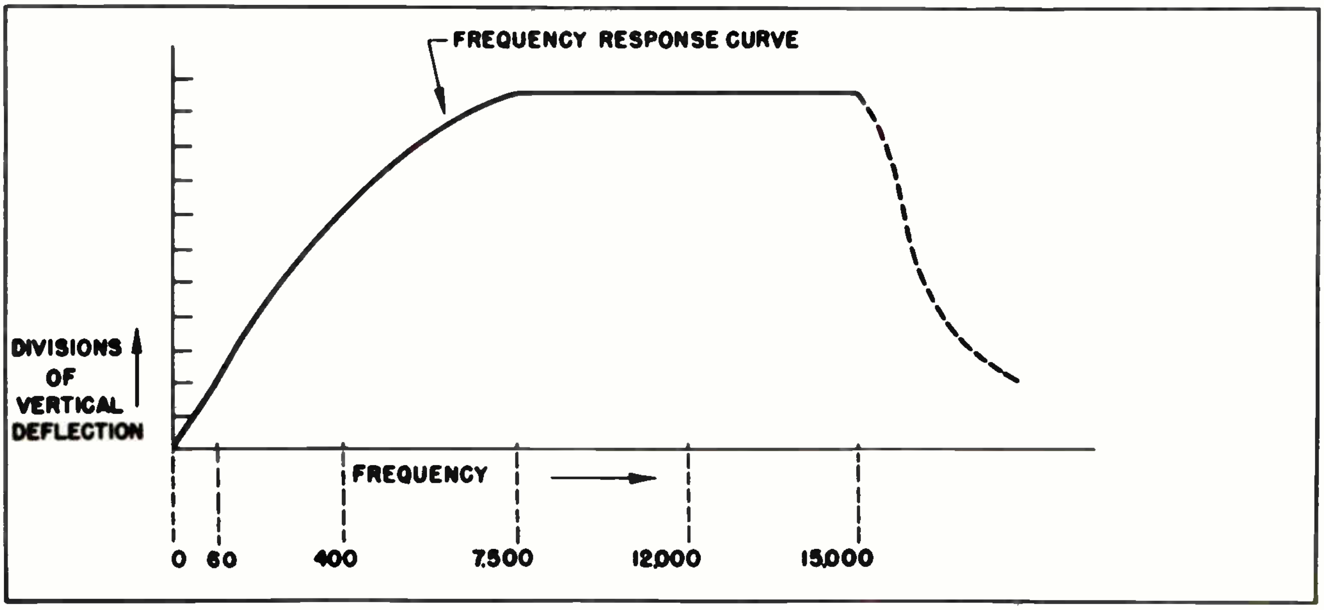

Fig. 7. This Audio Amplifier Discriminates Against Low Frequencies.

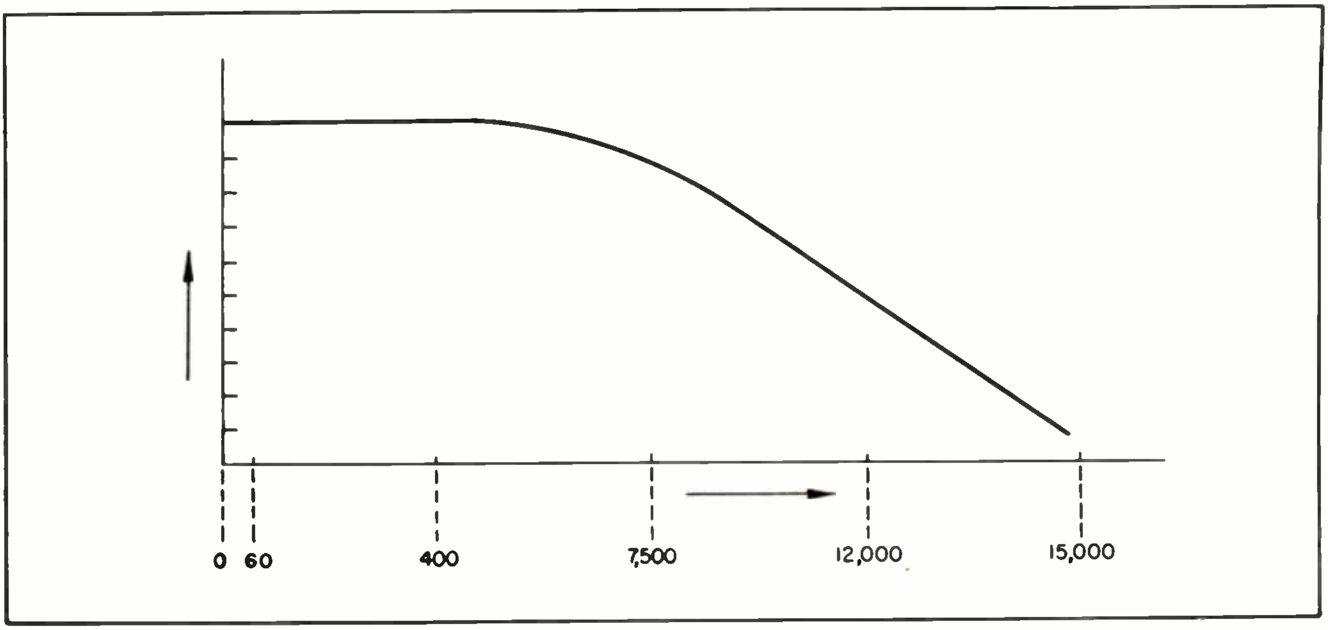

Fig.8. Discrimination Against the High Frequencies of an Audio Signal.

the graph, the extent of vertical deflection, and hence the voltage across the voice coil of Fig. 4, is the same for all the frequencies measured.

If the frequency response curve had appeared as in Fig. 7, a discrimination against the lower frequencies would be indicated, for this curve shows that the degree of deflection at 60 and 400 c/s is somewhat less than at the higher frequencies. This discrimination may easily cause a muscial or voice distortion, resulting in a "tinny" sound in the speaker.

As is evident in other lessons of this series dealing with audio stage troubleshooting, this fault -- discrimination against the lower frequencies -- is often caused by a partially opened or undersized audio coupling condenser. The correction for this condition is to install a good condenser of the proper capacitance. Another way of correcting for this fault would be to check for the presence of a cathode by-pass condenser in the output stage. If it is present, verify the possibility of an open within that condenser. If it is absent, as it may be in small receivers, the installation of one will often improve the tone of a receiver. A re-measurement of the frequency response would reveal, after corrections have been made, a more uniform response curve such as shown in Fig. 6.

On the other hand, if the frequency response curve had appeared as in Fig. 8, a discrimination against the higher range

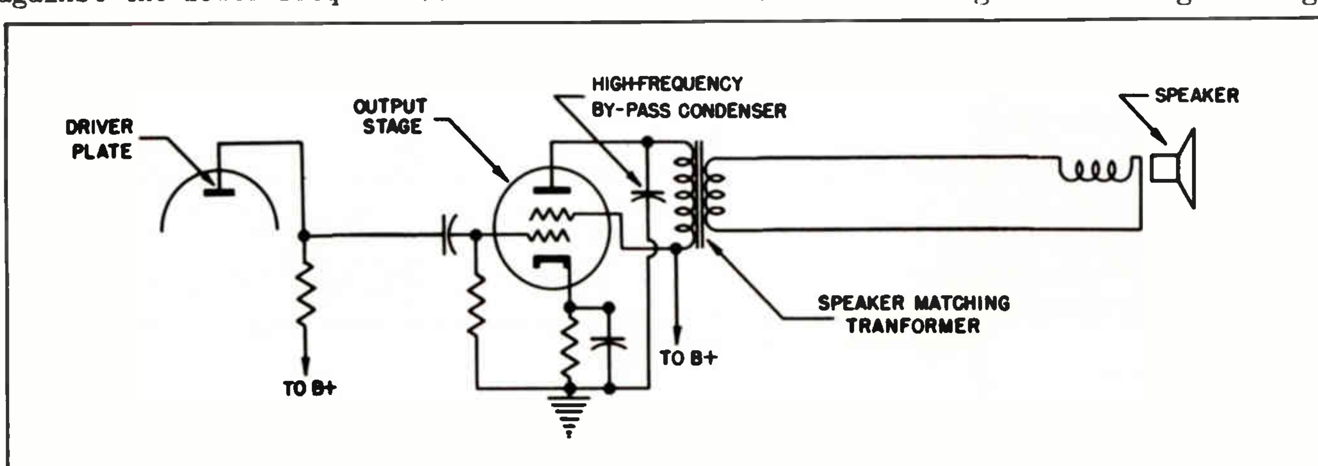

Fig.9. By-Pass Condenser has too much Capacitance; the Signal Sounds Fuzzy.

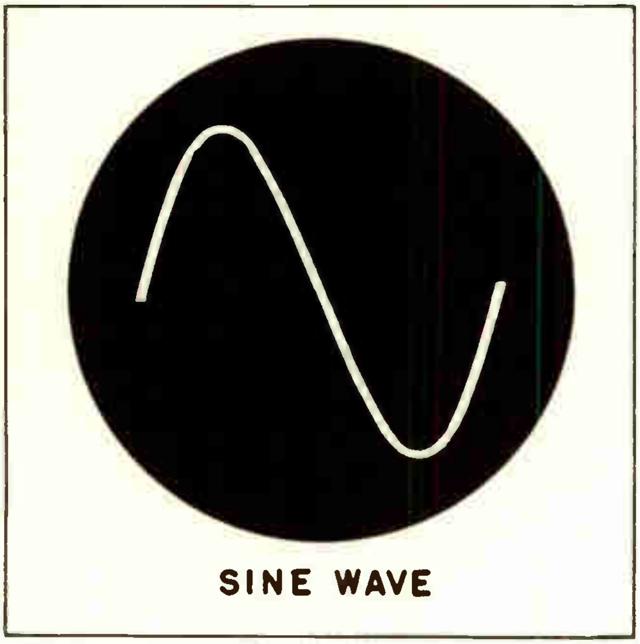

Fig.10. An Undistorted Sine Wave.

of frequencies would be indicated. This, too, may result in a perceptible tonal inferiority, this time being in the nature of a "fuzzy" signal. Cause for this condition is usually a short-circuited tone-control condenser, or too much capacitance in the by-pass condenser normally connecting the plate to cathode in the output stage.

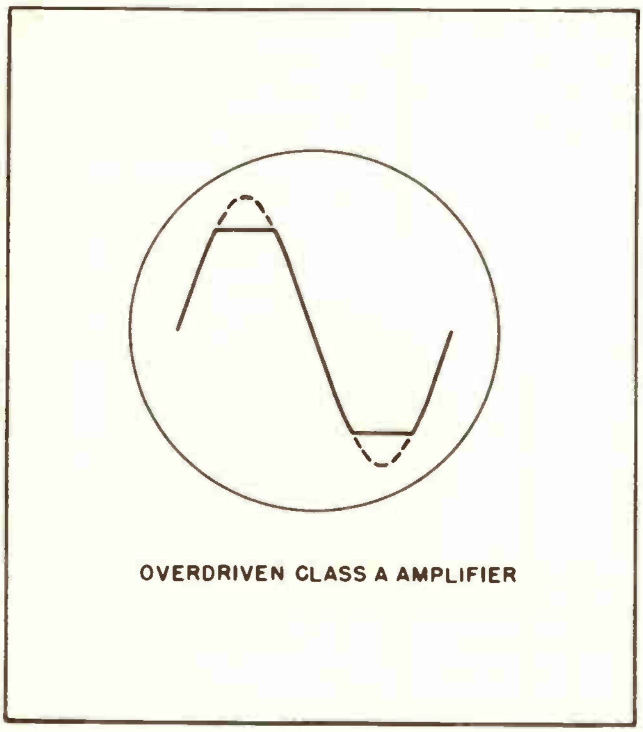

Fig.11. Flattening of the Sine Wave is Due to Overdriving the Audio Amplifier.

(See Fig. 9.) Correcting either of these two possible conditions would result in a clearer signal and -- if measured again -- a more uniform frequency response curve, nearer that of Fig. 6.

In an earlier paragraph, mention was made of using the above testing procedure to determine the degree of distortion in an audio amplifier. Since the stages of the schematic circuit of Fig. 4 are designed to operate Class A, the output of each should be pure sine wave, as shown in Fig. 10. If the sine wave is distorted, that is, flattened out at either the top or bottom, then the signal is known to be over-driving the amplifiers. However, distortion of the

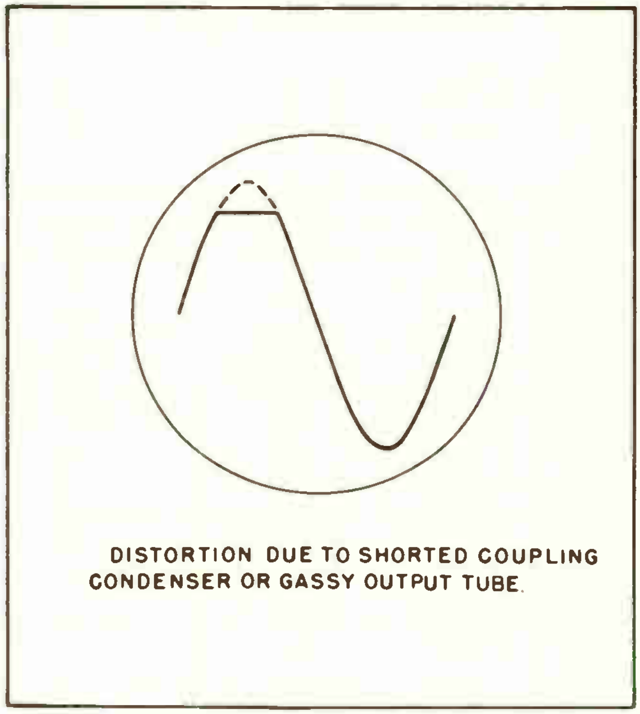

Fig.12. This Pattern Indicates the Stage is Biased Near Saturation; not Normal for Class A Amplifier.

sine wave, as shown in Fig. 11 may also be caused by other troubles. Among the most common of these are a short-circuited coupling condenser and a gassy output tube. In either case, noticeable distortion would be evident, and the 'scope pattern would of course clearly indicate this condition, as shown in Fig. 12.

An alternative, and somewhat simpler method of measuring the frequency response of an audio amplifier system would be accomplished by keeping the Sweep Range control at "Off" and thus omitting the sweep line. As can be

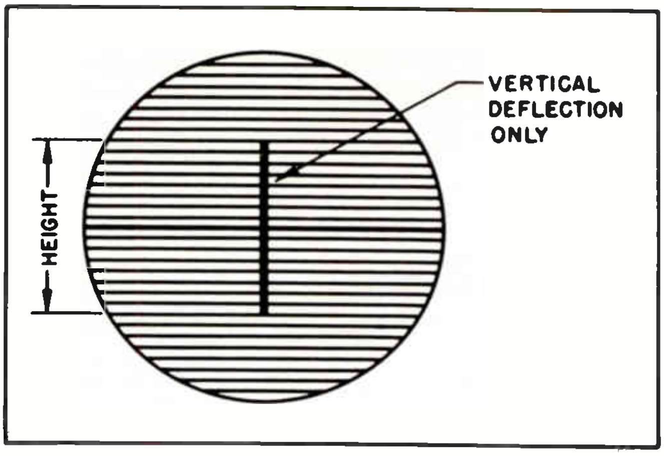

Fig.13. Appearance of Pattern when a Voltage is Applied to the Vertical Input and the Sweep is Removed.

seen from Fig. 13, vertical deflection would still take place in the normal manner; in the absence of the horizontal sweep the picture on the 'scope screen shows only a vertical line whose height is proportional to the amplitude of the voltage impressed on the vertical plates. While this method eliminates the need for synchronizing and locking the sweep and signal frequencies together, it has the disadvantage of failing to show the exact wave-form of the signal voltage and hence would not indicate any electrical distortion that may be present.

Section 4. USING THE OSCILLOSCOPE AS A VOLTMETER

In the previous discussion on using the oscilloscope as a means of measuring the frequency response of an audio amplifier system an important factor emerges: We were using the 'scope as an uncalibrated voltmeter, not for the purpose of determining the actual number of signal volts present at the speaker voice coil, but as a comparison between the voltages at the voice coil when carrying any one of a wide range of frequencies. We were interested primarily in the *relative* voltages at the voice coil. However, if we can *calibrate* the oscilloscope in the proper way, it can be used as a very accurate voltmeter whose precision matches that of the finest vacuum tube voltmeter.

A simple and dependable method of calibrating the vertical deflection of the 'scope in terms of the volts uses the *known* 115-volt A-C commercial supply voltage. Since it is precisely this voltage which powers the oscilloscope, it is always present wherever the oscilloscope is used. This method is as follows:

Attach leads from the 115-volt A-C supply source to the Vertical binding posts of the 'scope, as shown in Fig. 14. (In making these connections, attach the "Ground" side of the A-C line to the lower of the two binding posts, marked "G", the "high" or "hot" side going to the upper binding post.) Now put the 'scope in operation in the normal way, but leave the Sweep Range control set at "Off". Since we are at present not concerned with either the wave-shape or the frequency of the commercial power voltage, but only with its amplitude, we may dispense with the sweep line of the

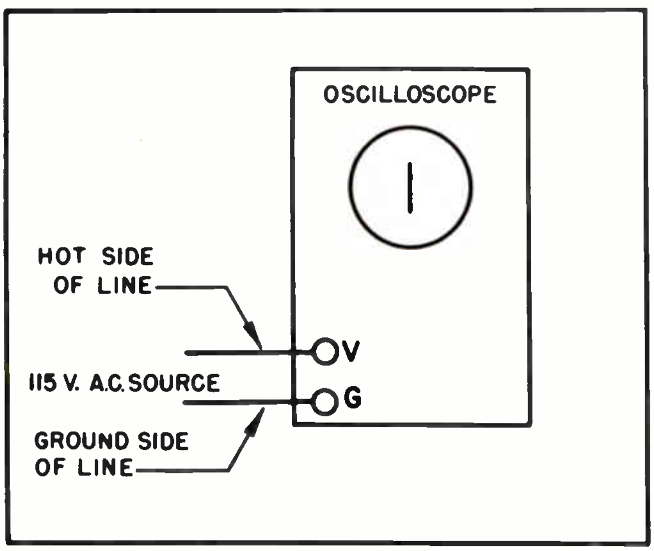

Fig.14. Calibrating the 'Scope, using 115 Volt A-C Source as a Standard Voltage.

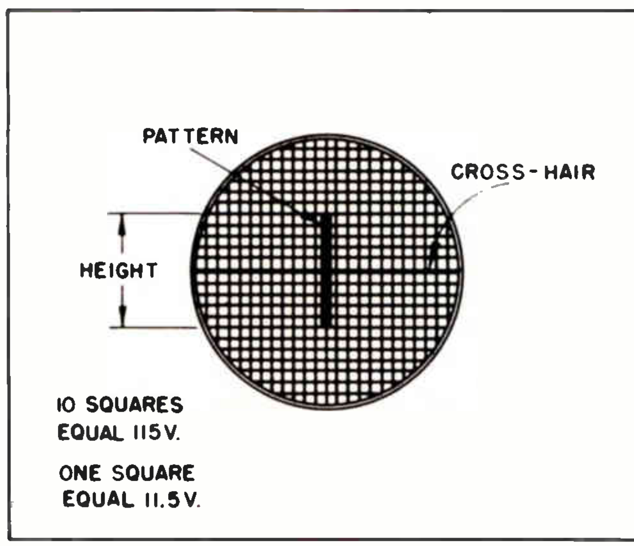

Fig.15. How the Pattern Appears When Calibrating the 'Scope as a Voltmeter.

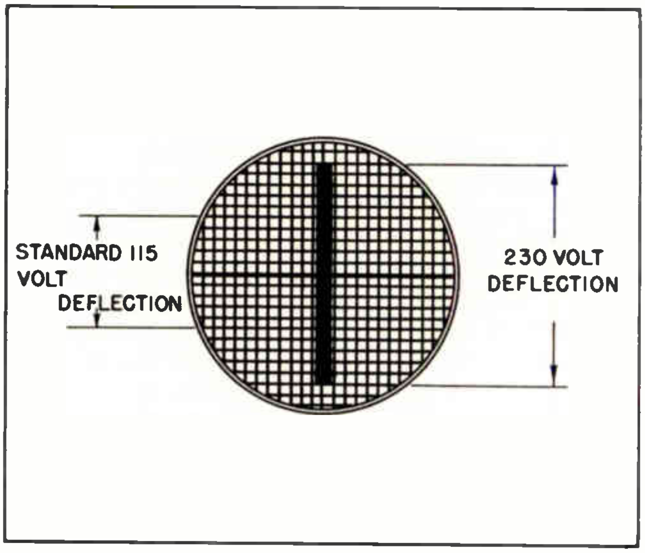

Fig.16. Compared to 115 Volt Deflection, 230 Volts will Deflect the Electron Stream Exactly Twice as Much.

'scope and direct our attention only to the degree of vertical deflection that represents 115 volts.

Brighten and sharpen the vertical line with the Intensity and Focus controls, and using the horizontal and vertical positioning controls, set the position of the pattern so that it is cut exactly in two by the center line (cross-hair) of the celluloid marker on the face of the 'scope screen. It should look like Fig. 15. Adjustment can now be conveniently made for making the height of the vertical line any given value, say 10 squares of the marker above the hair-line and an equal number below. To make this adjustment, turn the Vertical Gain Control, holding it in the required position.

If we have set the height of the vertical pattern on the 'scope at ten squares of the marker, and since we know that the voltage applied to the vertical amplifiers is 115 A-C volts, we can now use the 'scope as a calibrated voltmeter. For if 115 volts, A-C, deflect the electron beam to ten squares, then each square of deflection, as viewed and measured on the screen, will represent a voltage of 11.5 A-C volts. We can, therefore, apply any A-C voltage between five volts and about 300 volts, count the number of squares of vertical deflection and compute the value of the actual number of volts applied to the vertical binding posts of the 'scope. Fig. 16 illustrates the height of the 'scope pattern when 230 volts are applied, and Fig. 17 shows the extent of deflection measuring 57.5 volts,

It should be noted here that this procedure for measuring A-C voltages has three important limitations:

When applied to the Vertical binding posts on the front panel of the 'scope, the voltage to be measured passes through the vertical amplifier system of the 'scope. This means that while the voltage on the input binding posts is of a definite A-C value, the deflection on the screen can be varied considerably by the Vertical Gain control. Since the vertical amplifier is an attenuator as well as an amplifier, the number of A-C volts actually applied to the vertical deflecting plates depends upon the setting of the Vertical Gain control, and may be a good deal more or a good deal less than the voltage under test. In either case, however, the calibration made with a known 115-volt value is accurate, but the Vertical Gain control must be left unchanged until the test is completed.

Another limitation in using the method described is that only A-C voltages can be measured in this way. This is due to the nature of the input circuit connecting the vertical binding posts on the front panel of the 'scope to the vertical amplifier system. Both of these binding posts are condenser-coupled to the internal circuit, rendering the method useless for measuring D-C voltages.

Fig. 18 illustrates the series capacitance involved in this circuit. However, D-C voltages can be measured on the oscilloscope,

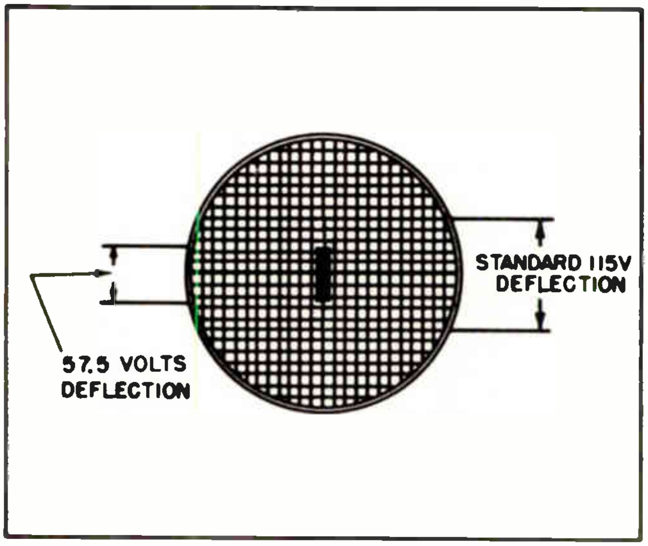

Fig.17. Compared to 115 Volt Deflection, 57.5 Volts will Deflect the Electron Stream Exactly Half as Much.

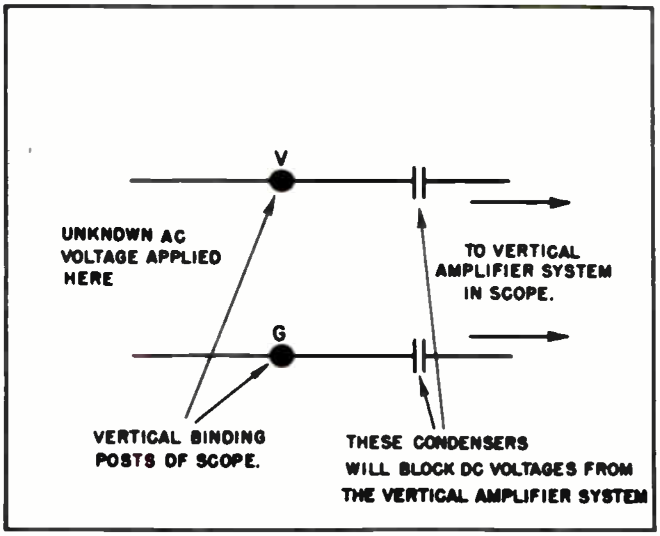

Fig. 18. D-C Voltages Cannot be Applied to the Vertical Amplifier Because of the Series Capacitance.

as indicated by the sketch in Fig. 19, which shows the back *panel* connections to the vertical deflection plates without benefit of either attenuation or amplification provided by the vertical amplifier of the 'scope.

Calibrating the degree of deflection, in squares per volt, or volts per square, will of course have to be done first with a known D-C voltage. To prevent damage to the cathode-ray tube, observe the precaution of not applying high voltages directly to these tie-points.

The third limitation of this method is that the calibration procedure must be repeated if the 'scope has been used for any other purpose since the last test. Since the Vertical Gain Control is one of the most commonly used controls of the oscilloscope, it is almost certain that it will have been moved to some other position if the 'scope has been used for anything else since the last test.

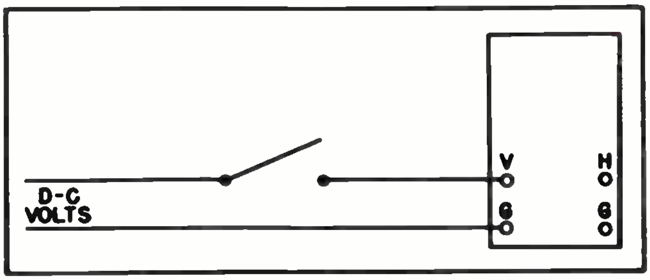

Fig. 19. D-C Connections to Back Panel.

Section 5. **MEASUREMENT OF HIGH FREQUENCY VOLTAGES**

Measuring the amplitude of high-frequency voltages, such as are commonly met in radio and television circuits, is an easy and useful task for the oscilloscope. Fig. 20 shows the connections suitable for this work. Calibration of the 'scope can be made with the usual 115-volt A-C value, as described above. If the high frequency voltage to be measured is of the same order of amplitude as the calibrating voltage, then it can be applied directly to the vertical binding posts of the 'scope. However, if the high frequency is much greater, a coupling transformer should be used. Note that to read accurately, we must know the step-down ratio of the transformer windings. We would then multiply the indicated voltage on the screen by this step-down ratio to compute the true voltage of the high-frequency to be measured.

Section 6. **MEASURING GAIN IN THE RADIO FREQUENCY STAGES OF A RECEIVER**

This procedure is also applicable to the gain of the I-F (intermediate frequency) stages of a superheterodyne radio or television receiver, and is basically a method of *comparing* the amplitude of the high-frequency output of an RF or (I-F) amplifier with the amplitude of its input. Fig. 21 shows a typical circuit of an I-F amplifier in a superheterodyne radio receiver, and indicates the electrical location of the test points used for this procedure.

For best results, after the 'scope has been put in operation, set the Sweep Range to 30K and the Sweep Vernier to its maximum clockwise position. Turn the receiver on and select a fairly strong station. As indicated in Fig. 21, run a jumper across the AVC circuit of the receiver, its purpose being to eliminate any change of gain due to automatic volume control action. Attach test leads to the vertical binding posts of

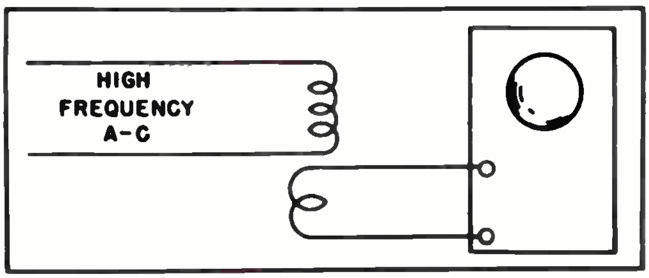

Fig. 20. Measuring High Frequency A-C.

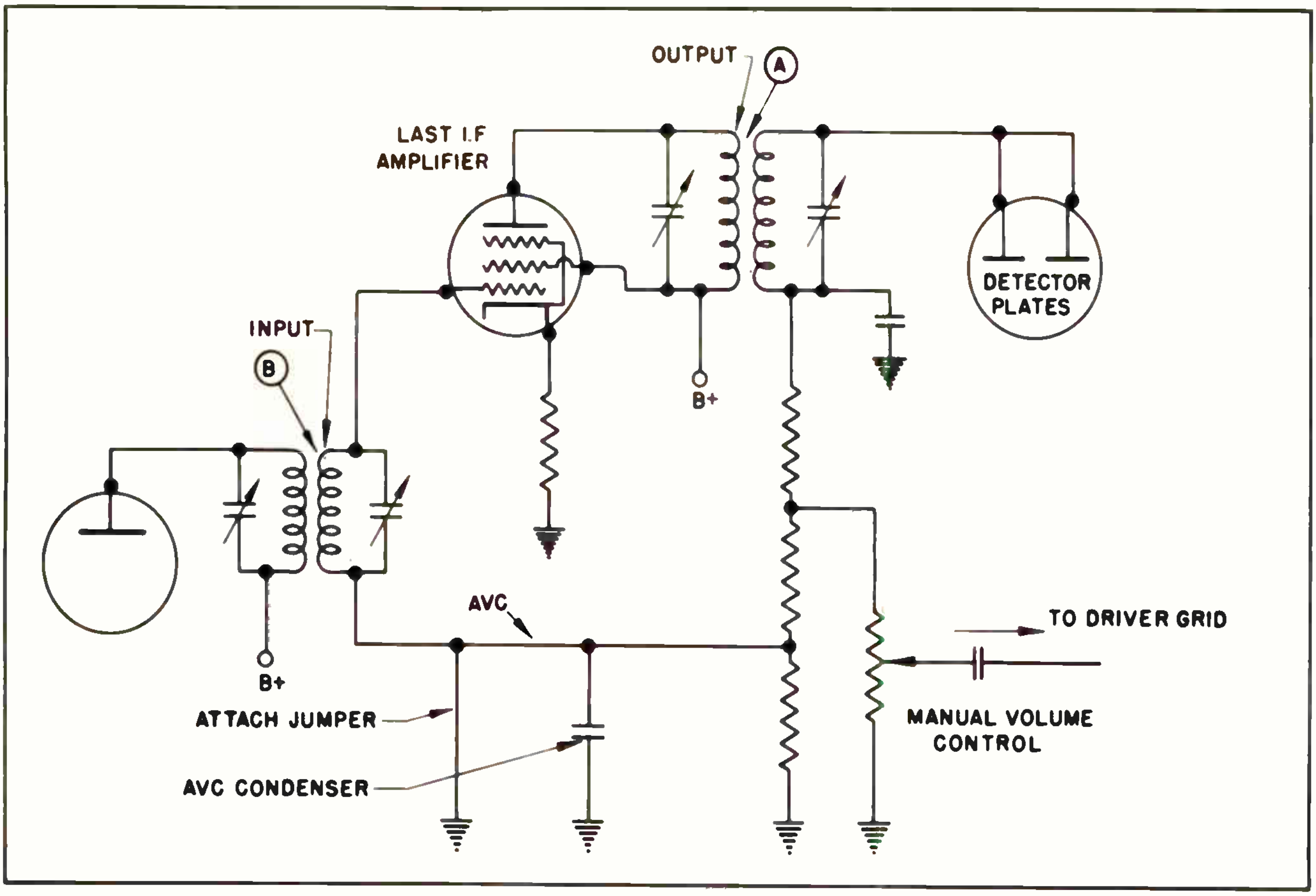

Fig.21. Circuit and Test Points Involved in Measuring the Gain of an I-F Amplifier Stage.

the 'scope, observing the grounding method shown in the figure, and using the test lead connected to the upper binding post as a probe for testing at points *A* and *B*.

Attach the test probe first to point *A*, which is the output of the I-F amplifier stage, and adjust the Vertical Gain control to a point where the pattern on the screen looks like that shown in Fig. 22. (To keep this pattern more or less stationary, set the Sync control in its maximum clockwise position.) The pattern now visible on the screen represents a modulated I-F signal whose maximum height, as set by the Vertical Gain control, is proportional to the signal voltage at the plate of this stage. Record the height of this signal, either in inches or divisions of the screen marker.

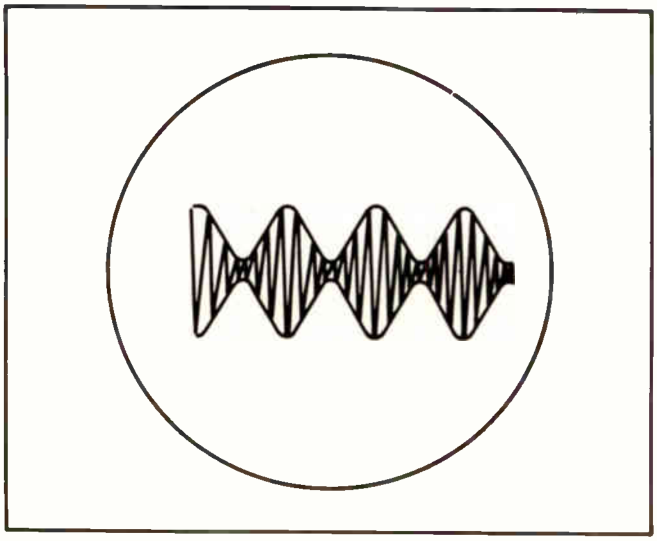

Fig.22. Modulated I-F at the Output of an I-F Amplifier.

Now, without changing the Vertical Gain control of the 'scope, place the test lead to point *B* of Fig. 21. This is the input, or grid circuit of this I-F amplifier. Observe on the 'scope screen the decrease in the height of the image. In a normally operating I-F stage, this should be a sharp decrease, resulting in a pattern where the vertical deflection on the grid side of the stage is barely perceptible to the eye, appearing similar to the pattern shown in Fig. 23.

The ratio of the output signal amplitude to that of the input measures the gain of the stage. If the ratio is high, then gain is normal. In stages such as these, normal gain is about 100. If the ratio is low, then the gain is low. Perhaps we will find no deflection in the output test, but can readily see the pattern at the input. This, of course, indicates serious trouble in the stage, and under these circumstances we should not expect a signal of any kind at the speaker of this receiver. Lack of gain as indicated by this method, accompanied by a weak signal at the speaker, generally indicates a weak amplifier tube or an open screen resistor in this stage. In some cases, low gain and its resultant weak signal can be caused by an open screen by-pass condenser although this fault may often cause the additional symptom known as "motor-boating".

You are probably already beginning to recognize that this method of measuring the gain in R-F and I-F stages can be used as a stage-to-stage monitor of a defective receiver. Any signal which is present in the input of an amplifier but absent at its output is evidently encountering serious trouble in getting through the stage. In trouble-shooting a receiver, one of the initial problems is to identify the stage in which trouble has occurred. Once this stage is known, a detailed check of its circuits will soon yield the exact fault. This method is further developed, together with some helpful variations, in the lessons on trouble-shooting R-F and I-F stages.

Where desired, this gain-measuring procedure may use the output of an audio-modulated signal generator in place of a

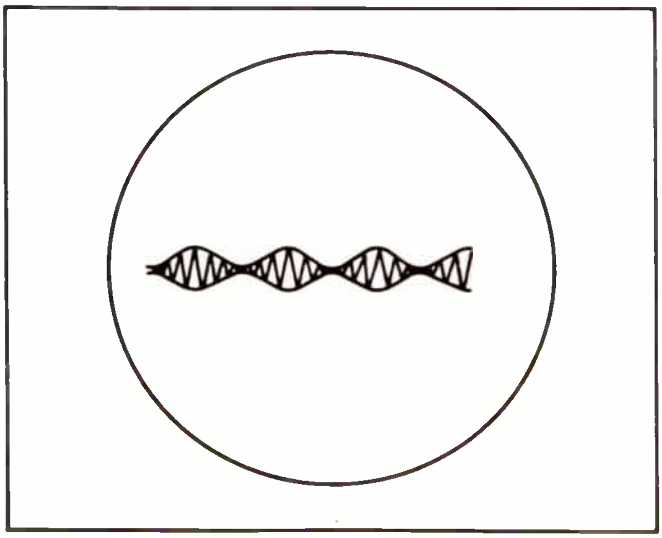

Fig. 23. I-F Input to Amplifier Stage Which Produced the Wave Form in Fig. 22.

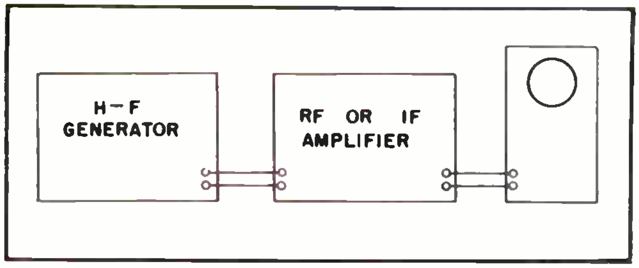

Fig. 24. Measuring Gain of I-F or R-F Stage.

strong signal from a nearby radio station. This variation of the procedure may be necessary in localities where no strong station signal is available, or when no strong station is on the air at the time. A block diagram of the connections involved in using a signal generator is shown in Fig. 24.

Using the signal generator instead of a radio station has another advantage. Since the audio modulation on a radio carrier wave is an ever-changing pattern, the *fixed* modulation of the signal generator provides a more stable screen image on the 'scope. This simplifies the synchronizing and locking operations for securing a satisfactory image.

Section 7. ALIGNING SUPERHET RECEIVER AND SETTING I-F BAND WIDTH

Alignment of the superhet receiver is the process of adjusting the I-F and R-F stages, in the order mentioned, to produce maximum gain at the correct frequencies. Setting the band width of the I-F stages is a part of the alignment procedure and insures the best tone response for both music and speech signals carried by these stages.

Using the oscilloscope, this alignment procedure is an offspring of the method used to measure the gain of high-frequency stages. Fig. 25 illustrates the hook-up required for the first phase of this procedure, aligning the I-F stages.

Set the 'scope controls as in the gain measurement procedure, as described in previous paragraphs. Short out the AVC circuit and place the signal generator output lead through a blocking capacitor (.05 mfd.) on the plate of the I-F amplifier stage. The signal generator is now set to produce the I-F frequency of the receiver, usually 456 k.c., modulated by a 400 cycle note. Now adjust the last I-F trimming condensers, mounted within the

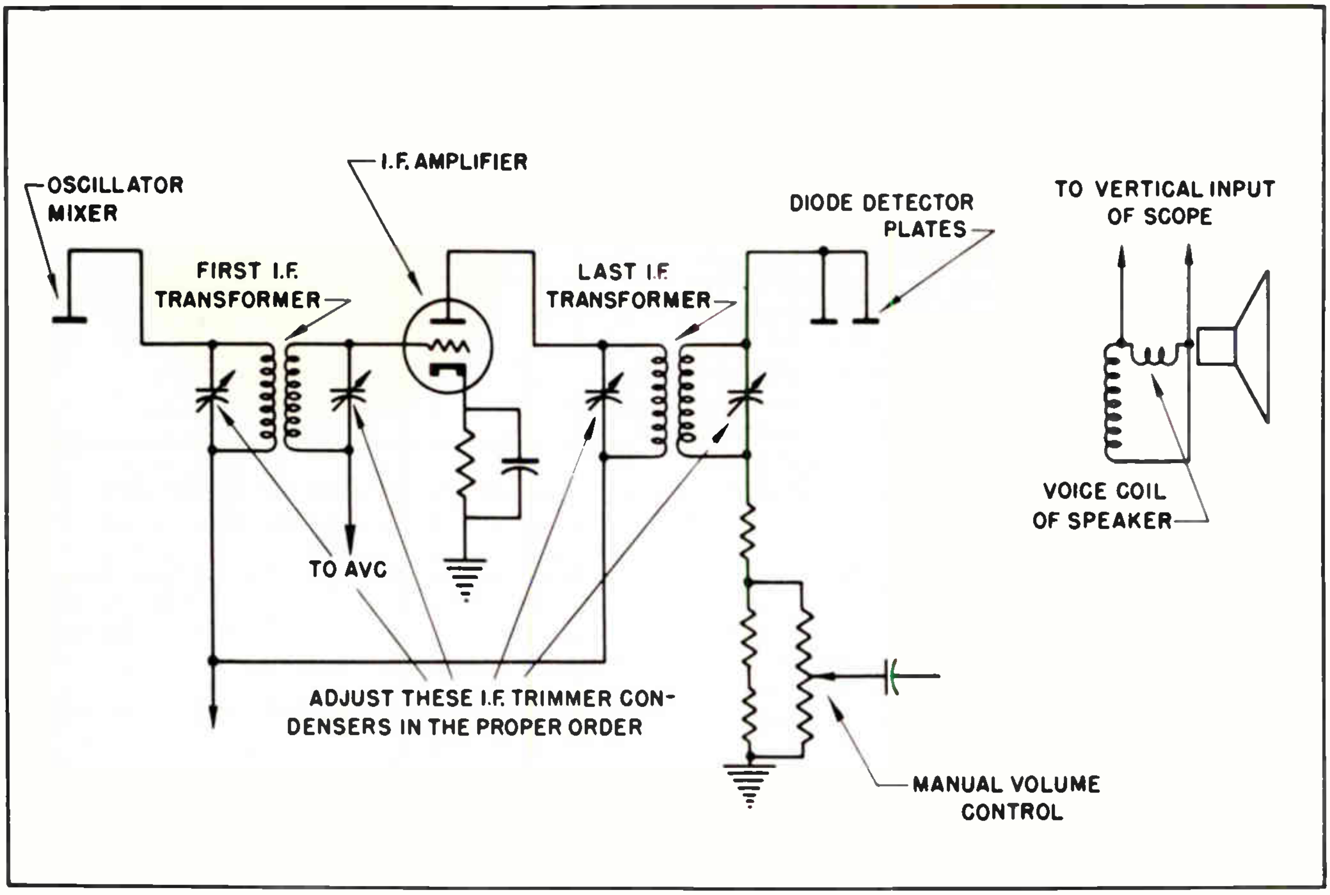

Fig.25. I-F Circuits Involved When Aligning a Superhet Receiver.

I-F transformer cans, to secure maximum height of the 'scope pattern. This accomplished, move the signal generator output lead to the plate of the oscillator-mixer stage and repeat the I-F trimmer adjustment on the *first* I-F transformer condensers, watching the 'scope screen for maximum height. If the audio system of the receiver is properly operating, the 400 cycle audio note can also be heard in the speaker, and its loudness will rise and fall with the height of its picture on the screen.

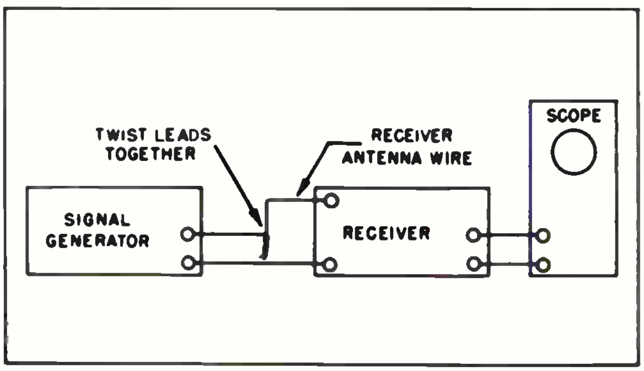

Fig.26. Twisting Lead from High Side of Signal Generator Output Around the Receiver Antenna Wire is a Good Method of Feeding Test Signal into the Receiver.

When the trimmers of both I-F transformers have been set to give maximum height of the 'scope image, we are ready to align the oscillator and the R-F circuits of the receiver. Fig. 26 shows how the signal generator output lead is connected to the antenna circuit of the receiver. We must now set the signal generator to a broadcast frequency, let us say 1000 k.c., and tune the receiver station selector to this same radio frequency.

Making certain that the signal generator and the tuning dial of the receiver are *both* set at the same frequency (1000 k.c. in our example) adjust the oscillator trimmer, usually mounted on the oscillator section of the variable ganged condenser, for maximum height of the 'scope image. This will coincide with maximum loudness of the 400 cycle note at the speaker. This procedure sets our oscillator at the proper frequency.

Next adjust the R-F trimming condenser, usually mounted on the R-F section of the variable ganged tuning condenser, for maximum height of the pattern on the 'scope. Repeat this step with *both* the signal generator and the receiver tuning dial set to 1500 k.c. This phase of the procedure corrects the R-F tuned circuit for best operation. Here again, maximum 'scope pattern height will coincide with the loudest 400 cycle tone at the speaker.

The R-F and I-F stages of the receiver are now aligned. We are ready to set the band width of the I-F stages to provide not only a sufficient gain for these circuits, but also a satisfactory degree of fidelity in amplifying the audio component of the modulated I-F signal. Because of the appearance on the 'scope screen of the desired pattern, (see Fig. 30) this procedure is called "flat-topping" the I-F signal wave form.

For the purpose of "flat-topping" we shall need a signal generator provided with a method of varying the frequency of the I-F

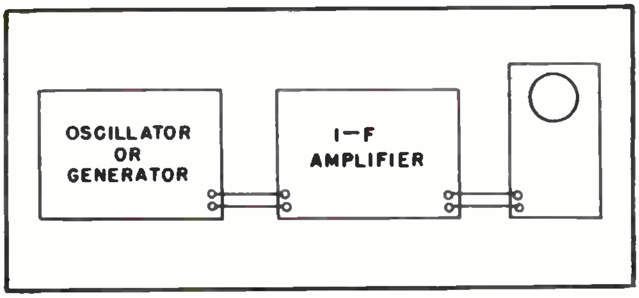

Fig. 27. Connections for Aligning I-F-

signal through the comparatively narrow range encircling the audio component. It is the uniformity of I-F gain through this range which determines the quality of the tone response as heard in the loud speaker. This required characteristic is provided in various types of signal generators by a "wobbulator". This device may be either mechanical or electrical. Its purpose is to change the *frequency* of the I-F signal at a uniform rate, usually about 60 times each second.

Connections between the signal generator, the receiver, and the 'scope are shown in Fig. 27. The signal generator is set to produce the I-F frequency of the receiver, say 456 k.c. Consult the instructions for any available signal generator for setting the wobbulator (or its frequency-changing equivalent) to a band width of 10,000 cycles. Connect the signal generator lead to the oscillator plate of the receiver through a .05 mfd condenser. On the 'scope, set

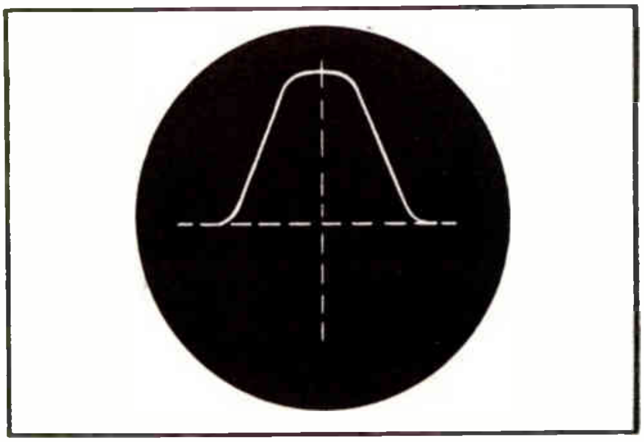

Fig. 28. Pattern of Correctly Aligned Receiver.

the Sweep Range to 60. The output from the last I-F stage can be taken between ground of the receiver and the "high" (ungrounded) end of the volume control.

What kind of a pattern will now appear on the 'scope?

If the signal generator is producing a frequency which varies through a range of 10,000 cycles each second, then this signal must go *up* 5,000 and *down* 5,000 cycles. If the midpoint of this swing is set at 456 k.c., it can be seen that the output will vary between 461 k.c. at maximum to 451 k.c. at minimum.

Keep in mind that we have already adjusted the I-F tuned circuits for maximum gain at 456 k.c. This means that both the 451 k.c. and the 461 k.c. signal will be somewhat discriminated against, and the gain for any frequency *other than* 456 k.c. will drop below maximum. The pattern on the screen will indicate this discrimination. In a receiver which is properly aligned but not flat-topped, the pattern will appear as in Fig. 28, with maximum gain at 456 k.c. In a receiver which is neither properly

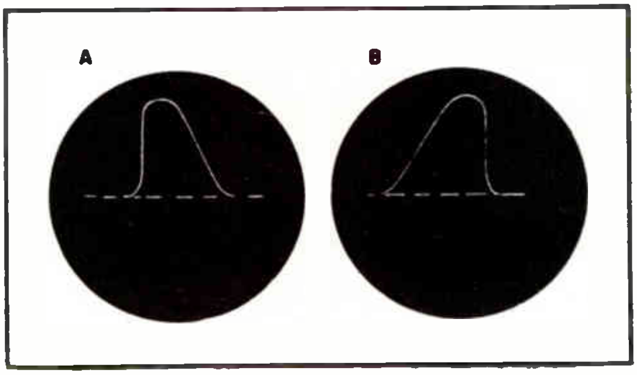

Fig. 29. Incorrectly Aligned.

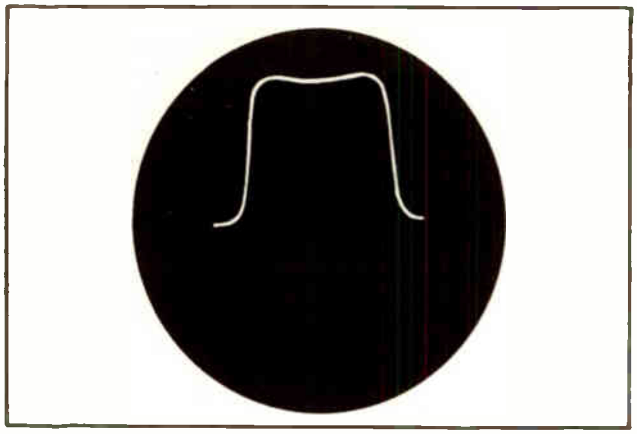

Fig.30. Pattern of Correctly Aligned High Fidelity I-F-

aligned nor flat-topped, the 'scope pattern will appear as in Fig. 29, with maximum gain taking place in *A* at 451 k.c. and in *B* at 461 k.c. Neither of these patterns are correct.

In a receiver which is both properly aligned and flat-topped, the pattern will appear as in Fig. 30, which shows a uniform response throughout the entire range between 451 and 461 k.c. This I-F amplifier system can be called a "high-fidelity" amplifier, for it displays no discrimination throughout the frequency range of an audio signal.

If the 'scope pattern appears as in Fig. 28, adjust the I-F trimmers in such a way as to "stagger" their resonant frequencies. This means to set the first trimmer somewhat *below* 456 k.c., the second trimmer an equal amount *above* 456 k.c., the third *below* 456 k.c., and the last trimmer *above* 456 k.c., watching the pattern on the 'scope for the degree of flat-topping desired. It is interesting to note that while the "staggering" procedure is a disturbance of the alignment, this disturbance is well worth the alignment sacrifice, for the benefit achieved in the tonal response of the receiver. The time spent on the alignment, however, has by no means been spent in vain. It has served to set the mid-point of the staggered tuned circuits, a fact which further improves the tone response.

If the pattern appears as in Fig. 29, an alignment is necessary before attempting the flat-topping. This procedure has been described in previous paragraphs of this lesson.

Section 8. MEASURING HIGH VOLTAGES

PRECAUTION: Make all connections with the source of high voltage turned OFF!

In measuring high voltages with the oscilloscope, the principle of calibrating the 'scope screen is basic. This principle, as well as the circuit connections involved, were described in earlier paragraphs and illustrated in Fig. 14. Measuring high voltages, either A-C or D-C, is possible without damage to the 'scope because we are not going to apply these high voltages directly to any part of the 'scope. Instead, we will sub-divide the D-C voltages, and either step down or sub-divide the A-C voltages for the purpose of measuring their amplitudes on the 'scope.

After calibrating the 'scope as a voltmeter, according to previous instructions in this lesson, we can proceed with measuring a high D-C voltage as follows:

Connect a voltage divider across the high D-C voltage to be measured -- suppose the voltage is 2,000 volts D-C -- in such a way as to tap off 1/20 of the total. This would give us 1/20 of 2,000, or 100 volts. See Fig. 31 for the values of resistances required, and for the method of connection. It is important that we know in advance the ratio of resistances in the voltage divider, for it is this ratio which enables us to convert the 'scope deflection back to the true value of the unknown voltage.

If our 'scope has been calibrated so that 11.5 vertical marker divisions represent

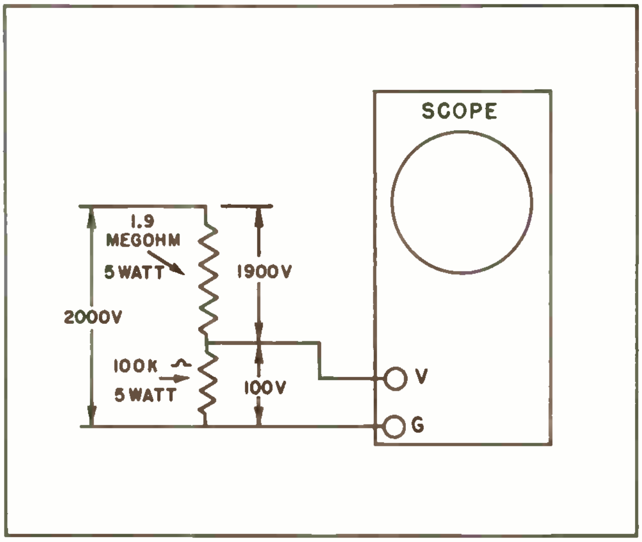

Fig.31. Measuring High Voltage D-C by Use of Voltage Divider.

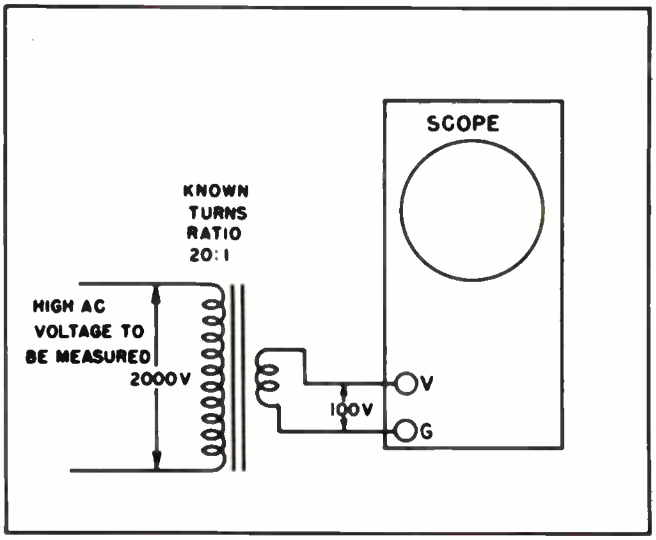

Fig.32. Measuring High Voltage A-C by Use of Transformer.

115 volts, then we possess the basic calibration of 10 volts per single vertical marker. We know that the ratio of resistances in the voltage divider circuit is 19:1, and that the lower resistor taps off 1/20 of the total voltage. If deflection to the extent of 10 vertical markers takes place, we know that the voltage applied to the vertical amplifier is 100 volts. Multiplying this value by the ratio of the sum of the two resistors to the lower one, we have 20 x 100 or 2000 volts as the total of our unknown voltage.

This method can also be applied to A-C voltages of high values, with the same method of calibration as in the case of D-C. (You will recall we originally calibrated the 'scope with the known 115 volt A-C from the power line.)

Another method of measuring high A-C voltages involves the use of a step-down transformer whose turns ratio is known. Connections and details for this procedure are given in Fig. 32.

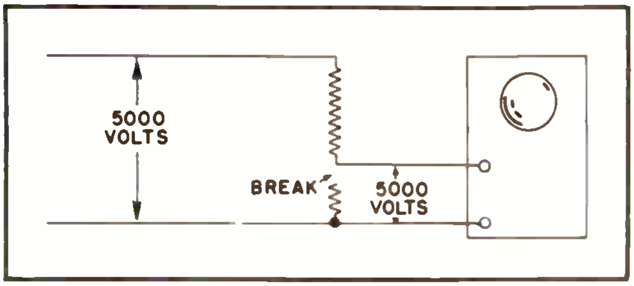

Fig.33. Broken, or Poor, Connection Will Place Full Voltage on 'Scope.

Fig. 33 illustrates an important precaution to be heeded in measuring high voltages with a voltage divider. Be sure to make good connections in this high voltage divider and use a good wire wound resistor to tap off the lower voltage. If the lower resistor burns out or opens up, or if the connections become loose, the entire voltage would be applied to the 'scope. This can cause serious damage to the equipment and can endanger you as well.

While such high voltages are seldom found in radio receivers, such as must be handled by the methods used, television receivers invariably contain voltages up to at least 2000 volts, and frequently much higher. Their measurement and handling must be done with extreme care.

Nevertheless, you should be warned at this time that even in radio receivers voltages as high as 750 volts are quite common and here, too, precautionary steps should be taken to protect technician and equipment from harm. Be careful!

Section 9. **OTHER RADIO RECEIVER TESTS**

The variety of radio receiver tests possible with the use of an oscilloscope is limited only by the ingenuity of the technician. Special radio trouble-shooting problems require special tests, and the technician who uses the 'scope with ease will find it an extremely helpful part of his equipment.

While by no means a complete list, the following tests are given as a guide by which you may develop your own methods for special cases as they arise.

We can test a whole radio receiver by connecting the modulated signal generator to the antenna and ground terminals and the 'scope to the receiver output, as illustrated in Fig. 34. The pattern on the screen

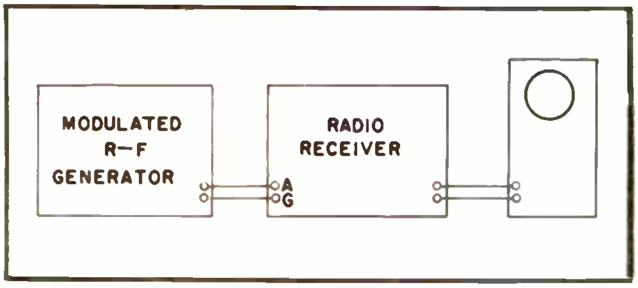

Fig.34. Testing a Complete Receiver.

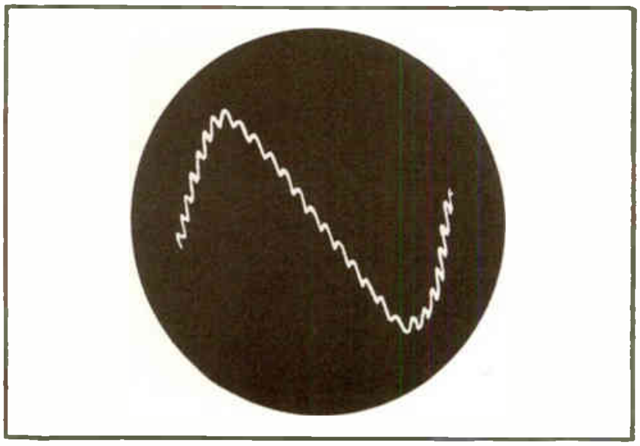

Fig.35. This Pattern Indicates Presence of Undesirable Hum Voltage in an Amplifier.

should be a sine wave. If any section of the receiver is not operating there will be only the horizontal line on the screen, that

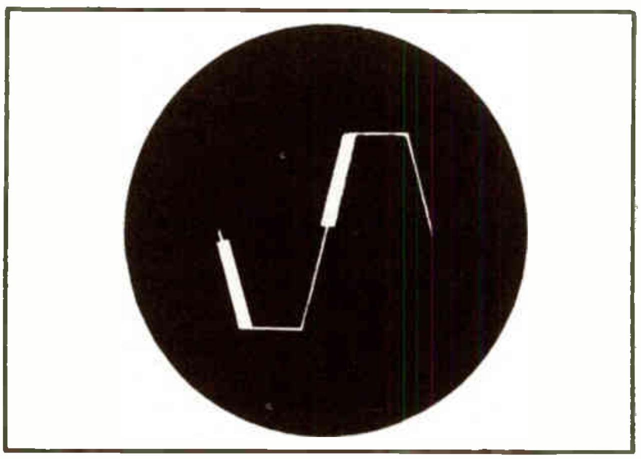

Fig.36. Pattern of Non-Synchronous Vibrator.

is, the sweep line. If we disconnect the signal generator and advance the receiver

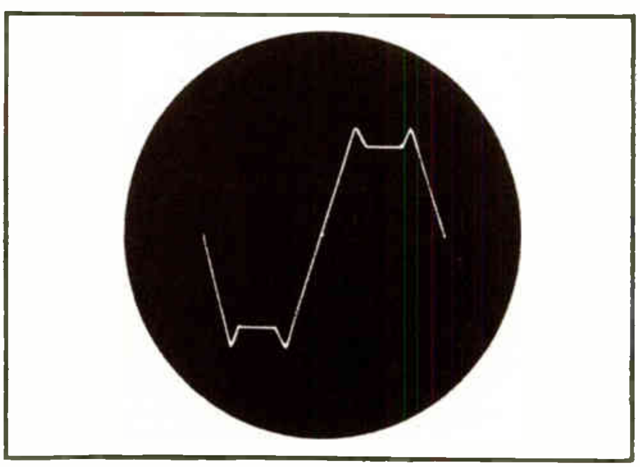

Fig.37. Pattern of Synchronous Vibrator.

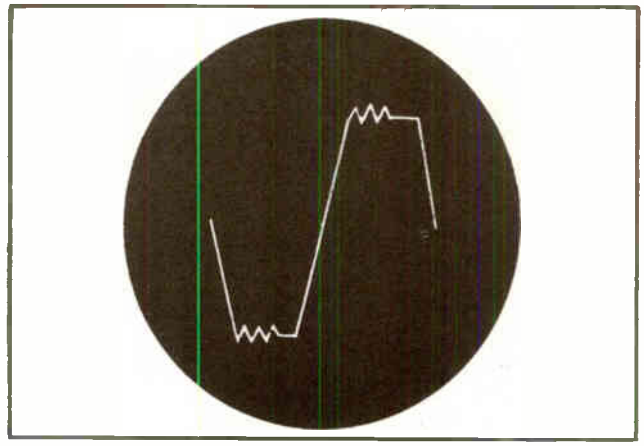

Fig.38. Pattern of Bouncing Contacts.

volume control, we should see only the horizontal deflection representing the sweep voltage. If a sine wave appears at this time, the presence of an undesired hum voltage is indicated. This, of course, can be verified by the *sound* of the hum interfering with the normal signal in the speaker. In a radio receiver, such hum voltages are due to deteriorated filter condensers or defective output tubes, to mention only two possibilities.

In an audio amplifier, or P.A. system, the presence of hums are mostly due to open or ungrounded shielding on microphone cables. These should be tested for such defects. By connecting the high side of the Vertical binding posts of the 'scope to any suspected point, the 'scope screen will indicate the presence of a hum voltage if it exists at that point. This would appear as in Fig. 35.

Automobile radio receivers, in addition to several models of farm and portable receivers,

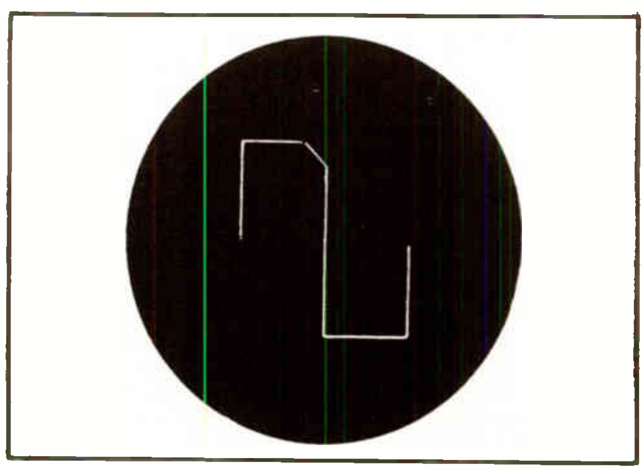

Fig.39. Vibrator Capacitor Too Large.

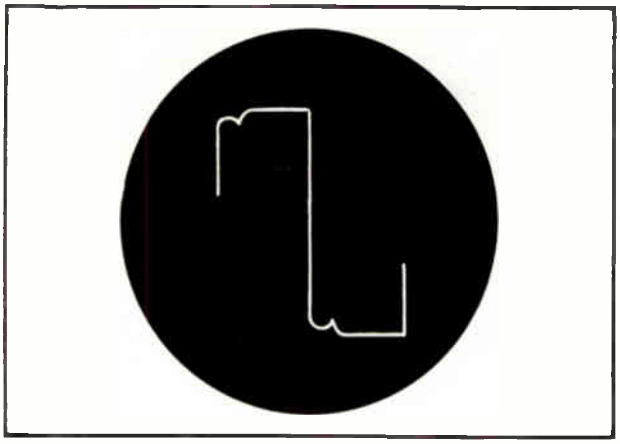

Fig. 40. Vibrator Capacitor Too Small.

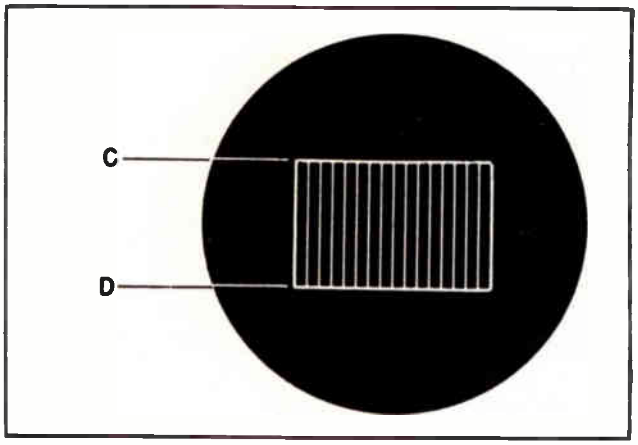

Fig. 41. Unmodulated High Frequency A-C.

are usually powered by a transformer-vibrator system to develop their necessary plate supply voltage. The vibrator used is an electro-mechanical device, and as such is subject to certain mechanical faults. These vibrators may be tested by connecting leads from the primary of the vibrator transformer of the receiver to the vertical input terminals of the 'scope. The pattern visible on the 'scope screen should appear as in Fig. 36 for a vibrator of the non-synchronous type. For a synchronous type, the pattern should appear as in Fig. 37. Synchronous vibrators are identified by the presence of five or more base prongs, while the non-synchronous type contains only four base prongs. The synchronous type will be found only in those receivers which do *not* contain a power rectifier tube. If the receiver contains a power rectifier tube, then it will also contain a non-synchronous vibrator.

A pattern such as that in Fig. 38 shows that the vibrator contacts are bouncing. The receiver, in this case, will operate with sub-normal volume, or it may not operate at all. The patterns illustrated in Figs. 39 and 40 show the effect of too large and too small a capacitor across the secondary of the vibrator transformer. This circuit

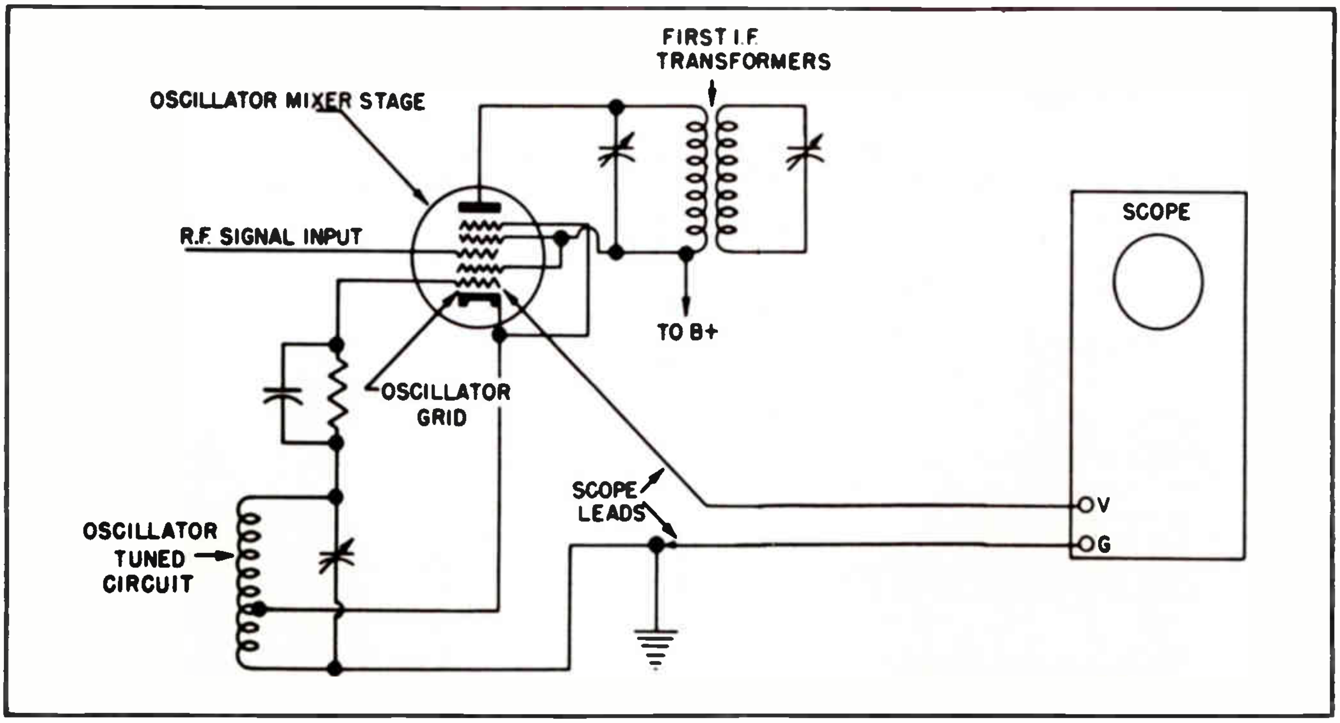

Fig. 42. Method of Connecting 'Scope to Determine if Oscillation is taking Place in Oscillator-Mixer Circuit.

should be resonant at vibrator frequency and it is kept so by the exact choice of the shunt condenser.

Determining whether a radio receiver oscillator is operating is an easy matter with the oscilloscope. If the Sweep Range and Sweep Vernier are both set at maximum, and the oscillator grid is connected to the upper of the two vertical input posts of the 'scope, an unmodulated R-F voltage will appear on the 'scope screen if the oscillator is operating. The screen pattern will appear as in Fig. 41. Connections for this test are shown in Fig. 42.

In addition to the applications of the oscilloscope to the problems of the radio repairman, as described in this lesson, the oscilloscope has many other accomplishments. The engineer at the transmitting station uses the 'scope to check the percentage of modulation of his broadcast signal. The design engineer uses the 'scope to provide him with necessary information about the properties of vacuum tubes. The electrical engineer uses the 'scope to determine the presence of transient voltages in his power lines. The mechanical engineer tracks down the source of unwanted vibration in his equipment.

The wide variety of uses to which the oscilloscope can be put makes it an ideal unit of test equipment for the radio and television repairman.

NOTES FOR REFERENCE

PRECAUTION: Use extreme care with the voltages which an oscilloscope is capable of handling. These voltages are dangerous.

Keep the spot on the 'scope screen either dim or in motion to prevent "burning" a blind spot on the screen.

Do not leave the 'scope while warming up. Stay with it until the trace appears.

Get acquainted with the operation of the 'scope before attempting any procedure. Make sure you know the purpose of all its controls.

The 'scope is designed to give the radio and television repairman precise information about the circuits with which he works. Do not use the 'scope on tests which may be accomplished more easily with other equipment.

The 'scope will not load a circuit appreciably. It, therefore, finds its chief use where loading by any other type of equipment will alter the information sought.

NOTES

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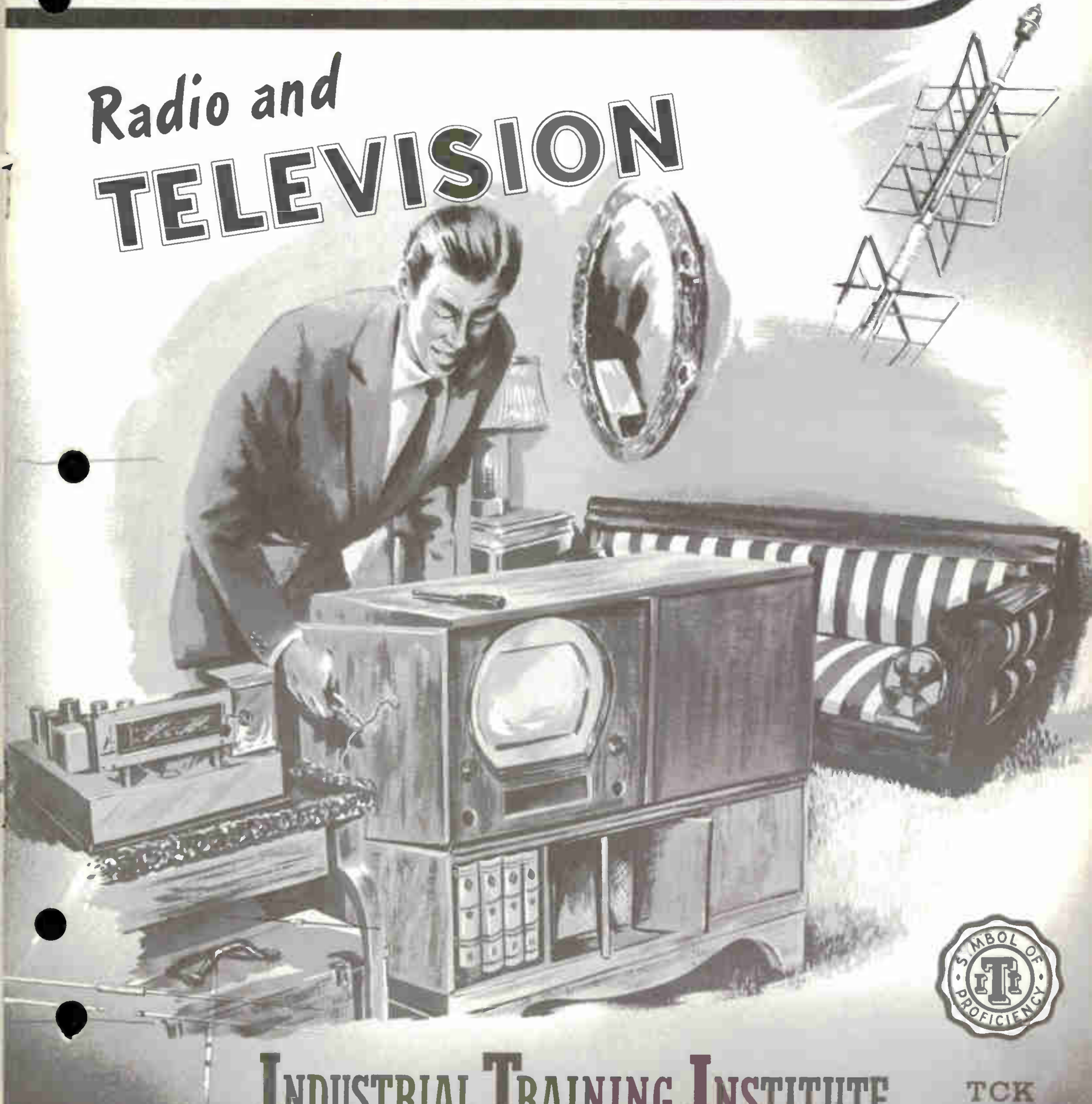

INDUSTRIAL TRAINING INSTITUTE

TCK 45

TECHNICAL TRAINING
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REVISED 1956

RADIO TELEVISION

AUTOMOBILE RECEIVERS

Contents: Introduction - Comparison with Other Receivers - The Test Bench for Automobile Receivers - The Vibrator Power Supply - Test-Bench Analysis - Checking the Non-Synchronous Vibrator Power Supply - Tests for Locating Other Power Supply Troubles - Rectifier Tube Troubles - Recognizing Vibrator Troubles - The Synchronous Vibrator - Checking the Synchronous Vibrator - The Synchronous Vibrator on the Test Bench - Power Supply Troubles Common to Vibrator Systems - The Dynamotor Power Supply - Automobile Static - Ignition Static - Generator Brush Static - Miscellaneous Static in the 6-Volt Lines - Wheel and Tire Static - The Car Antenna Static - Inductance Tuning - 12 Volt Electrical Systems - Using 6 Volt Radios on New 12 Volt Electrical Systems.

Section 1. INTRODUCTION

Any man who intends making Radio and Television his life's work should be familiar with all phases of the business. Some men who intend to specialize solely in the installation and servicing of television receivers are inclined to the attitude that they need know nothing about ordinary broadcast receivers. Nothing could be farther from the truth.

Virtually every man who specializes in the television end of the business must also devote much time to the service and repair of radio receivers. Despite the enormous growth of television in recent years, there is no denying that a major source of income for most television men is the money they make from the radio end of their business.

Even if he wanted to, there is little a television man can do to avoid having to work on radio receivers. Almost every home that has a television receiver also has one or more radio receivers. Often the best way of obtaining the customer's television business is through the servicing of his radio receivers. Should a television man attempt to avoid working on radio receivers by simply refusing them, it is likely that he will soon find he has neither radios nor television to work on. If he tells the customer he does not work on radios, only on television receivers, the customer is certain to take the radio somewhere else -- he is not going to allow it to remain inoperative merely because one serviceman refuses to repair it. Since he does have to take the radio somewhere else, there is a strong possibility that when he needs television service he is going to take it to the man who was willing to fix his radio.

On the other hand, should a television serviceman decline to fix a radio on the ground he does not know enough about it, he will merely be creating a clouding doubt

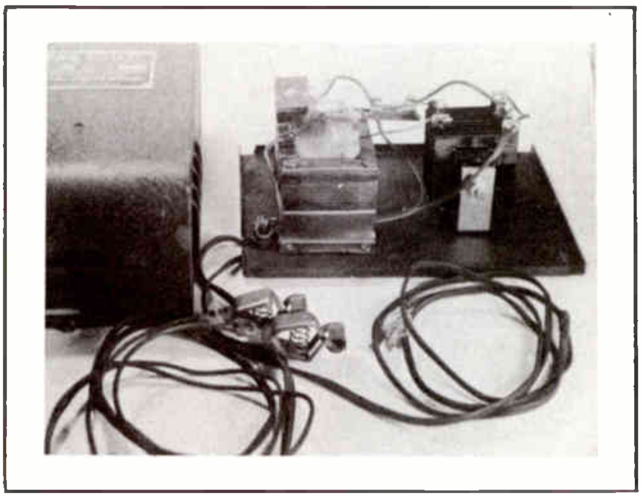

Fig.1. A Trickle Charger for Keeping a Test Battery in a Charged Condition.

in the customer's mind. It is only natural for the customer to wonder how the serviceman could be qualified to service a complicated television receiver if he feels himself incompetent to service a much less complicated radio receiver.

In previous lessons we have covered the many circuits which are found in both radio receivers and in television receivers. We have devoted much time to the study and discussion of both TRF and superheterodyne receivers. We have covered specialized jobs such as the portable and the ever-popular AC-DC receiver. We have covered these types of receivers in great detail, and perhaps spent more time on them than you thought absolutely necessary. Just the same you will realize the importance of the large amount of time spent studying them when you open your own shop or go to work in the shop of someone else. If your experience is like that of the average serviceman you will sepnd about half your working hours servicing those types of receivers.

With this lesson we take up the discussion of another type of receiver which takes up much of the time of most servicemen. This is the automobile radio receiver. The importance of understanding automobile receivers lies in the fact there are so many of them. When it is realized there are more than thirty million passenger automobiles on the road today, and that more than ninety percent of them are equipped with radio receivers, the opportunities which lie in this one field alone can be understood. Then when you add the seven to ten million trucks which are now radio equipped, the breadth of the field becomes even greater. Only a few years ago relatively few trucks were equipped with radio. Today, nearly all the over-the-road trucks are equipped with radio broadcast receivers, and many of the lighter trucks are so equipped. All of which makes the subject of automobile receivers an important one for any person entering the radio and television field.

Section 2. COMPARISON WITH OTHER RECEIVERS

We may begin our study of the automobile receiver by comparing it to those with which we are already familiar. From the point of view of its power source, receivers may be classified in the following manner:

Those that operate from a purely A-C source, the 60-cycle, 115-volt domestic and industrial power line. These are designated A-C receivers, and derive their B-plus voltage through a full-wave rectifier system using a step-up transformer.

Those that operate from either a 115-volt A-C or a 115-volt D-C source so they are adaptable in the locality using A-C power as well as in a locality using D-C power. These are known as "universal" or "transformerless" receivers, and here B-plus voltage is developed through a half-wave rectifier system. (In occasional cases, B-plus voltage is developed from the A-C line through a voltage-doubler, which operates on A-C only. While these examples are "transformerless", they are not "universal", for they do not operate on D-C.)

Those that operate from either A-C or D-C commercial power source of 115-volts, or from a set of batteries contained within the portable cabinet. These are designated *3-way portables*, and develop their B-plus voltages from a half-wave rectifier when plugged into the power line, or from the "B" battery carried in the cabinet.

Those that use batteries only. Here B-plus voltage is taken from the battery only, and there is no provision for plugging into a commercial power source.

Those that operate from a 6-volt battery source, such as are found in automobiles, trucks, and other self-propelled vehicles. These are called *automobile*, or *mobile* receivers. In this type the B-plus voltage is developed through a vibrator-transformer full-wave-rectifier system in most cases; less frequently, B-plus power is taken from a motor-generator (dynamotor) system in which rectification is unnecessary. It is the automobile receiver with which we are concerned in this lesson.

In addition to power differences between the automobile receiver and other types, there are numerous other considerations which deserve mention.

In the A-C or AC-DC receiver, which have a "permanent" location in the home, office or factory, a comparatively long antenna may be connected where necessary. Such an antenna would be necessary where the receiver is far removed from powerful broadcasting stations ordinarily found in the great cities. On the average, if a receiver is located permanently at a distance in excess of two hundred miles from a large city, it will need a substantial outdoor antenna to bring stations in from the city. The range of a 50,000 watt transmitter for a "home" type receiver using a loop antenna is around two hundred miles. Hence, if a receiver located beyond this distance is to receive stations over a wide area, it should be equipped with an outdoor antenna for greater signal strength.

Many models of the portable receiver are likewise provided with means for connecting up an outside antenna for long-range reception. The automobile receiver, however, due to its necessarily limited antenna size, must make up in signal gain what it loses through limited antenna size. A car which finds itself several hundred miles from the nearest transmitter will, in order to receive the signal at this distance, have to build up the signal considerably in its amplifier stages. This means, of course, that either the automobile receiver must contain more amplifiers, or must provide greater gain for each stage.

While in the city, or within normal range of strong stations, this same car receiver will bring in the stations of the locality with great strength, even with its small antenna. But since the automobile receiver is *mobile*, it should provide satisfactory reception of signals at almost any given place in the country. The experience of millions of automobile receiver owners has been that this ideal performance is almost fully realized. The extremely high gain of the amplifier stages of a modern car receiver makes it possible for a motorist to make a cross-country trip and never be outside the range of at least one strong radio transmitter. This excellent sensitivity is no accident in the car receiver -- it is built right into the circuits with high gain as a prime objective.

The automobile receiver, installed as it is in a vehicle which is literally cracking with static from spark-generated sources, must also provide additional protection from static interference. This problem alone is a major one in automobile or other mobile receivers. Except in cases of hotels, factories, office-buildings, and rooming houses, the "home" type of receiver is not bothered by man-made static. Static is the automobile receiver's greatest enemy, and must be dealt with by special suppressing techniques. These will be explained.

Section 3. THE TEST BENCH FOR AUTOMOBILE RECEIVERS

Because of the nature of their installation, automobile receivers can seldom be repaired in the car, but must almost always be removed and analyzed on the test-bench. Exceptions to this rule are when the tubes and vibrator are accessible through a

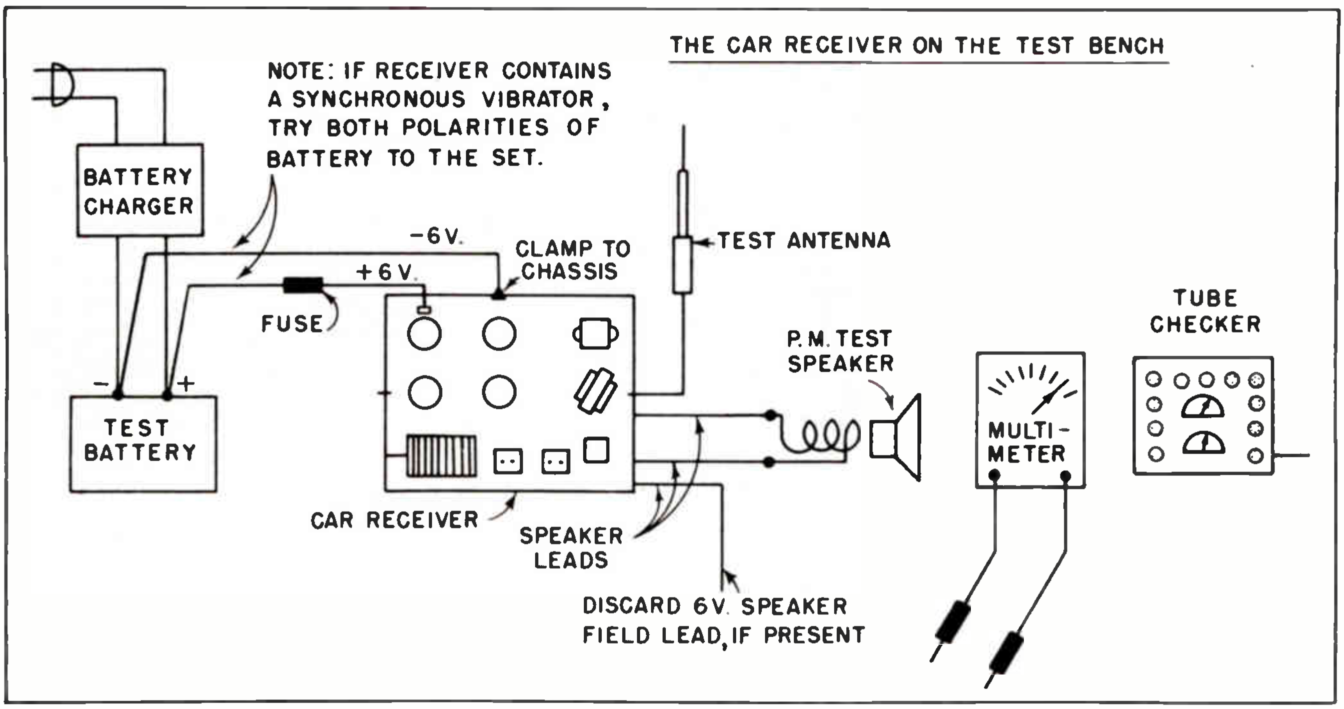

Fig. 2. Bench Set-Up for Testing an Automobile Receiver.

removable case cover, or when the trouble lies in the antenna. Even granting the fact that many car receiver troubles lie in tubes and vibrators, it is the exception rather than the rule that these components are removable without taking the receiver from the car.

Removing the receiver from the car deprives the set of its normal power source, which is the car battery. The test-bench for this type of receiver, therefore, must include a 6-volt battery capable of heavy current drain over prolonged periods of time. Since the battery drain is high with a receiver connected to it, the test-bench must also provide a means for recharging the test battery. This is done by a battery-charger of the standard type, usually by one termed a "trickle charger". (See Fig. 1.)

Another consideration also enters into the matter of the test-bench for automobile receivers. In many models, the speaker is not included within the receiver case, but is located behind the dash-board of the car or at some other convenient spot. While it is possible to remove most of these extended speakers without too much difficulty, the technician will often expedite his work by mounting a low-impedance test speaker at his bench. Thus the speaker of a receiver need not be removed from the car, if it is mounted separately.

Fig. 2 illustrates the special test set-up for automobile receivers, and will enable the technician to devote his attention directly to trouble-shooting the receiver,

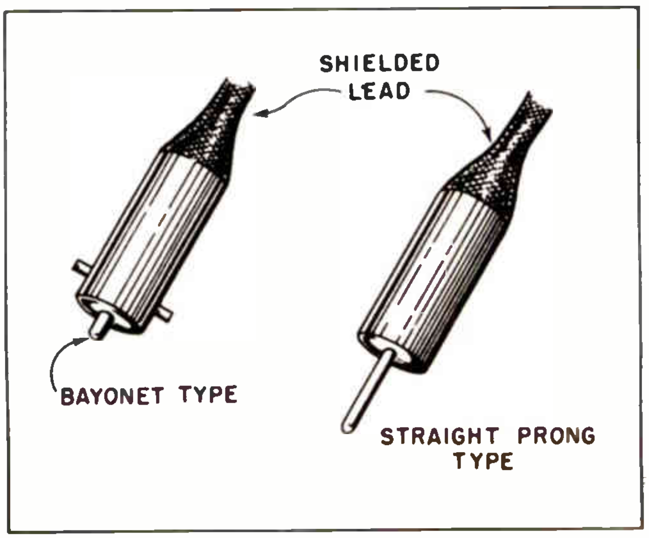

Fig.3. Two Types of Automobile Antenna Plugs.

rather than to many auxiliary details involved in making a special set-up for each car receiver before trouble-shooting can begin.

In order to duplicate most accurately the conditions prevailing in the car receiver installation, the test bench should include: a 6-volt battery, a 6-volt trickle charger, a low impedance loud-speaker, and a short antenna equipped with both types of antenna plugs. These antenna plugs are shown in Fig. 3.

Section 4. **THE VIBRATOR POWER SUPPLY**

A typical automobile receiver power supply, using a non-synchronous vibrator, is shown in Fig. 4. This is by far the most common type, and due attention will be devoted to its analysis. The prime power source, of course, is a 6-volt battery. The power switch is generally connected in series with a fuse to the "hot" side of the ignition switch in the car. Operating directly from the battery are:

(1) The tube heaters and pilot lamp.

(2) The speaker field, unless a PM speaker is used.

(3) The push-button station selector relay, if present.

(4) The vibrator, which "chops-up" the 6-volt D-C.

(5) The power transformer, which originates the B-voltage.

The initial inspection of the defective car receiver may include the checking of the 6-volt supply line operation by noticing if the above listed components are being fed with the required power. Keep in mind that we are merely checking the receiver before it has been removed from the car. This means that we cannot see if the tubes light, we cannot tell if B-plus is present in the receiver, and cannot yet tell if the speaker field is being energized.

However, there still remain several important facts which we may definitely ascertain. These are: we can see if the pilot lamp lights, we can hear the vibrator "buzz", we can test for operation of the push-button station-selector relay. Besides, we can examine the supply fuse, and can usually read the current drain on the car

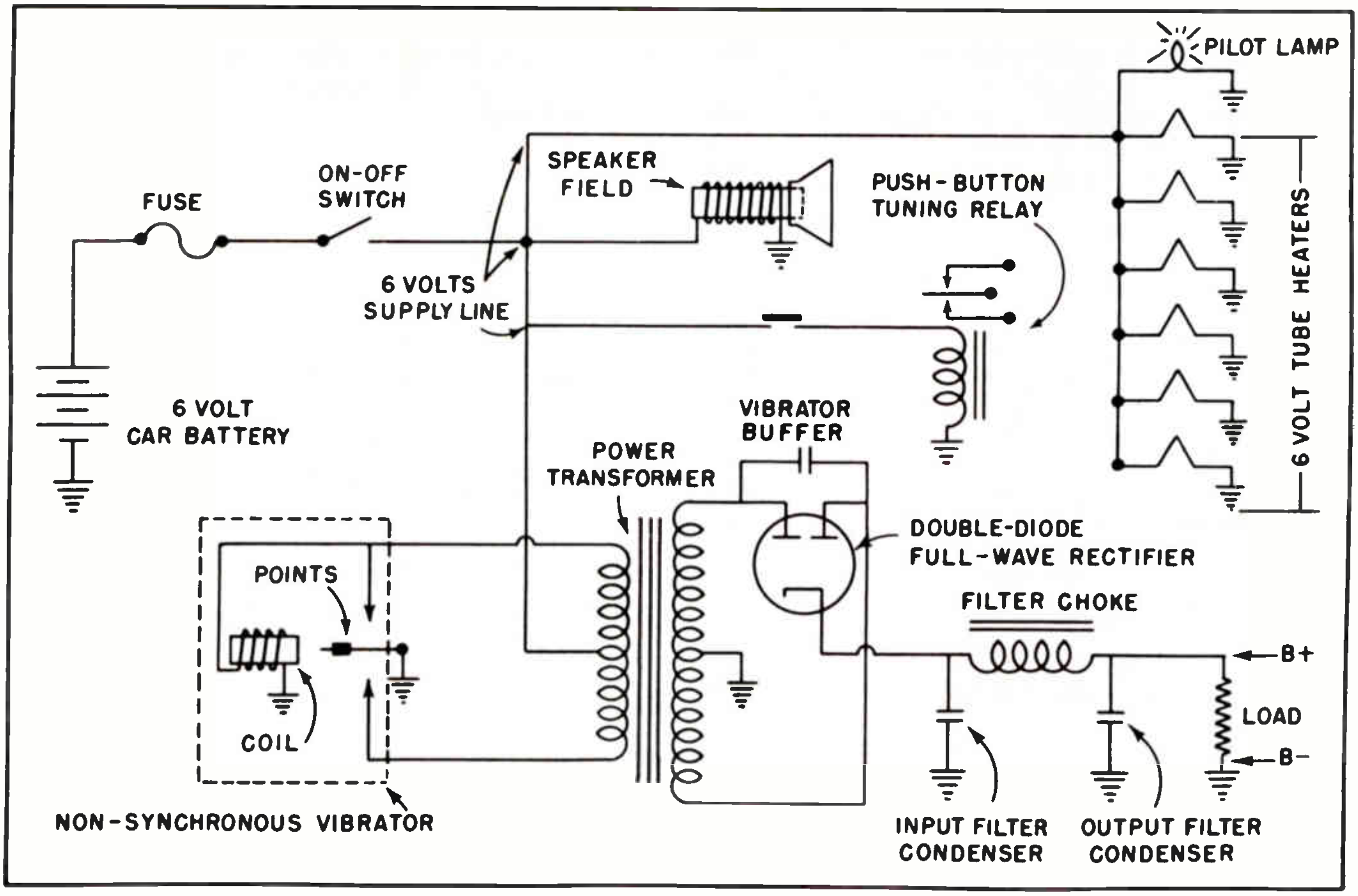

Fig. 4. The Principal Components of the Non-Synchronous Vibrator Power Supply.

ammeter. Note that these things can be determined without removing the receiver from the car.

Let us now study the results of our initial inspection to determine first, the general nature of the trouble; and second, whether the receiver must be taken from the car in order to repair the trouble.

If the ammeter in the car reads *zero* when the receiver is turned on, examine the fuse. It will probably be found burned out or (in rare cases, defective.) This means that none of the components using the 6-volt power directly will be energized. The pilot lamp and tube heaters will not light, the vibrator will not buzz, and the push-button relay, if there is one, will not operate.

If the fuse tests open with an ohmmeter, but does not look burned-out, replace it with another fuse and try the receiver again, Some fuses open up within the cartridge without being overloaded. While these are the exception rather than the rule, it is a good idea to verify this point first. If the receiver plays when the fuse is replaced, then the old fuse may be assumed defective and there is probably no other trouble in the set.

Most likely, however, the fuse will be blown when the car ammeter reads zero with receiver power turned on. In this case, it is obvious that a short-circuit within the set is blowing the fuse, and the technician can then decide that the receiver must be removed from the car and the trouble further investigated. Checking for shorts in the 6-volt line within the receiver will be treated in later paragraphs.

If the car ammeter reads a small amount of current, about two amperes, the pilot lamp lights, but the vibrator does not buzz, then vibrator trouble should be suspected. The ammeter will then read the current which flows through every 6-volt component except the vibrator. The lighted pilot lamp indicates that heater voltage is present, the station selector relay (if it is present) will operate. Since we do not ordinarily assume more than one trouble in a receiver at one time, we can justifiably assume the speaker field must be operating. A wise

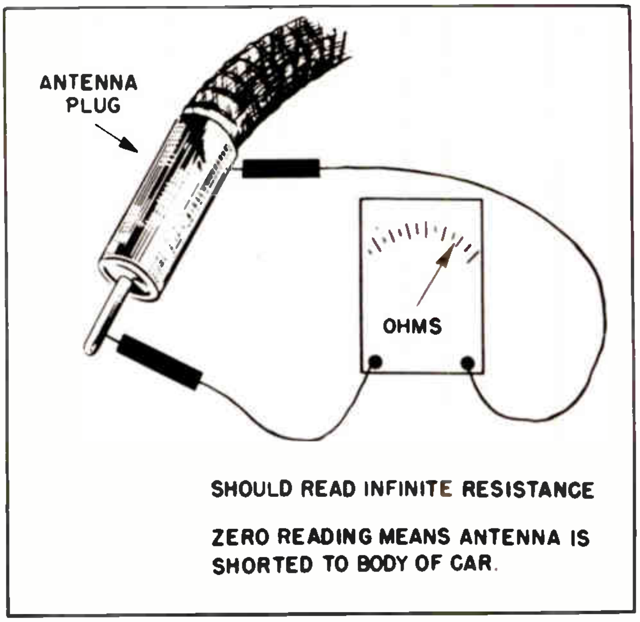

Fig.5. Testing for a Short-Circuit Between the Antenna and Chassis of the Automobile.

step is to replace the vibrator with a new exact duplicate, if this can be done without removing the receiver from the car, and test the correction by operating the receiver.

If the vibrator cannot be replaced easily without removing the set from the car, then it will have to be removed. Now, since the set is removed from the car and the case cover is open, it is a good idea to check the tubes at the same time. However, if the vibrator can be replaced while the receiver is in the car, and the new vibrator succeeds in eliminating the trouble, the tubes may be assumed good and no further time nor effort need usually be taken to check them.

If the ammeter current drain is normal (about 5 to 10 amperes), the pilot lamp lights, and the vibrator buzzes, test the antenna before removing the receiver from the car. This can be easily done by two rather simple steps. The first is to test it for shorts to ground (the car chassis or body), and the second for opens in the antenna line. Proceed as follows:

To test for a shorted antenna. Pull out the plug which connects the antenna to the receiver and place an ohmmeter between the center prong and the outside (grounded) shielding. (See Fig. 5.) If the ohmmeter reads zero on its lowest scale, the antenna is shorted to ground. Resistance should be infinite for this test, to indicate no shorts between the antenna and ground. To locate the exact fault, dis-assemble the antenna supports and look for loose or faulty connections.

To test for an open antenna lead. Place the ohmmeter leads, as shown in Fig. 6, between the top of the antenna itself and the center prong of the plug which couples the antenna cable to the receiver. If the line is continuous, the meter will read zero resistance. If open, the resistance will be infinite. To locate the exact fault, it will be necessary to dis-assemble the antenna mountings and check the cable by itself, and then the antenna by itself, to determine which of them contains the break.

If the antenna proves to be in operating condition, having neither a short nor an open, you should remove the receiver for further analysis on the bench.

We may conclude from the foregoing preliminary inspection of the automobile receiver, while it is still in the car, that the receiver should be removed from the car when the trouble does *not* lie in the antenna, nor in an easily-removed vibrator. With rare exception, this rule will hold good. A few of the exceptions will be mentioned later.

Section 5. TEST-BENCH ANALYSIS

After the receiver has been removed from the car, the receiver may be placed on the

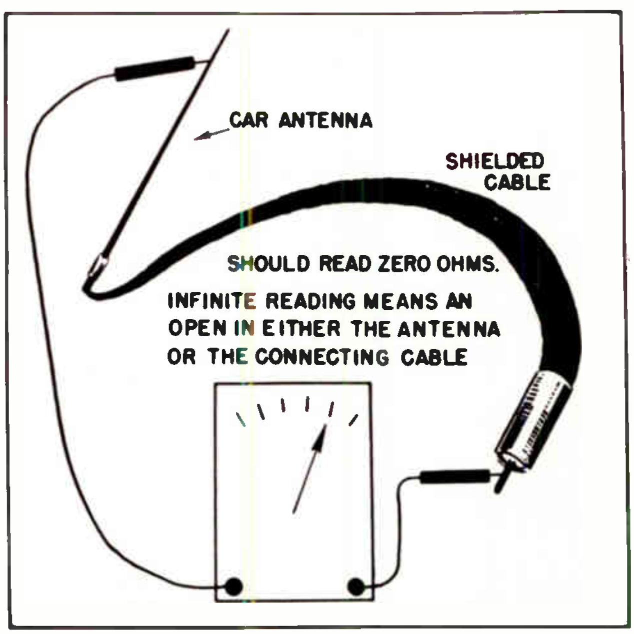

Fig.6. Testing for an Open Antenna Circuit.

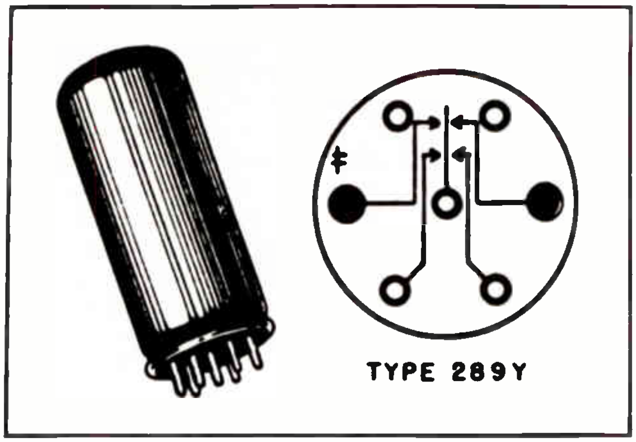

Fig. 7. Schematic Diagram of the Synchronous Vibrator.

bench and test equipment connected as shown in Fig. 2. However, before applying power to the receiver, the standard (and very important) first step is to check all of the tubes carefully on the tube-checker for emission, shorts, and leakage. Replace those which are found defective. In the tube-checking procedure, the technician will have the opportunity to notice the type of rectifier tube used.

Suppose there is no rectifier tube in a given receiver? What does this mean? The lack of a rectifier tube in an automobile receiver indicates a most significant fact about that receiver. In automobile receivers without rectifier tubes, the vibrator is of the synchronous type.

In the synchronous type of vibrator, Fig. 7, rectification takes place within the vibrator itself, being effected by an extra set of breaker points. In the non-synchronous type such rectification does not take place and must be provided for by the rectifier tube, usually an 0Z4, a 6X5, or a 7Y4.

Testing the power supply with synchronous and non-synchronous vibrators require somewhat different techniques, and will be presently discussed. However, as far as the test bench is concerned, the nature of the vibrator (whether it is synchronous or non-synchronous) is an important consideration. For if the set is equipped with a synchronous vibrator and the power leads from the storage battery happen to be of the wrong polarity, the receiver will not operate under any condition. In view of this, then, the vibrator should be recognized as either synchronous or non-synchronous, and the proper battery connections made.

Looking at the vibrator itself for this information, the following points of identity can be established:

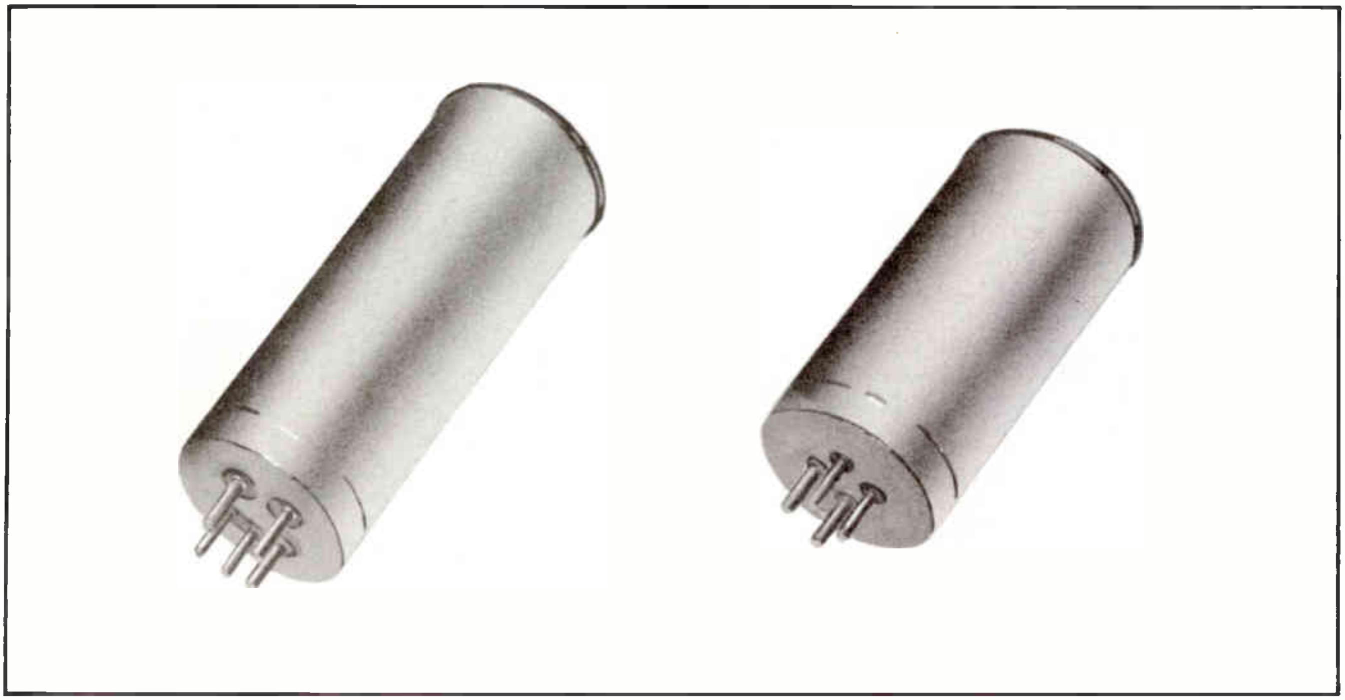

Fig. 8. The Synchronous Vibrator has Five or More Base Prongs, while the Non-synchronous Type has Only Four.

The *non-synchronous* vibrator has only four base prongs, and the receiver which contains it will also have a power rectifier tube.

The *synchronous* vibrator contains five or more base prongs, is often larger than the non-synchronous type, and the receiver that contains it is *not* equipped with a power rectifier tube. The size comparison and the prongs are shown in Fig. 8.

In the receiver containing the synchronous type of vibrator, it is to be noted that the tubes will light, and the vibrator will buzz, even if the battery polarity is wrong. However, there will be no B-plus voltage of any kind at any place in the receiver. Any signals, of course, will therefore be completely absent.

Section 6. CHECKING THE NON-SYNCHRONOUS VIBRATOR POWER SUPPLY

Test bench analysis of the automobile receiver power supply using the non-synchronous vibrator (the most common type), may begin as soon as the tubes have been checked. Only two important voltages need first be sought -- namely, the 6-volt D-C at the power switch, and the B-plus voltage at the output filter condenser. Fig. 9 shows the fundamental components comprising this power supply, and the voltages to be expected at the various points throughout the circuit.

If the 6-volt battery power is not present at the power switch, there will be no need to check for B-plus. In this case, the power switch should be checked, as well as the fuse, the connections to the test battery and the test battery itself.

However, if the 6-volt battery power *is* present at the test point indicated in the diagram, and still there is no B-plus voltage at any place in the receiver, especially at the output filter condenser, then serious trouble is indicated.

First, turn off the power switch and measure the ohmic resistance between the two plates of the rectifier tube. As reference to the diagram will clearly show, this is a test for a short-circuited vibrator buffer condenser, which is connected directly between the two rectifier tube plates. If this condenser is short-circuited, the meter will read a very low resistance, practically zero in most cases. In good condition, this condenser itself will have infinite resistance -- but remember that in this circuit the buffer is connected across the transformer secondary, and any resistance reading across the condenser will include the resistance of the transformer windings. These windings are on the order of 400 to 500 ohms, end-to-end, with half of this value between either end and ground. When making an ohmmeter

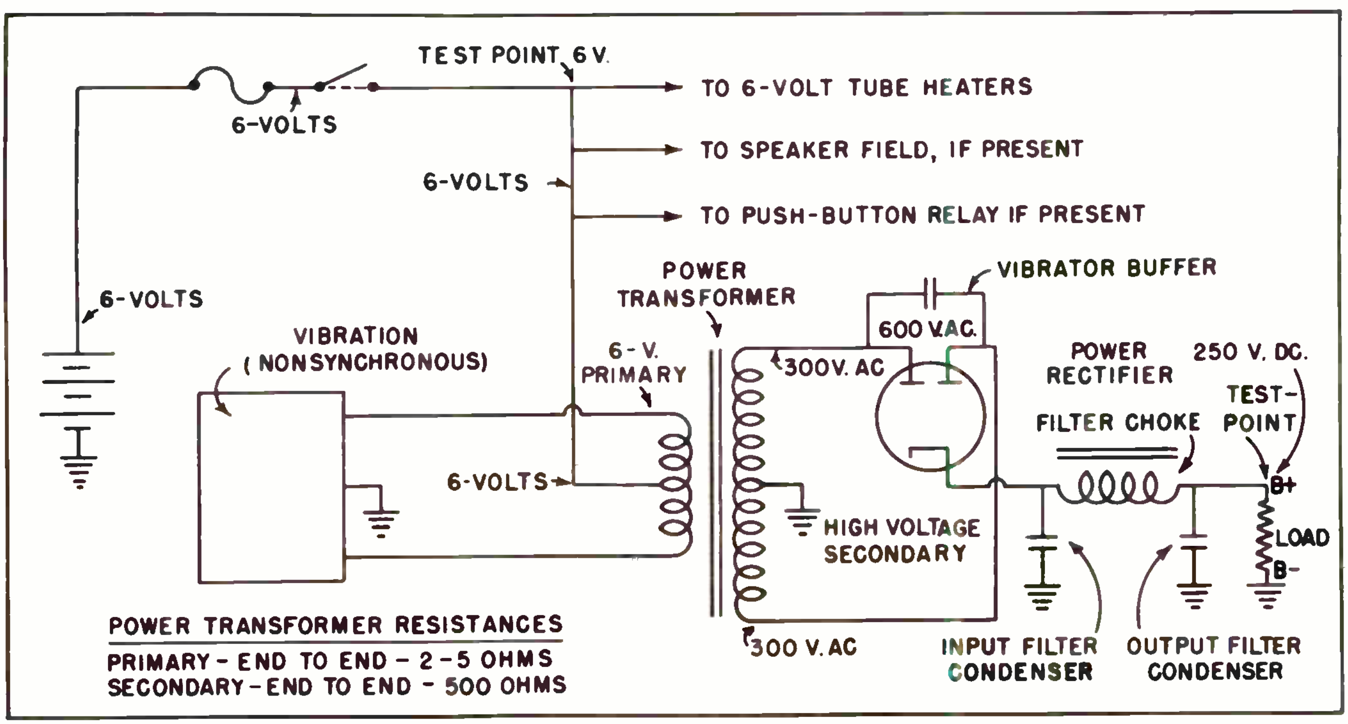

Fig. 9. Important Data in Testing the Non-Synchronous Vibrator Power Supply.

test for a shorted buffer condenser you should expect a reading across the transformer windings of around 500 ohms, and not erroneously attribute this resistance to a shorted or partially-shorted vibrator buffer. In case of doubt, one end of the buffer may be lifted from its tie point and the ohmmeter applied directly across its leads.

While shorted vibrator buffer condensers are most commonly the cause of the complete lack of B-voltage in the car receiver, they are by no means the only ones.

Short-circuited filter condensers, especially the input section, may also remove B-plus from every component in the receiver normally carrying it. The test for a short filter condenser, or any other short-circuit between B-plus and B-minus, is to measure across the B-supply with an ohmmeter while the receiver power is turned off. Convenient test points for this ohmmeter check are between the screen-grid of the output tube and chassis ground, as illustrated in Fig. 10. These are easy points to locate and will save time in analysis.

In case the short-circuit exists in the B-supply, each branch will have to be tested separately to locate the exact fault.

It should be noted that either a short-circuited vibrator buffer capacitor or a short across the B-supply will probably blow the line fuse. It is interesting to notice, however, that the manner in which the supply fuse is blown by these two different causes will help to distinguish between them.

It can be seen that a short-circuited buffer capacitor will blow the fuse as soon as power is applied to the transformer. A short across the B-supply, on the other hand, will not blow the fuse at once, since it takes about 30 seconds for the rectifier tube to heat up enough to conduct heavy current. We may conclude, then, that if a delay of over 30 seconds takes place before the fuse blows, then the short is probably across the B-supply. If the fuse blows as soon as power is applied to the circuit, the short probably lies in either the vibrator buffer capacitor or one of the 6-volt components immediately following the on-off switch.

Another interesting fact is also worth mention. If the rectifier tube is a clear glass envelope, like the 6X5 and the short-circuit occurs across the B-supply but the

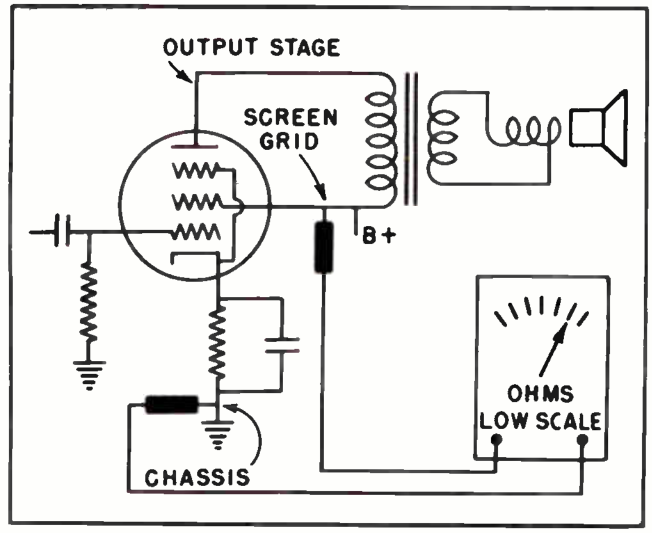

Fig. 10. Checking with the Ohmmeter for a Short-Circuit Across the B-Voltage Supply.

fuse holds, the plates of the rectifier tube can be seen to turn a cherry-red. A shorted vibrator buffer, since its current does not flow through the rectifier tube, will not cause this effect.

The final confirmation, however, of either of these suspicions, will be the ohmmeter check, as previously outlined.

Section 7. TESTS FOR LOCATING OTHER POWER SUPPLY TROUBLES

The non-synchronous vibrator power supply is a frequent victim of other types of troubles. Among these are the lack of sufficient B-plus, and the presence of hums and motor-boating.

If all of the tubes check good, the vibrator buzzes, and no shorts are evident across either the vibrator buffer or the B-supply, yet B-plus is below normal value by a considerable amount, then other avenues of investigation must be followed.

Displaying these same symptoms and conditions is another fairly common trouble associated with the power transformer secondary, the exact fault being secondary turns shorted to each other. This fault is indicated, as a rule, when the supply fuse blows at intermittent intervals, and the signal, though audible, is flat and below normal volume.

Reference to Fig. 11 shows why these symptoms occur in the manner mentioned. Since the secondary of the power transformer

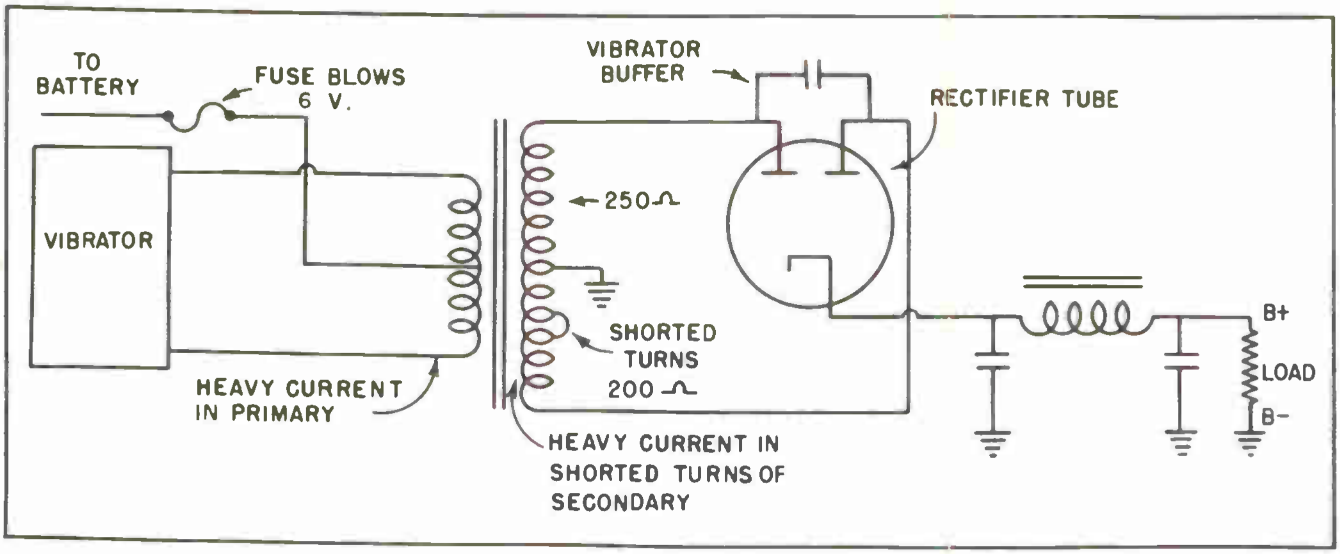

Fig. 11. Indications of Shorted Turns in the Secondary Winding of the High Voltage Transformer.

(due to its many turns) is wound of thin wire, there is always the chance of adjacent windings shorting out between themselves. If this happens, the current through the shorted turns will be very heavy. This heavy current *opposes* the counter emf in the primary and permits the primary to also conduct heavy current. Since primary current is protected by a fuse, the extra current drain usually blows the fuse. Moreover, since so much current is moving in both the primary and the secondary of the power transformer it will become hot to the touch. It often reaches a temperature that melts out the wax. In many cases, the vibrator will also become hot.

The test for shorted turns in the transformer secondary is a relatively simple one, consisting of the measurement of the ohmic resistance of each half of this winding separately, as indicated in Fig. 11. If there is any measurable difference between the resistances of the two halves of this winding when the low scale of the ohmmeter is used, shorted turns may be suspected. To further check this suspicion, turn the receiver power on, and read the A-C voltages between either end of the secondary winding and ground. These voltages should be exactly equal when measured on the voltmeter's 300-volt A-C scale. If there is any difference whatever, it is certain that there are shorted turns in the secondary. In this case, of course, rather than trying to repair the transformer, it should be replaced with its exact duplicate, obtainable from the manufacturer of the receiver, or a well-stocked supply house.

Section 8. RECTIFIER TUBE TROUBLES

Ordinarily the tube-checker may be depended upon for reliable information regarding automobile power rectifier tubes. This is especially true of the heated cathode type of rectifier tube, such as the 6X5, the 7Y4, and the 84-6Z4. If these tubes show no shorts or leakage, and their emission is indicated as well past the "questionable" portion of the tube-checker scale, they may be assumed good. If, however, the tube checker indicates them as either bad, questionable, or only slightly "good", they should be immediately replaced.

The 0Z4 power rectifier commonly found in automobile receivers, on the other hand, should be checked very carefully. Since this rectifier is of the cold-cathode type, and depends upon high-field emission for its initial conducting action, the tube-checker may check the 0Z4 "good" while its emission is actually below normal. When checking the 0Z4 for cathode emission, therefore, look for a sudden increase in the cathode current (as indicated by the tube-checker pointer) after power has been applied to it for 10 to 30 seconds. (See Fig. 12.) The meter pointer will hover around the "questionable" section of the tube-checker dial for a short interval, and then suddenly deflect all the way over to maximum reading of the scale. This action of the meter will indicate a good 0Z4. The failure of the meter to respond in this special way will indicate that the 0Z4 tube is defective. The audible symptoms accompanying a weak 0Z4 tube are varied, but usually take one of the following forms:

While in the car, the signal will be absent until the motor is raced. Then the signal will come in, swiftly *but smoothly* (without a sharp click). Then, when the car motor is turned off or allowed to idle, the signal will drop out, swiftly but smoothly.

While in the car, the signal may come in and drop out at fairly rapid intervals, regardless of the speed of the car motor. Here, too, fading in and out of the signal will be *smooth,* and not accompanied by a sharp click.

While on the test bench, the signal will be absent, and B-plus will be very low, so long as the battery-charger is not connected to the test battery. When the charger is connected up to the battery, the signal will come in (smoothly), and the value of B-plus will rise (smoothly) to normal at the same time.

While on the test bench, the signal may not come in even when the charger is connected, and B-plus will remain correspondingly low. If there are no shorts across the B-supply, and the fuse does not blow, then a defective 0Z4 is indicated.

It is important in these tests that we know that the vibrator is buzzing, whether the set is playing or not. Then these symptoms tell us to replace the 0Z4 whether it tests good or bad on the tube-checker. Another point of importance is that a signal which fades in and out *smoothly* will result from different causes from one which cuts in and out sharply, and with a click. Examples of the latter may be readily found in antenna troubles, where any car vibration may make and break a loose antenna connection. This would, of course, act to cut the signal in or out with a sharp click. In contrast, 0Z4 troubles are characterized by *smooth* changes in signal intermittence.

Section 9. RECOGNIZING VIBRATOR TROUBLES

Non-synchronous vibrator troubles may take one of three separate forms.

(1) Its points may be frozen in a closed position. In this case, the vibrator will not buzz when power is applied to it, and the fuse will immediately burn out.

(2) Its points may be rigid in an open position. In this case, the vibrator will not buzz, but the fuse will not burn out. The pilot lamp and tubes will light, but there will be no life in the set.

(3) Only one of its two sets of points may be in operating condition. Here the vibrator will buzz, there will be a measurable (but decidedly low) value of B-plus, and there may or may not be a signal in the set.

To verify *(1)*, remove the vibrator from its socket, replace the fuse, and apply power again. If the fuse does not blow out this time, replace the vibrator to correct the trouble.

To confirm *(2)*, replace the vibrator with its exact duplicate and test the receiver. If the wiring to the vibrator is intact, there can be no other trouble accounting for the complete lack of signal in the receiver.

To confirm *(3)* is somewhat more elaborate, but may be done accurately and quickly by carefully testing the rectifier tube for emission, and then testing across the B-supply for voltage and resistance. If B-plus is considerably below normal, and no shorts are across any branch of the B-supply (including the plates and screens of the amplifier tubes) then a defective vibrator is practically certain. The final test of this is the replacement of the vibrator by its exact duplicate, and checking for signal reception.

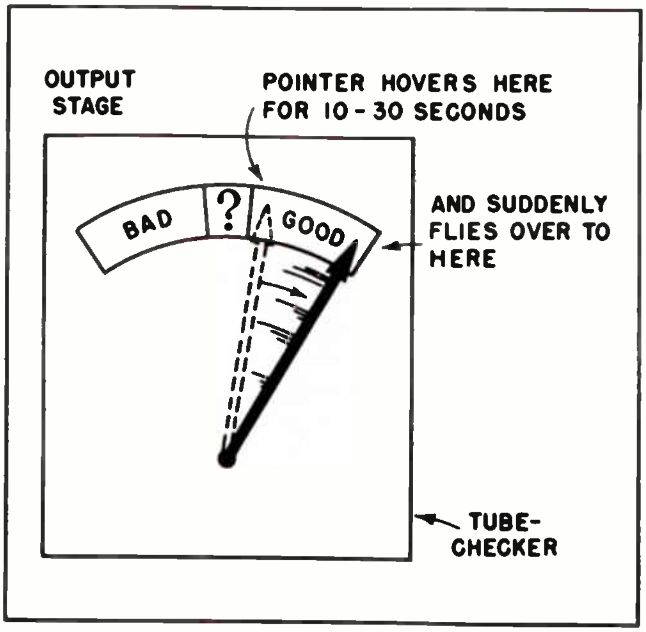

Fig.12. Special Response of the Tube-Checker Meter Pointer when Testing an 0Z4 Tube.

Note that in all three of these cases, the corrections are the same -- replace the vibrator with its exact duplicate. Due to the precision with which vibrators are manufactured and adjusted for use, it is not feasible to attempt vibrator repairs. In view of this, the easiest, fastest, and most dependable remedy for a defective vibrator is to replace it. They are relatively inexpensive. Radio parts establishments ordinarily stock all makes and models of vibrators, or standard replacements for them. Their cross-reference guides for different manufacturers are reliable and complete. In securing a replacement vibrator, the serviceman should bring the vibrator (or its complete model number and make) to the supply house. This practice will avoid guesswork that may lead to confusing results and possible damage to the receiver under repair.

Section 10. THE SYNCHRONOUS VIBRATOR

The purpose of any type of vibrator (whether synchronous or non-synchronous) is to chop up the steady D-C current so that high secondary voltage may be obtained. The principle used is that a secondary transformer voltage is induced only when primary current undergoes *changes*. The non-synchronous vibrator, previously discussed, was seen to chop up the primary current. This is its only function.

The synchronous vibrator chops up primary current, and at the same time, rectifies the secondary voltage. Thus, where the non-synchronous vibrator-transformer system requires a rectifier tube, the synchronous vibrator-transformer system does not require a rectifier tube. The advantages are

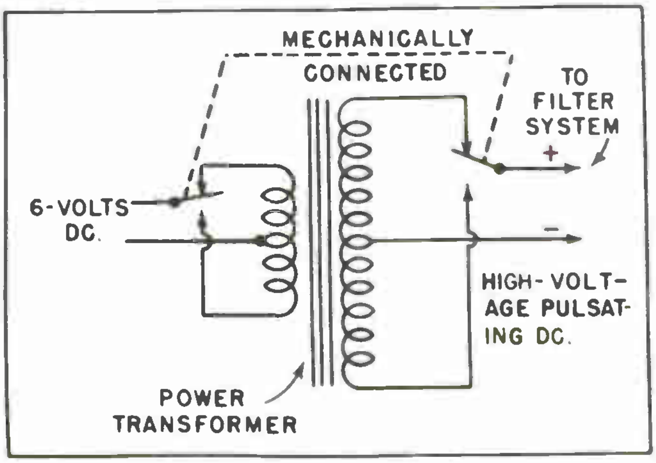

Fig.13. The Principle of the Synchronous Vibrator.

obvious -- the receiver requires one tube less, which accounts for a saving of space, and also for a saving of battery power.

It may be added that the synchronous vibrator, due to the fact that it contains more contact points, is subject to more troubles than the non-synchronous type. For this reason, and because of the development of cold-cathode rectifiers (like the OZ4), the synchronous vibrator has become less popular in recent years. Fig. 13 illustrates the electrical principle used by the synchronous vibrator.

Identifying the synchronous vibrator has already been mentioned -- it is characterized by the presence of five or more base prongs. In addition, an automobile receiver containing a synchronous vibrator will omit the rectifier tube, since the synchronous vibrator performs the same function as a rectifier tube.

Section 11. CHECKING THE SYNCHRONOUS VIBRATOR

In the car it will usually be impossible from external inspection to determine if the vibrator is synchronous or not. However, the symptoms resulting from a defective synchronous vibrator are identical with those caused by a defective non-synchronous vibrator, with an exception presently to be discussed.

A synchronous vibrator whose 6-volt points are frozen in a closed position, as may be expected, will immediately blow the fuse.

If the synchronous vibrator 6-volt points are rigid in an open position, the fuse will not blow, but the vibrator will not buzz. Another possibility in this case, the exception mentioned previously, is that the synchronous vibrator is placed in its socket in a *reverse position*. The only time this can happen is when someone removes the vibrator for some reason, and then replaces it in the wrong position. Fig. 14 illustrates why this error is possible in the synchronous vibrator and impossible in the non-synchronous type.

A third type of trouble with the synchronous vibrator is when only one point of either the 6-volt pair of points or the high-voltage pair of points is in good condition. The results will be a low value of B-plus, and the signal -- if present at all -- will be extremely quiet and flat.

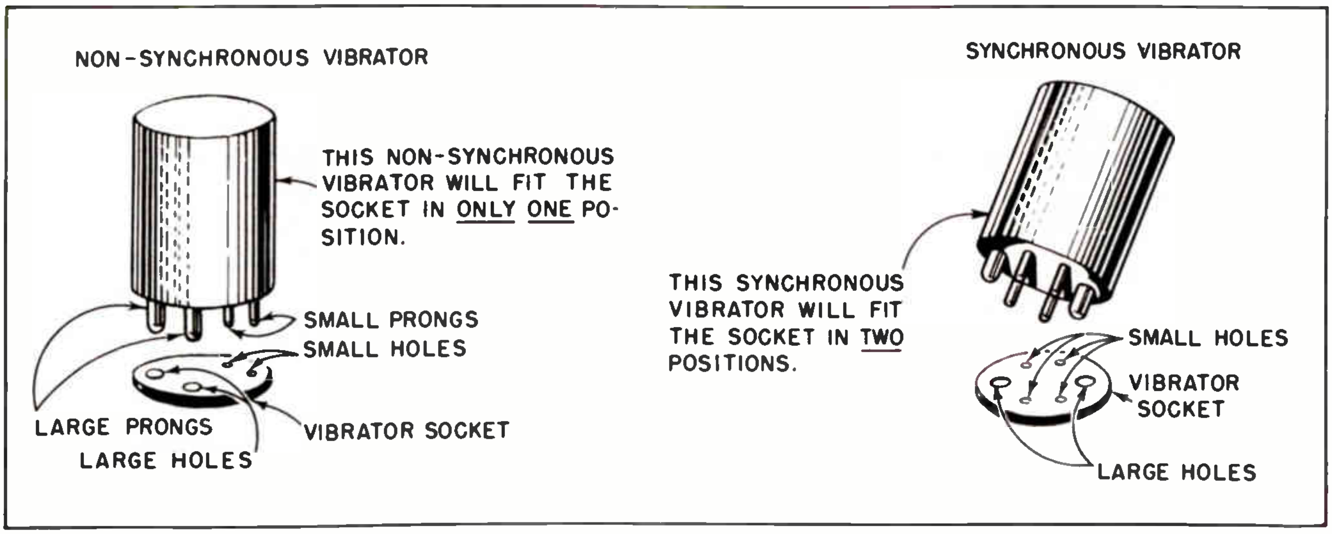

Fig. 14.

Section 12. **THE SYNCHRONOUS VIBRATOR ON THE TEST BENCH**

On the test bench, confusion may result from connecting the test battery to the receiver so as to have the wrong polarity. If the battery polarity of the car from which the receiver is removed is known, then duplicate this polarity in the test-connections. (As the average automobile owner knows, in some cars the *negative* side of the battery is connected to chassis, while in others the *positive* side of the battery is connected to chassis.) The non-synchronous vibrator does not distinguish between these opposite polarities; the synchronous vibrator, however, does distinguish between them, and will not produce B-plus when connected in the wrong polarity.

When the polarity is determined and the receiver connected up properly, observe if: (1) the vibrator buzzes; (2) the fuse blows; (3) B-plus voltage is present, measuring for it between the screen grid of the output tube and chassis; (4) if the signal is normal, quiet, or absent.

If the vibrator buzzes and the signal and B-plus are both absent, pull out the synchronous vibrator and after turning it around 180 degrees (1/2 turn) replace it in the socket. Make the tests again. This procedure is meant to eliminate any doubt about the polarization of the vibrator. Now, if the symptoms are the same as before (no signal, no B-plus, and the vibrator buzzes) place the vibrator back in its socket the way it was. Measure the resistance between the screen-grid of the output tube and chassis ground, and the resistance across the filter condensers. If no short is indicated at either point, and still B-plus voltage is absent, we may reasonably infer the synchronous vibrator is defective. To confirm this possibility, there is no better test than replacing the vibrator with its exact duplicate.

If the fuse blows when power is applied, confirm the suspicion of defective 6-volt vibrator points by removing the vibrator, replacing the burnt-out fuse, and applying power again. If this time the fuse does not blow, then replace the vibrator with its exact duplicate.

If B-plus voltage is either low or absent, and no short circuits (by ohmmeter tests) appear across any branch of B-plus, then replace the vibrator with its exact duplicate.

Here again we notice that in the case of any type of vibrator trouble, confirmation and correction are accomplished by actually replacing the suspected synchronous vibrator. Keep in mind that we are not only using the tests outlined for the vibrator. We also possess valuable information regarding the value of B-plus, the battery polarity, and the condition of the tubes (which should all be checked on the tube-checker). We also know if a blown fuse is due to a defective vibrator, by the tests outlined, or whether the fuse is blown by defects in some electrical circuit other than that of the vibrator.

These apparently scattered bits of data, while they may seem unrelated on superficial

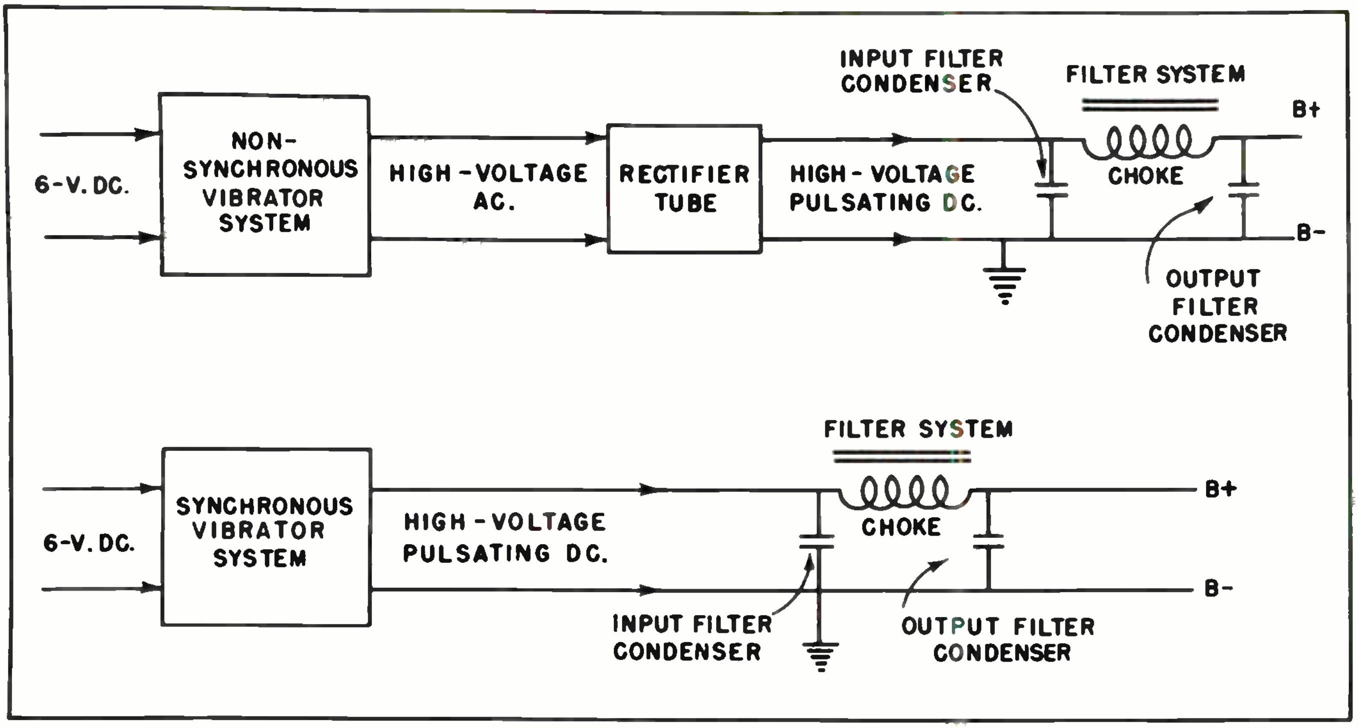

Fig. 15. The Non-Synchronous Vibrator Needs a Rectifier Tube, while the Synchronous Vibrator Does Not.

consideration, really are quite important when subjected to intelligent study. They are the threads of information which make up the whole cloth of service work. It is not any one, isolated, piece of information which is useful to the technician. It is the combination of visual and audible symptoms, meter readings, and keen observation which enables the alert technician to "go right to the trouble". But "going right to the trouble" is not a matter of guess-work. It is the result of intelligent appraisal of all the known facts, a process which narrows down the probable trouble to the one thing which prevents proper operation of the receiver. The skilled technician will learn more about a receiver in five minutes than the average person (including the owner of the set) will ever know.

Section 13. POWER SUPPLY TROUBLES COMMON TO VIBRATOR SYSTEMS

The non-synchronous vibrator-transformer system produces a high A-C voltage which is fed to the rectifier tube for rectification. The synchronous vibrator-transformer system produces a high voltage A-C and rectifies it before sending it to the filter system for smoothing out the vibrator ripple. Fig. 15 shows that the non-synchronous system, with its rectifier tube, is in most ways, exactly equivalent to the synchronous system *without* the rectifier tube. The output of both systems provides the necessary rectified high A-C voltage. In order to be of use to the amplifier tubes and their circuits, this pulsating D-C must be filtered. The filtering systems of the synchronous and the non-synchronous systems are identical, and contain an input filter condenser, a filter choke, and an output filter condenser. These are shown in Fig. 15.

Trouble shooting the filtering components is relatively simple, but must be done on the test-bench. The symptoms of defective filter system components, and their causes may be outlined as follows:

Before seeking trouble in the power supply we should make sure all tubes have been tested and replaced where necessary, the vibrator is in good condition, and the test battery is well-charged.

Signal tunable across the dial but has considerable 60-cycle hum. The cause may be either a defective input or output filter condenser. In some cases, the common negative of both sections may be open. Verify by shunting each section separately with another (equivalent) filter condenser and note results. If the hum clears up only partially when each of the two sections are shunted separately by the test condenser, replace both the input and output sections.

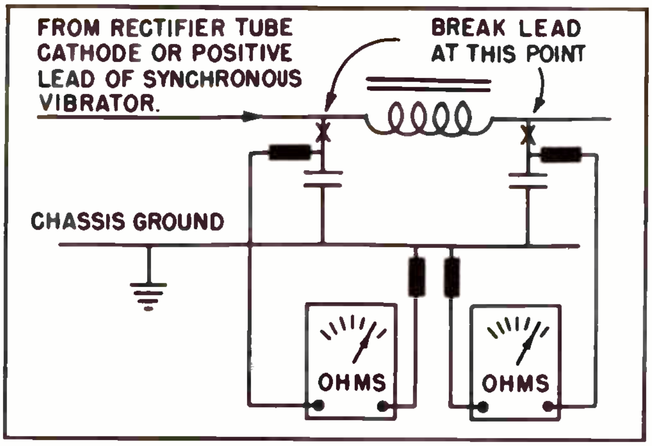

Fig.16. Using the Ohmmeter to Measure Across Each Filter Condenser Separately to Locate Short-Circuits.

No signal of any kind, and no B-plus voltage, as measured across the output filter condenser. Turn off receiver power and measure for a short circuit across each filter condenser separately. Open the positive side of each and test it by itself. (See Fig. 16.) If neither one of the tests discloses a short when one of the condenser terminals is disconnected from all other circuits, a search will have to be made in each branch of the B-voltage circuits. The diagram in Fig. 17 indicates the manner of doing this. It is obvious from this diagram that a short circuit across a screen by-pass capacitor in an amplifier tube will be equivalent to a short across either of the filter condensers.

Violent motor-boating. The most common cause of this symptom is an open output filter condenser. Confirmation of this suspicion is to bridge the output filter condenser with an equivalent condenser and note the results. If the motor-boating clears up during this procedure, replace the open output section of the filter condenser. The frequency of motor-boating due to this cause is normally around 10 cycles per second.

Fast motorboating. This differs from the above by the fact this type usually occurs at a frequency of 25 cycles and up. It is not ordinarily so violent as that mentioned above. The most probable cause is an open screen by-pass condenser in an R-F or I-F amplifier tube. To verify this, first find all of the screen by-pass condensers, and then proceed to shunt each of them separately with its equivalent. (Since these condensers are not electrolytic, no observance of polarity need be followed.) If the test condenser succeeds in eliminating the motor-boating while placed across a certain screen by-pass condenser, replace that condenser.

Signal very weak and deep-toned, but B-plus is normal. While this symptom may not seem to indicate a power supply trouble, it can often be traced to a shorted screen by-pass capacitor. The difference between this case and the shorted screen by-pass mentioned above being that sometimes when the receiver is used for a prolonged period of time, the continuous current through the screen-dropping resistor will eventually burn up the resistor. B-plus will rise from a low value to normal when the resistor opens, but the signal will be weakened by the absence of positive voltage at the

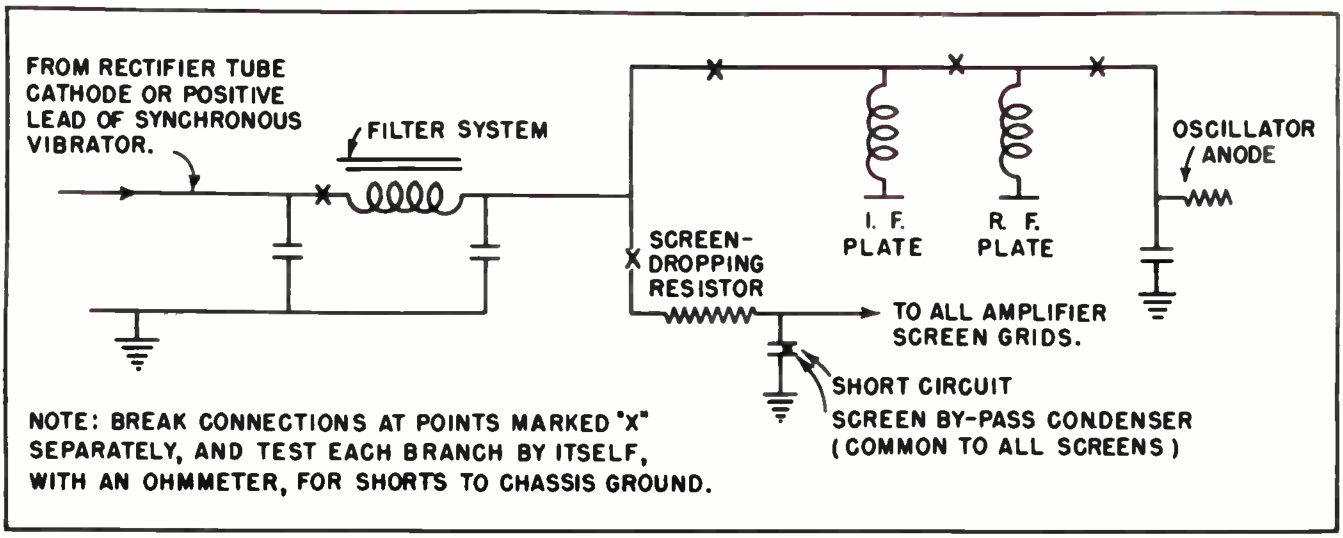

Fig.17. How to Check for Short Circuits in Each Branch of the B-voltage Supply Lines.

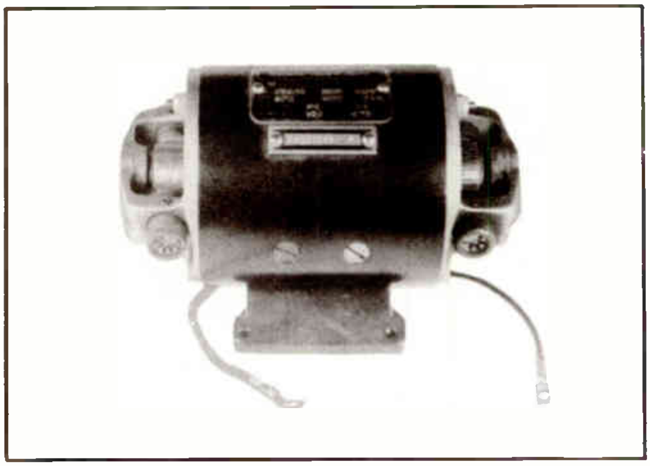

Fig. 18. The Dynamotor is Sometimes Used in Place of a Vibrator-Transformer System.

screen grid of the tube. Confirm this double-trouble with an ohmmeter, reading first across the suspected by-pass capacitor, then across the burned resistor. If a screen dropping resistor is hot, or if it looks charred or burnt, the associated by-pass will usually be found shorted to ground.

Section 14. THE DYNAMOTOR POWER SUPPLY

In some cases, where the automobile receiver has high power requirements, the vibrator power supply is replaced with a dynamotor system. (See Fig. 18.) This would be the case in some of the receivers used by police and military mobile receivers and also by many amateurs. Fig. 19 shows the functional block diagram of such a system, and indicates the connections between the components. Notice that the dynamotor is fed by the 6-volt storage battery of the car, and that its output is a high D-C voltage suitable for use as B-plus in the receiver after sufficient filtering of the ripple inherent in the output of D-C generating machinery. In some cases, the dynamotor unit, which is somewhat removed from the receiver itself, may contain the filtering components. In most cases, however, the filter system is contained within the receiver case.

Testing the dynamotor power supply is equivalent to testing the vibrator power supply. A voltmeter placed across the output will indicate the presence of sufficient B-voltage (around 300 volts, D-C) or will indicate its absence. The system, being a rotary unit, can be observed for rotational speed, and any discrepancy in its speed may be easily observed and traced to faults in the 6-volt wiring of the motor half of the unit.

Where the output high voltage is absent or eratic, the voltmeter will readily indicate this condition and point to defects in the high-voltage wiring in the generator half of the unit. Commutator and brushes on the motor and generator sections may be inspected for wear and corrosion, and corrected accordingly.

Section 15. AUTOMOBILE STATIC

It was previously stated that the worst enemy of the automobile receiver is static. This serious interference to automobile radio reception may be discussed under several headings.

Section 16. IGNITION STATIC

Since the gasoline engine depends for its operation upon a jumping spark within the cylinder, and since amplitude-modulated

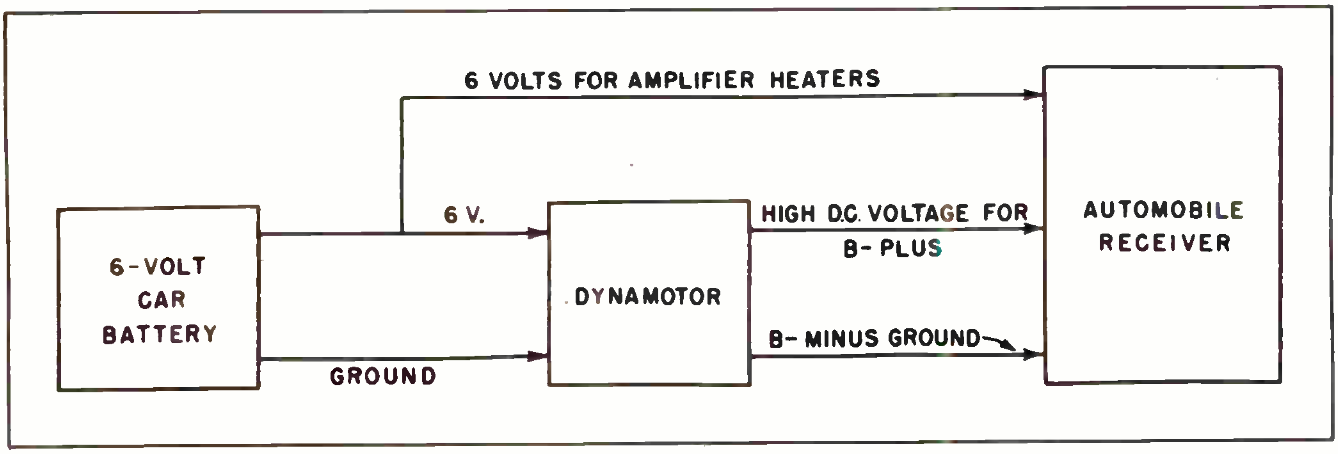

Fig. 19. Block Diagram Showing how the Battery, the Dynamotor and the Car Receiver are Connected Together.

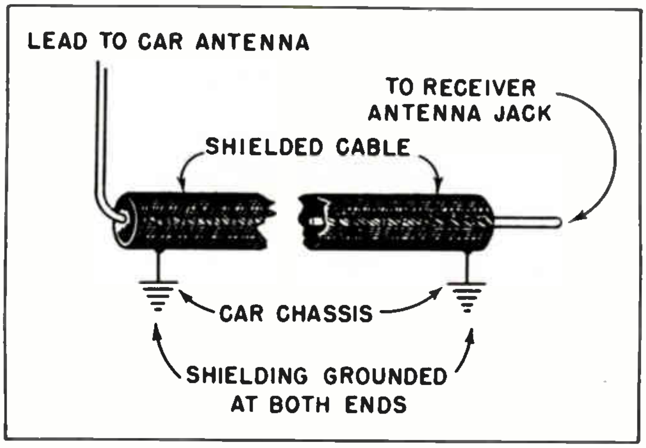

Fig. 20. Failure to Bond the Shielded Cable at Both Ends will Result in Strong Static Interference.

receivers pick up any sparking device, the automobile receiver is especially subject to ignition interference. Actually, *three* separate sparks in the ignition system take place when a cylinder fires. These are the spark across the spark plug gap, the spark across the distributor gap, and the spark across the 6-volt breaker points. These three sparks all occur simultaneously for any given cylinder. However, in order to eliminate ignition interference, all three sources must be considered. First, however, let us see how ignition interference may be identified. Since the rate of firing of the cylinders depends upon the speed of the gasoline motor, ignition interference may be recognized by the fact that its frequency changes as the speed of the motor is changed. Besides, when the motor is turned off, there is no static noise from the ignition spark and the receiver should pick up none. We may therefore conclude that if the static interference changes with the speed of the motor, and disappears when the motor is turned off, the cause must be due to the ignition system.

There are several ways of minimizing ignition static. The first is to make sure that the antenna lead is not only well-shielded, but that the shielding is bonded to car chassis at both ends. (See Fig. 20.) The bonding to the chassis of the car is of the utmost importance. Even if one end of the shielding is bonded to chassis, but the other left hanging free, the amplitude of ignition static will be tremendous.

Another method of minimizing ignition static is to use a distributor suppressor. This is usually a 10,000 ohm resistor which is placed in series with the center distributor wire, as in Fig. 21. Sometimes a choke is placed within the suppressor, for better suppression characteristics. In any case, the device is small and inexpensive, and usually does some good.

The third method of minimizing ignition static is to install a suppressor at each spark plug. In some cars, the center distributor wire is not accessible, therefore each plug must be separately suppressed. In construction and appearance, these plugs suppressors are almost identical with the center-wire suppressors and are easy to install.

It may be that no single one of the above methods may take all ignition interference out of the receiver. But by applying one or more of these methods, the static due to ignition interference can generally be reduced to a satisfactory level.

Section 17. GENERATOR BRUSH STATIC

The carbon brushes as they sweep across the segments of the generator commutator during rotation also develop sparks. Like ignition static, these sparks constitute a form of amplitude-modulated interference which the car receiver picks up as static. Here the noise is not so much the "tattoo" of ignition static, but rather a hissing or rushing sound. Like ignition interference however, the hissing or rushing sound seems

Fig. 21. How a Distributor Suppressor is Installed.

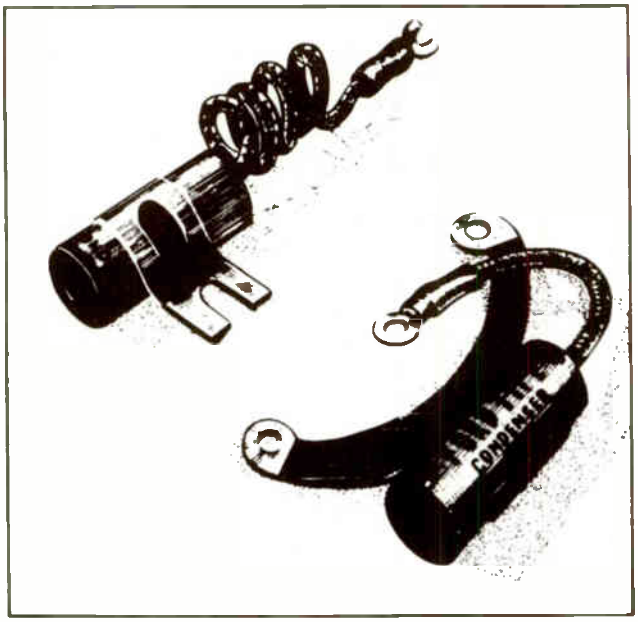

Fig. 22. Generator Suppressor Capacitors.

to increase its pitch with an increase in motor speed.

The remedy for brush static is a simple one. A capacitor is placed across the generator, from the "hot" side to chassis ground. A unit is made for this precise purpose, being suitable for mounting upon the generator itself. Capacity of these condensers is of the order of fractional microfarads, and they are voltage-rated at around 50 to 200 volts D-C.

Illustrated in Fig. 22 are a Sprague type AR generator suppressor condenser, and a special model built for Ford cars.

Section 18. MISCELLANEOUS STATIC IN THE 6-VOLT LINES

Other static interference originating in the 6-volt battery lines, their switches and contacts, may be successfully suppressed by special condensers built for the job. Fig. 23 shows a variety of these capacitors. In this Figure, type DL1 is a dome light filter, GG5 a gas gauge filter, OG50 an oil gauge filter, P2077 a special Ford replacement, P3402 an ammeter by-pass, and P2153 a special Motorola replacement.

These capacitors, once they are properly installed, seldom open. Hence they are not so much the repairman's problem as they are the problem of the car manufacturer. However, it should be mentioned that these capacitors are designed into the car itself for the specific purpose of suppressing static interference at these electrical devices. Any defect in one of them will show up in an increase of static.

Section 19. WHEEL AND TIRE STATIC

Wheel and tire static may be distinguished from all other forms of interference by the fact that it is present only during times the car is in motion, regardless of whether the motor is running or not. It may sound like clicking, at irregular intervals, or it may sound like a hissing noise. But in no case will it *disappear* if the motor is turned off and the car permitted to coast. It will be noticed on hard pavements, such as asphalt, macadam, or concrete. Sometimes brick pavement will also bring out wheel or tire static. In wet or snowy weather, this

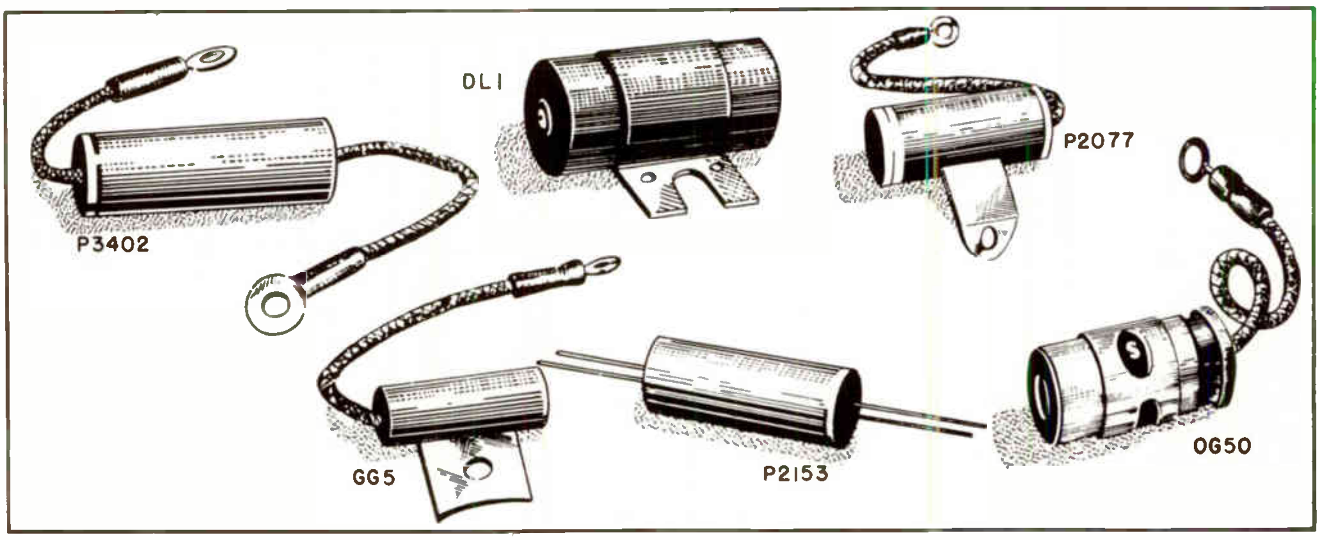

Fig. 23. A Variety of Static-Eliminating Capacitors.

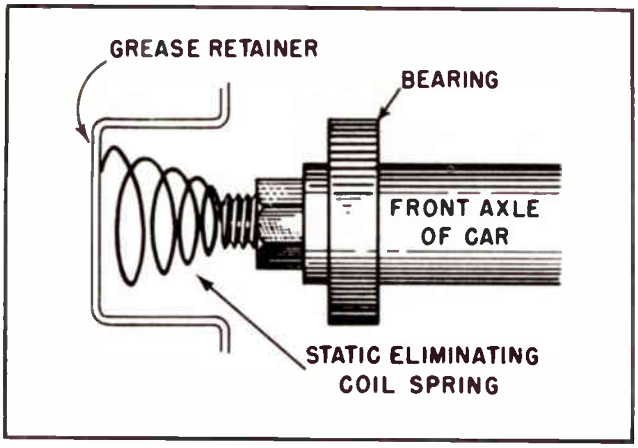

Fig. 24. Installation of the Static-Eliminating Coil Spring.

interference will not be present, due to the easy leakage path for static charges over the surface of the wet tires. In many cases wheel and tire static are present only when the car exceeds a certain speed on dry pavement.

There are three generally accepted cures for this type of static interference. The first is to introduce a coiled spring within the grease caps of the car's front wheels. A coil of this type is shown in Fig. 24, and is made for this purpose by Motorola and carries their part number M-6, wheel static eliminator. When some of the turns of this coil are cut off, this eliminator can be adapted to the rear wheels as well.

Another remedy for this type of static is to insert a metal clincher into the edge of the tire where it can make electrical contact with the tire rim.

A third remedy for wheel and tire static may be successful where the other two methods fail. This is the light spraying of the inner side of the casing with graphite powder. The powder, a conductor, may so decrease the resistance of the leakage path for the static charges that they may run off at a steady rate rather than discharge in jumps.

Section 20. THE CAR ANTENNA AND STATIC

In the days of the roof and running board car antennas, the problem of car static was more acute than it is today. This was due to the fact that the roof antenna was unfortunately located so as to pick up ignition and generator noises. The running board antenna was rather well shielded from ignition static, but its proximity to the ground made it especially vulnerable to corrosion and weathering.

When all-steel car tops were introduced, the roof antenna was no longer useful, since the shielding of the all-steel car top prebented the incoming signal from reaching the antenna.

The side-cowl (or whip) antenna was designed and manufactured to replace both the old roof antenna and the running board model. It soon became evident the whip antenna was better than the two types it superceded. This was primarily due to the fact the whip antenna is mounted completely outside of the car, and hence shielded from all car static by the metal body. Yet, for the same reason, the station signal was not attenuated at all by the metallic framework of the car. A side-cowl, or whip, antenna is shown in Fig. 25.

The presence of a strong signal at the antenna is excellent assurance against all types of car static. We recall that the Automatic Volume Control (AVC) circuit of the modern receiver acts to decrease the gain of the receiver when a strong signal strikes the antenna. When the antenna is located entirely outside the car, its position encourages strong signal reception, operates the AVC circuit and de-sensitizes the receiver against static interference.

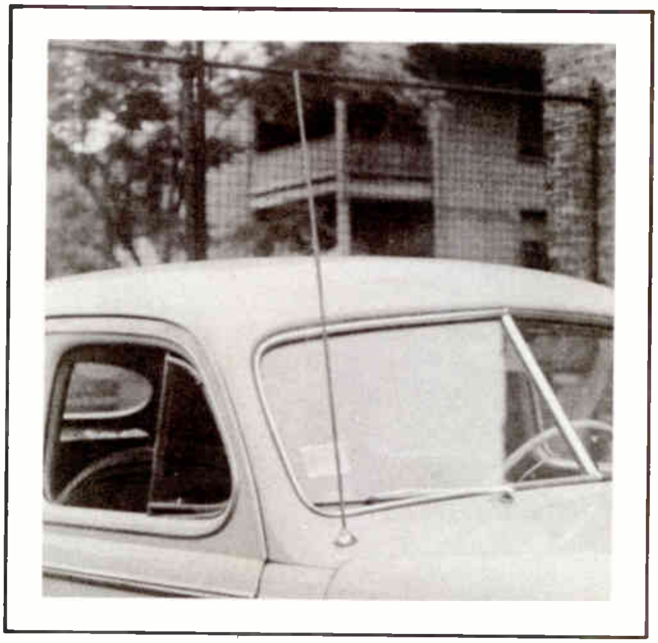

Fig. 25. Whip Type Antenna Mounted on an Automobile.

This leads to the conclusion that testing for a signal in a car receiver should be done with the antenna extended as far as possible. It will often be found this will bring in a stronger signal, reduce the level of interfering static, and make the receiver more enjoyable. Another precaution of importance is that when attempting to suppress static in a car receiver, be sure all testing is done with the hood down. If an outside antenna is used, and the hood is up, the ignition static will no longer be shielded by the metal of the hood, and no amount of effort in static suppression will be successful.

Section 21. INDUCTANCE TUNING

Tuned circuits consist of an inductance coil in parallel with a capacitor. The resonant frequency of such a tuned circuit can be changed by varying either the capacity or the inductance.

In most radio receivers the tuning section is designed to tune to a desired frequency by varying either the inductance or the capacity. In the very earliest days, radio receivers were tuned from one station to another by changing from one tap to another on the inductance coil which was tapped at various convenient locations. That method was discarded when radio receivers were designed for use by the general public.

For many years it has been standard practice to tune a radio receiver from one station to another by varying the capacity of a variable tuning capacitor. In the overwhelming majority of cases that variable capacitor has been "ganged" so as to vary the capacity of several circuits at the same time. That is the familiar gang tuning capacitor which is such a common component in most commercially built receivers.

But it must not be forgotten that the tuning action can be obtained by varying the inductance just as well as by varying the capacitance.

Several manufacturers of automobile radios have used variable inductance tuning in their receivers. Such a system of tuning seems to withstand road shocks somewhat better; there is not the tendency for such shocks to create short-circuits such as occasionally occur between the rotor and stator plates of gang tuning capacitors.

The inductance is made variable by using movable powdered iron slugs. The slugs are moved into, or out of, the forms of the tuning coils. Changing the inductance of the coils changes the resonant frequency of the circuits, thus making it possible to tune to any desired station.

The diagram in Fig. 26 shows the details of the tuning section of a receiver using variable inductance tuning. Such a receiver usually uses one stage of RF amplification ahead of the mixer tube. This calls for a tuned coupling circuit between the RF amplifier and the mixer tube, thus making three variable tuned circuits in all.

One of the coils is in the tuned circuit ahead of the RF amplifier. A second is in the variably tuned coupling circuit between the stages. The third is for the oscillator.

The inductance of all three coils is varied simultaneously during the process of tuning. This is made possible by mounting the powdered iron core slugs for all three coils on a rigid plate, usually plastic, then moving the three slugs in or out of the hollow forms of the three coils.

A system of this kind provides extra sensitivity, excellent selectivity, reasonable freedom from trouble, and a very compact form of construction. The overall size of a radio using this form of construction is much smaller than one using the more conventional ganged tuning capacitors.

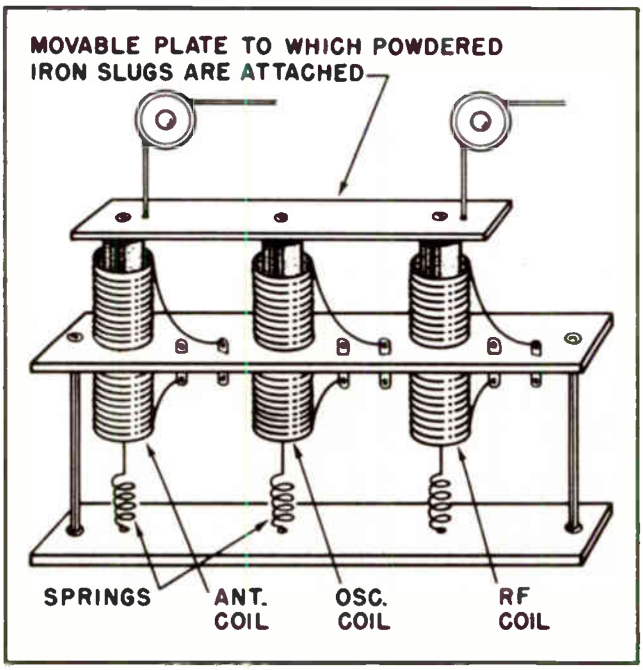

Fig. 26. Variable Inductance Tuning.

This method of tuning does occasionally provide some problems for service men who are not familiar with the system. Especially, when the cord used for moving the slug plate becomes broken or worn. However, once the principles of the action are thoroughly understood the alignment is usually easy.

It should be kept in mind that the drawing in Fig. 26 is intended to represent the principles involved in variable inductance tuning as used in automobile receivers. It is not intended to represent any specific model receiver.

Almost any receiver you examine will differ from this drawing. Most will be considerably more compact. But this drawing has been deliberately exaggerated to bring out those points we believe you should understand.

Other than the fact the inductance of the coils is made variable, rather than the capacity of the capacitors, there is little difference between this radio and any other we have discussed.

Section 22. **12-VOLT ELECTRICAL SYSTEMS**

Many of the newer automobiles now use 12-volt electrical systems. With the passage of time 6-volt systems will probably disappear entirely.

For some years automotive radiomen will be faced with the problems of 6-volt systems and 12-volt systems. It is well that we take a look at this matter.

Little trouble will be experienced with the new automobile radios which have been designed to work on twelve volts. Some of those radios use tubes designed to operate on twelve volts, such as the 12SA7, 12SQ7 and the 12SK7, and their variations such as the 12BE6. Others use 6-volt tubes, but connect them in pairs. The filaments of two tubes are connected in series across the 12-volt electrical system.

Except for the serviceman providing himself with a source of 12-volt electrical power, these radios present no special problem which differ from those in other automobile radios.

Nevertheless, the serviceman must provide a reliable source of electrical power. Some do this by installing one of the new 12-volt storage batteries, then keeping it charged by using some form of trickle charger. Others use a pair of 6-volt storage batteries connected in series.

The arrangement shown in Fig. 27 is one often used in service shops which specialize in automobile radio service. Such an arrangement makes it easy to tap off 12 volts for the 12-volt radios requiring service. It also provides a convenient source of voltage for the older 6-volt radios.

The 12-volt radios would be provided with power by connecting them across both storage batteries when they are in series. This means the 12-volt radios would be connected to the two extreme terminals.

The 6-volt radios would be connected between the center tap and either of the two ends.

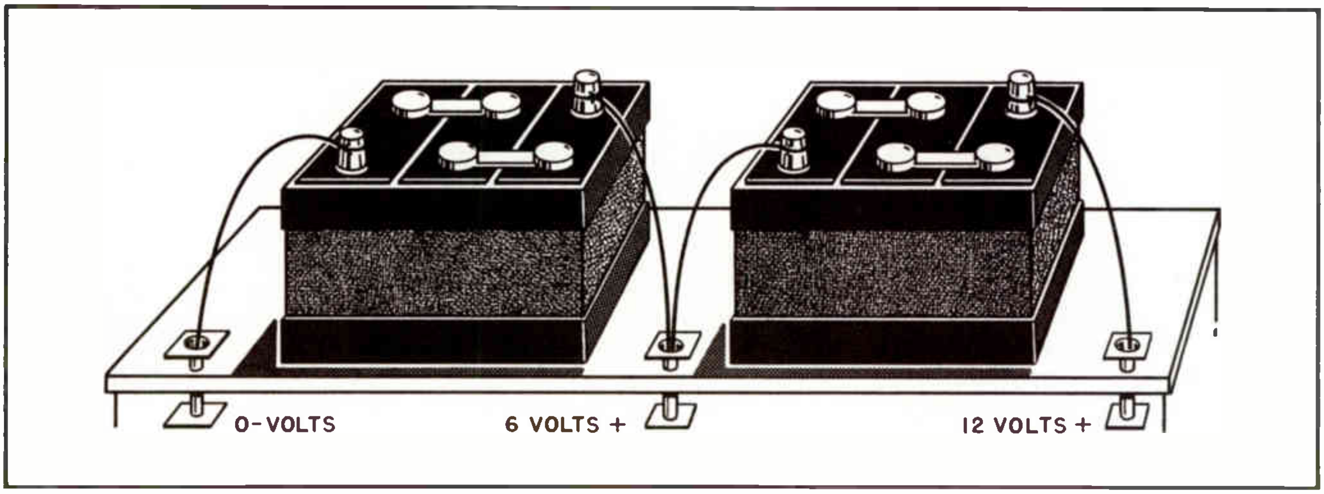

Fig. 27. Using Two 6-volt Batteries as Power Source for Servicing Automobile Radios.

Section 23. USING 6-VOLT RADIOS ON NEW 12-VOLT ELECTRICAL SYSTEMS

When automobile owners trade in their old automobiles on new ones they frequently remove the old radio from the old car with the intention of using it in their new car. This practice runs into complications when the radio is one designed to operate from a 6-volt electrical system, if the new automobile has a 12-volt system.

Many servicemen are confronted with this problem almost every day. For those without experience it sometimes presents a bit of a problem.

There are two ways the 6-volt radio can be made to work on a 12-volt electrical system. One is to connect a voltage-dropping resistor in series with the electrical lead which supplies electrical power to the radio. The other is to tap the storage battery to secure a special voltage supply.

The manner in which the dropping resistor is connected is shown in Fig. 28.

The size of resistor to be used in this case is determined entirely by the power normally drawn by the radio. The voltage must be dropped in half -- from 12 volts to 6 volts. This means the resistance must be whatever value is needed to drop the voltage by that much when the current drawn by the radio flows through it.

All radios do not draw the same amount of current. Therefore, you must first determine how much current any given radio uses, then calculate the resistance of the dropping resistor from that.

The amount of resistance is calculated by using Ohm's Law.

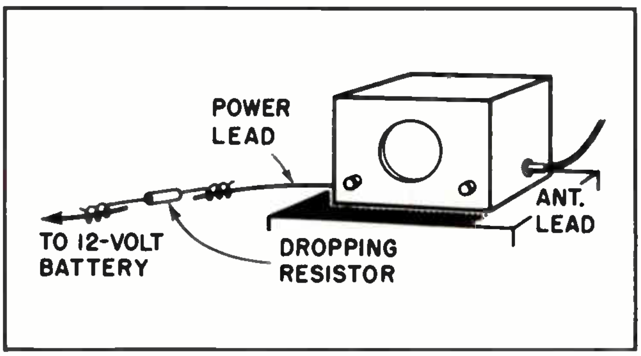

Fig. 28. Dropping the Voltage from a 12-volt Source to a 6-volt Automobile Radio.

Many radios show on a name plate how much current is drawn from the electrical systems. That information can be used for calculating the resistance needed in the dropping resistor. Other radios do not provide that information. Whenever that information is not given it must be obtained in some other manner.

One way the information can be obtained is to actually measure the current with an ammeter. That is probably the quickest and easiest despite the fact it is necessary to open the circuit to insert the ammeter.

However, inserting a dropping resistor in the lead to the radio is not one that meets the approval of many service men. Unless the job is done well it always presents a sloppy, and unprofessional appearance.

Many prefer to tap the 12-volt battery between the two center cells, and tap off the voltage for the radio at that spot. The voltage between the center of the 12-volt battery and either terminal is 6 volts.

The diagram in Fig. 29 shows how to tap the battery. The exact mechanical means used to tap depends on what is available to the technician. In most cases a strong alligator clip could be used, and would provide a good electrical connection. It would probably prove reasonably satisfactory in most cases.

However, there is always the danger the clip would work loose with passage of time, and through vibration from operation of the automobile. Furthermore, there is also the possibility that corrosion could occur between the metal of the alligator clip jaws and the lead of the battery link. That would interfere with conduction.

It is possible to solder a wire to the lead connecting link. That makes a better electrical connection.

A third method available to those who have drills and taps, is to drill a small hole in the lead connecting link, then thread it with a tap. A terminal of some kind can then be screwed into the threaded hole. This probably makes the best electrical connection, one that remains reasonably permanent.

Connecting a radio across three cells of the storage battery throws a heavier load on those three cells than on the other three. This will probably result in a slightly un-

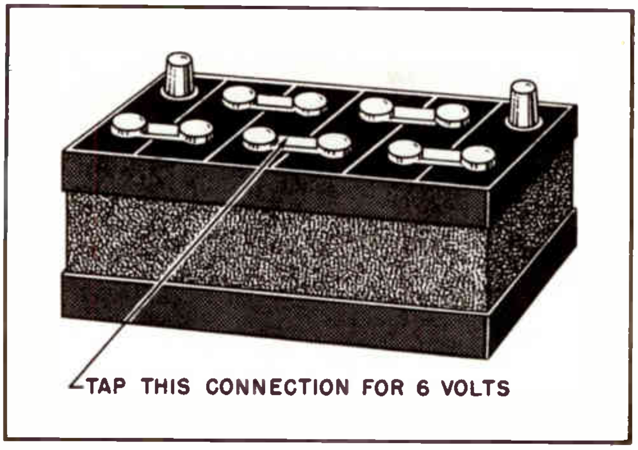

Fig. 29. Where to Tap a 12-volt Storage Battery for Operation of a 6-volt Radio.

balanced condition inside those cells. It may also result in the battery wearing out slightly before its normal time.

However, these latter items are usually relatively minor in nature, and in those cases where the radio is not used constantly there should not be any serious interference with normal operation of the battery.

Operating a 6-volt radio from a 12-volt electrical system is not quite so ideal a situation as using a radio specially designed to operate from the higher voltage. Never-the less, if the installation is carefully made the low-voltage radio can be made to operate almost as well as a regular 12-volt radio, and most owners will not detect any difference.

A few precautions must be observed in making such an installation. Most important, of course, is to make certain the mechanical connections and arrangements are neat and secure. No wires should be permitted to dangle. Electrical connections should be firmly made.

In those cases where a voltage-dropping resistor is used it is important that it have sufficient wattage to dissipate the heat developed within it. Remember, the resistor will dissipate the same amount of electrical power as the radio itself. This means that if the radio uses 35 watts of power the resistor will dissipate 35 watts. If the radio uses a larger amount of power, the resistor will do likewise.

If you attempt to get by with a resistor rated at 2 watts, or 5 watts, or even a 10 watts, you are just asking for trouble. There is a real danger that such a low wattage resistor will become so hot it may even set the automobile on fire. Even in those cases where no fire results, the resistor would probably burn itself open.

NOTES FOR REFERENCE

The automobile receiver power supply may contain a synchronous vibrator, a non-synchronous vibrator, or a dynamotor.

The synchronous vibrator is less popular than the non-synchronous.

The synchronous vibrator has five or more base pins. The non-synchronous type has only four.

A receiver with a synchronous vibrator does not contain a rectifier tube.

When testing a car receiver while it is still in the car, look for indications of current drain on the car ammeter, for the lighting up of the pilot lamp, and for burned out fuses. Listen for the sound of the vibrator buzz.

In testing the car receiver on the test-bench, be sure the battery is properly connected (in the case of a synchronous vibrator) and that an antenna is properly connected to the receiver. Also, make sure the test battery is sufficiently charged.

If the loud-speaker is left in the car when the set is removed, do not forget to connect up a low impedance test speaker.

If the power supply of an automobile receiver is known to be in operating condition by test-bench analysis, and still the set does not operate, proceed as in the case of any other superheterodyne receiver. Check from stage to stage with the signal generator. First locate the defective stage, and then check this stage against standards for the stage. The manufacturer's wiring diagram is the final authority for stage readings.

Before removing a receiver from the car for test-bench analysis, make a resistance-check on the antenna and its shielded cable to make certain the trouble is not in these components.

Car static is the car receiver's worst enemy. Only when the receiver AVC circuit is sufficiently energized by a strong signal, and all suppression measures have been taken, can we expect the static to be completely removed.

Among the most common troubles in car receivers are defective tubes, vibrators, and filter condensers. For this reason, they should be checked as early as possible, before checking the more complicated circuits.

Radio receivers can be tuned by varying either the inductance or the capacity of the tuning circuit.

Some automobile radios use variable inductance tuning.

Variable inductance tuning is more expensive than variable capacity, but is more sensitive, more compact, and more free from trouble.

Many newer automobiles use a 12-volt electrical system.

Older 6-volt automobile radios can be converted to operate from the newer 12-volt electrical systems.

To use a 6-volt radio on a 12-volt electrical system it is necessary to either drop part of the voltage or connect the radio across only a part of the storage battery.

If a voltage-dropping resistor is used to operate a 6-volt radio from a 12-volt electrical system it is necessary to carefully calculate the resistance needed, and use a resistor with adequate wattage.

NOTES

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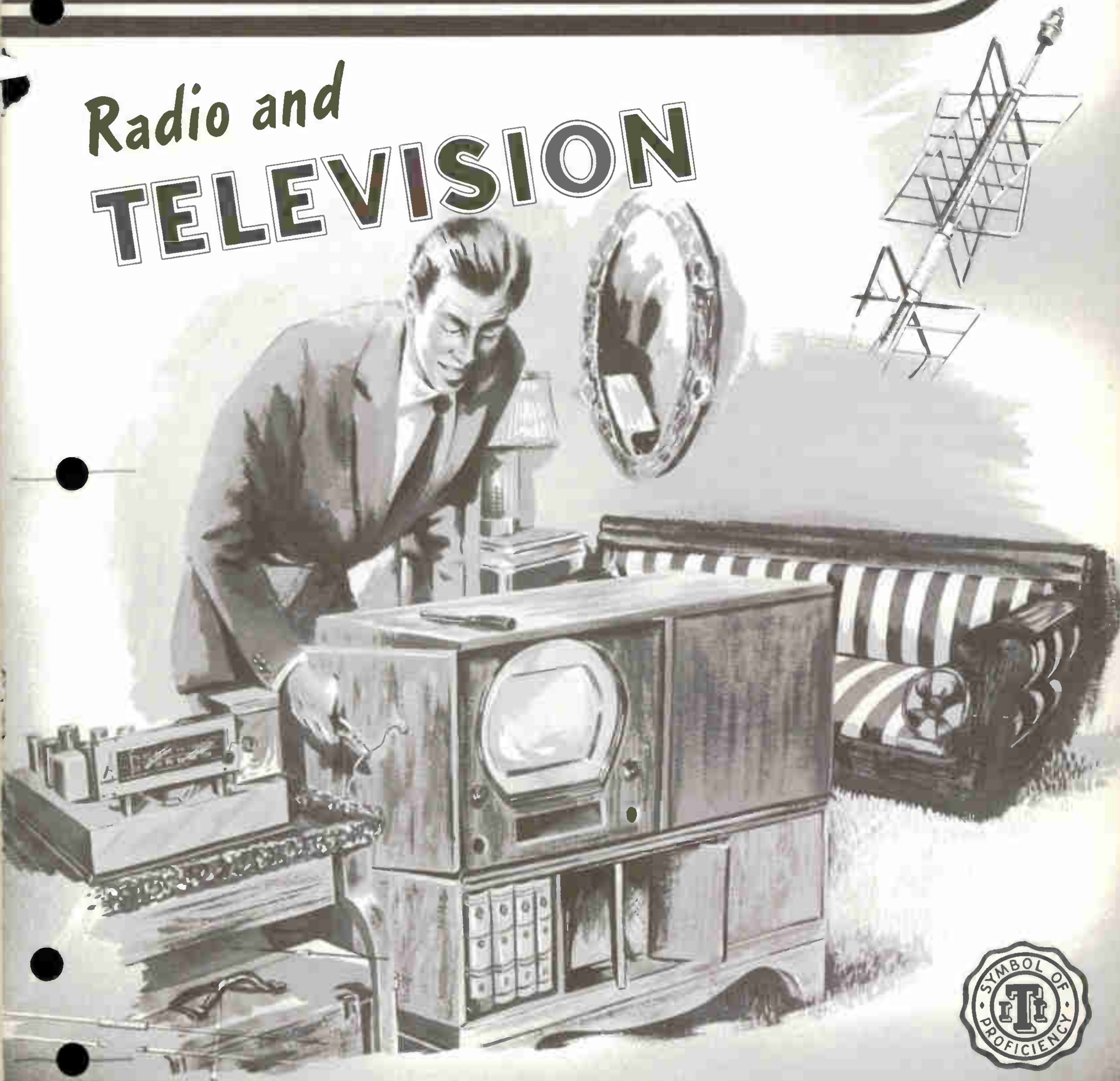

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TECHNICAL TRAINING SERVICE

REVISED 1952

RADIO TELEVISION

AUTOMATIC CONTROLS

Contents: Introduction - Types of Automatic Controls - Electrical Push-Button Tuning - Mechanical Push-Button Tuning - Electro-Mechanical Push-Button Tuning - Motor-Driven Automatic Tuning - Solenoid-Operated Push-Buttons - Setting the Motorola Automatic Tuner - Trouble-Shooting Push-Buttons - Crystal Phasing - Fully Automatic Controls - The Tuning-Eye Indicator - Automatic Frequency Control - How AFC Works - Notes for Reference.

Section 1. INTRODUCTION

As the art of radio and television receiver design has improved with the passing years it is only natural that many refinements would be added to them. These refinements have been designed to increase the enjoyment of those who use them. To fully appreciate the changes which have taken place during the passing years it is necessary to review the construction of the very earliest receivers. To most of us who have become accustomed to receivers built during recent years the operation of one of the earliest commercial receivers would seem unbelievably complex.

The earliest radio receivers offered the public by radio manufacturers were all built on the TRF principle. Several stages of RF amplification was included. These several stages were not mechanically coupled together; to select a station it was necessary to tune each stage individually. It was often necessary to fiddle with the multiplicity of dials for the various stages for many minutes before all of them could be tuned to the same frequency -- and the same broadcast station.

The first step toward simplification of the controls was the introduction of the ganged condenser. Because several stages of RF amplification was necessary for reasonably good reception most of the earlier gangs had three or four sections. But the then new type condenser served the purpose of reducing the number of controls needed to tune in a station from some four or eight to not more than two or three. This was a tremendous advance in the art of radio reception[1]. Anyone could now operate a radio receiver; no special knowledge was needed.

The development of the superheterodyne improved still further the simplification of controls needed for operating the receiver.

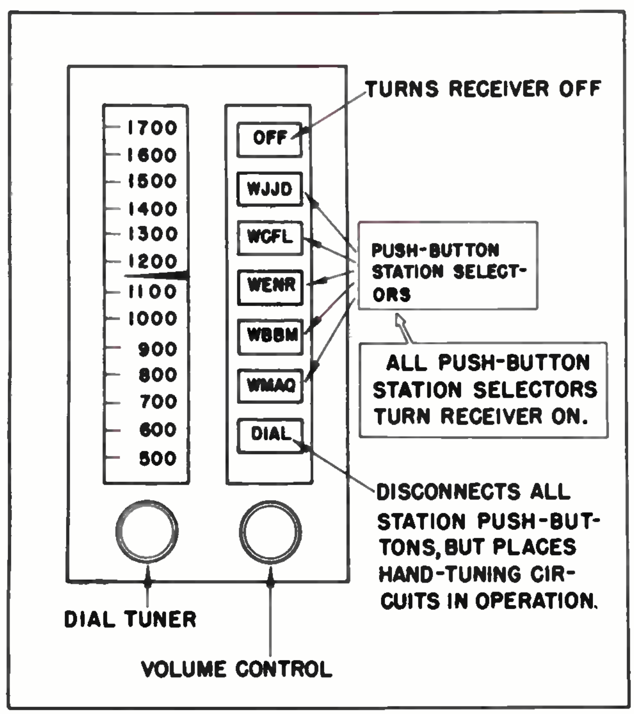


Fig.1. Front Panel of an Automobile Receiver Using Electrical Push-Button Tuning.

But even this stage of simplicity was not enough. Many persons still seemed to experience trouble in properly tuning their receivers. It might be argued they were unnecessarily lazy. Still other things might be said about them. The real truth, of course, is that they are Americans. And Americans are accustomed to having the very finest of everything, and having everything designed to give them the greatest enjoyment.

To make these things possible in the radio field, designing engineers have continued to improve on the operation of radio receivers. Now it is often only necessary to push a button to select the program one wants to listen to, or in the case of television, to watch.

In many cases a special tube is provided -- a "tuning" eye -- which aids the user in properly selecting the station. In many receivers the frequency is automatically locked in properly if the receiver is tuned only approximately correct. In these receivers it is impossible to tune in a station improperly, provided the controls themselves are functioning properly.

All of these things have made the operation of the receiver much easier for the user. More enjoyable. But it has added to the work of the repairmen. It has placed more demands on him, made it necessary for him to know many more things about the work than formerly.

The purpose of this lesson is to describe the operation of these automatic controls. It is scarcely possible to describe the operation of every individual automatic control in existence. Such a description would make extremely tedious reading, and would serve no real purpose. A description of the principle involved in each of the various types will make it possible for you to understand the actual operation of any type you will ever encounter.

Self-operating controls, some of them semi-automatic and others completely automatic, have become an integral part of all kinds of electronic equipment. They are not confined to radio and television alone. They also extend into the fields of radar, sonar and loran, as well as into industrial electronics.

The refinements in these controls have been carefully developed and engineered. In all cases certain specific requirements have been kept in mind. Among the requirements are these:

(1) Safety.

(2) Efficiency.

(3) Stability.

(4) Accuracy.

(5) Simplicity.

(6) Convenience.

The automatic controls studied in this lesson will fulfill one or more of the above requirements.

Not all automatic controls are adapted to all types of receiving equipment. The automatic push-button tuning in an automobile receiver, for instance, would be out of place in a portable receiver. The tuning-eye indicator, so useful to the Deluxe Console home receiver, would be entirely superfluous in a television receiver. Many other examples could be listed.

This lesson is devoted to the application, operation, adjustment, and trouble-shooting of automatic controls as found in modern electronic receiving equipment.

Section 2. TYPES OF AUTOMATIC CONTROLS

Automatic controls in electronic receiving equipment may be studied under two separate groupings: Those which are semi-automatic, and those which are fully automatic.

Semi-automatic controls are those whose action is manually initiated, and include electrical push-button tuning, mechanical push-button tuning, electro-mechanical push-button tuning, and crystal-controlled tuning.

Fully automatic controls are those whose action is independent of manual adjustment, but which respond to various changes in signal strength or signal frequency at one or more points in the receiving circuits. Under this grouping may be listed automatic volume control (AVC), delayed automatic volume control (DAVC), tuning-eye indicators, and automatic frequency control (AFC).

Section 3. ELECTRICAL PUSH-BUTTON TUNING

The purpose of any type of push-button tuning is to easily and accurately set the

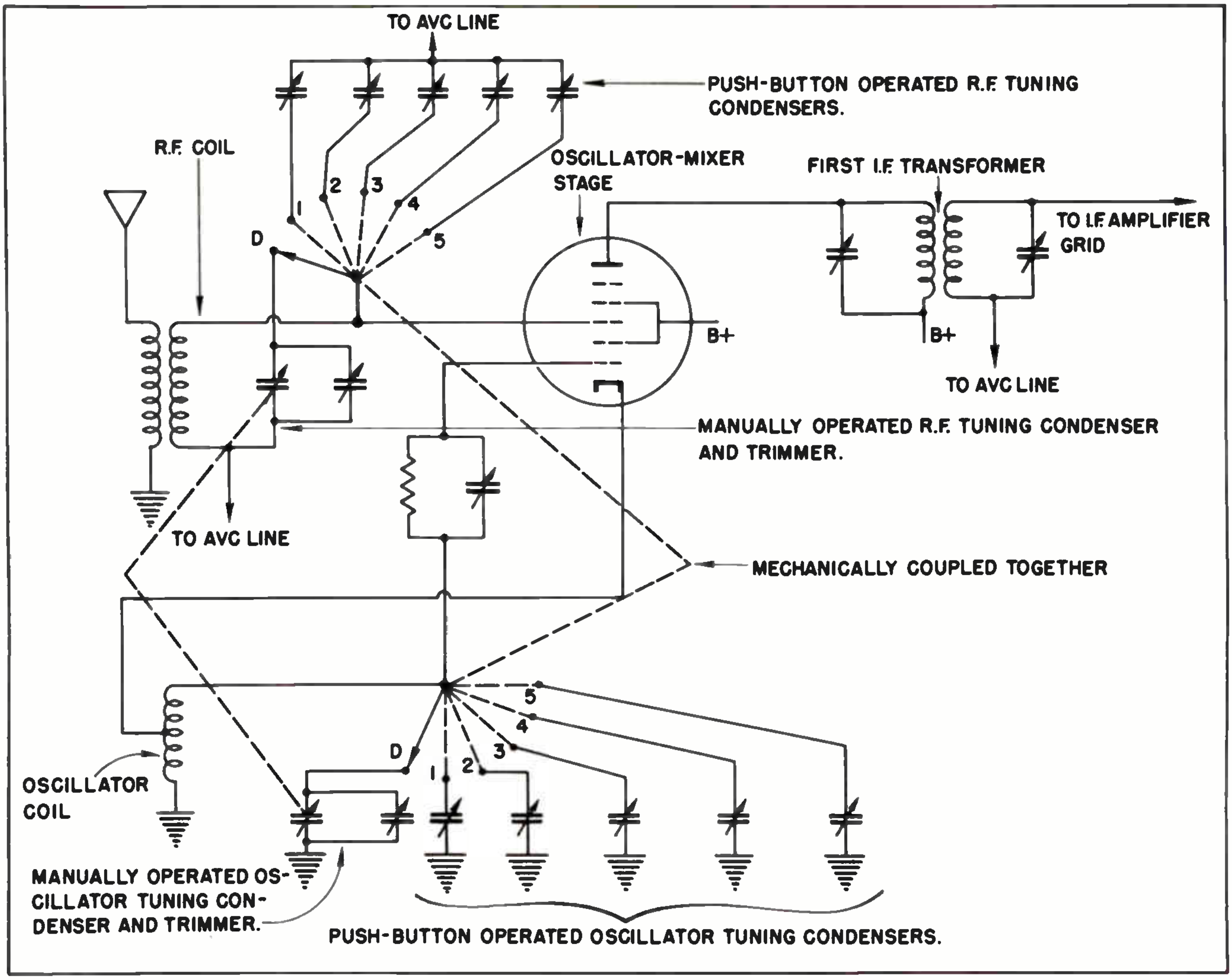


Fig.2. Schematic Circuit of an Electrically-Operated Automatic Push-Button System.

receiver station-selector to a pre-determined place on the dial. Its advantages are obvious. In the automobile receiver, the push-button tuning system is an important factor of safety, for it permits the driver of the car to devote a minimum of attention to the receiver tuning apparatus while selecting a desired station on the dial. A fast glance out of the corner of his eye is usually sufficient to enable him to pick out and manipulate the correct button for the station desired. In fact, after a short time, he learns to select a desired station from the feel of the push-buttons, and he need not take his eyes from the road while driving. The importance of this feature of safety cannot be overestimated.

In the home receiver, push-button tuning of any type is also useful and convenient. In the first place, it is fast. Secondly, it is accurate, once it has been properly adjusted. Then, too, push-button tuning is a boon to the blind listener, and to those with poor eyesight. Children, listening to their favorite programs, may select their stations with little effort by using the push-buttons. They are always assured of clear reception which may be lacking if they tried to tune the station in on the regular station selector knob.

Few television receivers use an automatic tuning system for selecting desired channels.

The purely electrical form of automatic push-button tuning is simple in principle and adjustment, and easy to trouble-shoot. Fig. 2 shows the fundamental circuits involved.

The only tuned circuits involved here are those of the RF tuning section and the oscillator resonant circuit. We recall that any signal tuned in by the RF circuit is immediately met, in the oscillator-mixer stage, by an oscillator output which beats with it to achieve the I-F difference. When the push-button system is in position "D" (for dial), the manually operated tuning condenser of both the RF and oscillator resonant circuits are placed in use. As the diagram illustrates, the contacts of position "D" connects this pair of manually operated condensers -- adjusted by the station selector knob -- to their respective resonant coils. Position "D", therefore, is the dial position, permitting the operator to select desired stations by manual tuning.

Note that the RF coil is always connected to the signal grid of the oscillator-mixer stage, and that the oscillator coil is always connected through the biasing network to the oscillator grid of this stage. This means that when the push-button position 1 is selected, the manually operated condensers of position "D" are disconnected, but in their places are connected two new condensers, one for the RF coil and one for the oscillator coil.

These condensers, which are of the trimmer type, resonate their respective coils each to its specific frequency, so that there is still the I-F difference between the incoming signal and the oscillator frequency. The adjustment of this new pair of condensers can be made with a screw-driver for any desired station within a wide range on the dial. Once adjusted, and neglecting drifts, these condensers will continue to resonate their coils to a desired station whenever the push-button calls them into service. This, of course, is when push-button 1 is selected.

In similar manner, when the push-button system is in position 2, still another pair of condensers is selected to resonate the RF and oscillator coils to frequencies corresponding to another desired station. The system shown in Fig. 2 provides for five stations on push-buttons, and manual dial tuning as well. This is common practice in the purely electrical type of push-button tuning.

While Fig. 2 shows the circuit for this type of push-button tuning employing rotary switches, in actual practice it appears different, from the physical point of view. If a rotary switch is used, as in some automobile receivers, this switch is not located on the dial panel of the receiver, but is mechanically operated through a steel cable connection between a single push-button and the chassis of the receiver itself. The button is then pressed once for each step of the rotary switch. If the button is pressed twice, then the rotary switch will turn through two positions.

Another popular variation of the purely electrical push-button tuning system is to use a specially built assembly operating on the bar principle. Fig. 1 shows the front panel view of this type of system.

There are generally an array of seven or eight separate buttons in this system. The upper one is used only to turn the receiver off, and will remain in the depressed position after being operated. When the receiver is turned on again by any of the other push-buttons, the top button springs out. This is accomplished with a mechanical bar and switch within the receiver. If a certain station is desired -- let us say WBBM -- then the button with WBBM is pressed. The receiver power is turned on and when the set warms up, the listener will hear the signal from WBBM. Should he desire to change to another station, for instance WJJD, he merely presses that button, and when he does so the WBBM button will spring out while the WJJD button will remain depressed.

Now, if he should want to operate the manual tuning knob, he presses the dial button. The WJJD button will now spring out and the dial button will remain depressed. The hand tuning condenser is now in the circuit and any station on the dial may be tuned in.

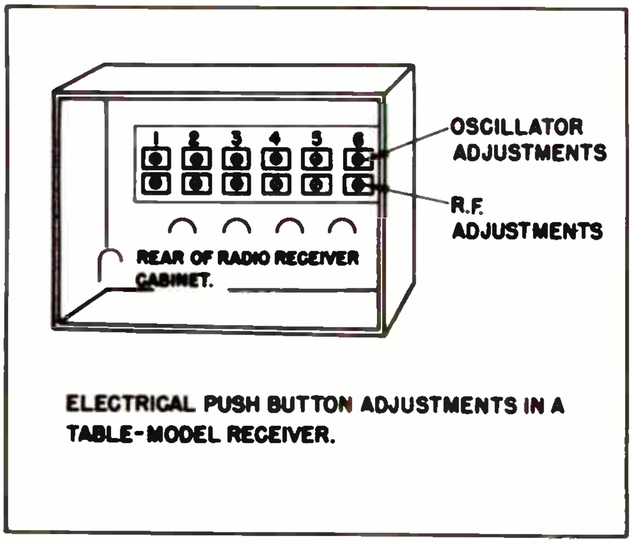


Fig.3. Rear View of a Receiver Using Electrical Push-Button Tuning.

Except for the addition of the on-off switching in this arrangement, this method is identical with that of Fig. 2. The difference is solely in the mechanical method of effecting the switching changes.

In some receivers, including a number of Zenith models, the push-button makes and breaks circuits in the oscillator and RF coils instead of in the condensers. A fixed condenser is then placed in common to all of the separate coils, and desired resonance is obtained by pre-setting the inductance of each coil by adjusting the slug core around which it is wound. This adjusting operation may be done either by removing each push-button cover individually, or by removing a plate covering them all.

Note that in both types of push-button systems, there are two adjustments for each push-button: The oscillator adjustment, and the RF adjustment.

In making the adjustments in a purely electrical push-button tuning system, the following procedure will be helpful.

1. Find the adjusting screws. In console and table-model receivers these adjusting screws are usually accessible from the rear of the cabinet. (See Fig. 3.) In automobile receivers, as well as in those of the radio-phonograph type, the adjusting screws are most often (but not always) found beneath the individual push-buttons, which are removable for the purpose of making the adjustments. (See Fig. 4.) Portable receivers seldom are equipped with push-button tuning.

2. Using the manual tuning, select the station desired for a given push-button and identify the signal from that station.

3. Depress the push-button on which that station is to be placed, and adjust the oscillator trimmer screw until the signal from that station is heard.

4. Finally, adjust the RF trimmer screw until that station signal comes in the loudest.

5. Make a final check by manually setting the dial to make sure that the push-button and the dial both bring in the same signal.

6. Place the proper station call-letters on the button.

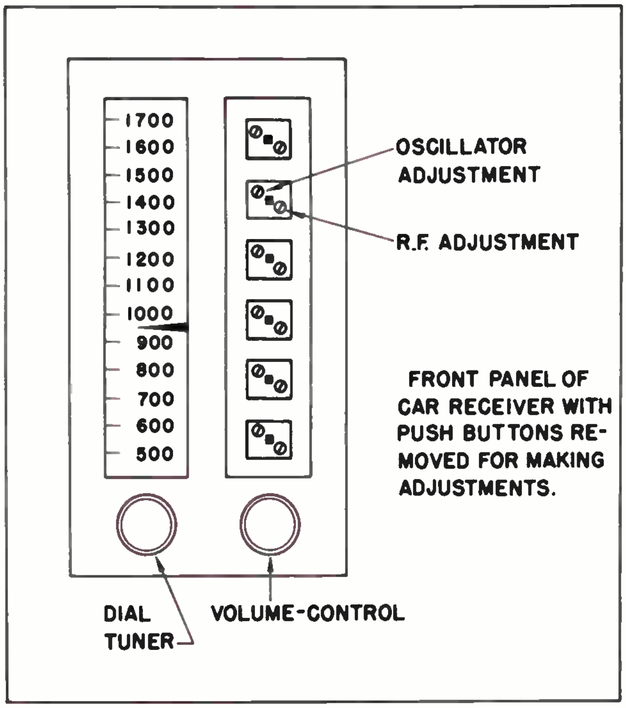


Fig. 4. Front View of a Receiver Using Electrical Push-Button Tuning. The Push-Buttons Have Been Removed to Expose the Adjusting Screws.

Because of the wide variety of receivers containing electrical push-button tuning, the procedure outlined may have to be altered to suit special cases. In general, however, and with the ingenuity of the technician, this procedure is satisfactory. Where special cases arise, the technician can generally adapt his methods to the requirements of the case.

Section 4. MECHANICAL PUSH-BUTTON TUNING

This method of automatic tuning involves the use of levers and gears to couple the push-button to the same tuning apparatus used in manual station selection. The essential parts of this type of push-button tuning are shown in Fig. 5.

The adjusting screw may be reached when the push-button is removed. The operation is extremely simple, as can be seen from the diagram. When the push-button is depressed, the pre-set adjustable nut on the screw shaft comes to rest at the mechanical stop. This permits the push-rod to move the rocker lever only a certain amount. The gears cut into the rocker, engage a circular gear which is fastened to the variable condenser gang shaft. Thus the variable condenser

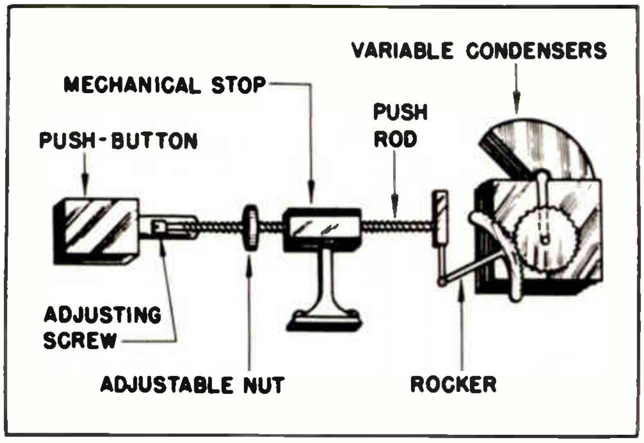


Fig. 5. The Principle of Mechanical Push-Button Tuning.

gang will move to a certain position. A spring, not shown in the illustration, returns the push-button and adjusting screw to the normal position after the button is pressed and released.

While this system is not the only one employed by mechanical push-buttons, it is the most common. Here, too, engineers devise various means of accomplishing the job.

The procedure for aligning this type of mechanical push-button system may be outlined as follows:

1. Remove the push-button itself by pulling it forward.

2. Set the manual station selector in a position to bring in the desired station.

3. Loosen the adjusting screw by turning counter-clockwise with a screw-driver.

4. This step must be done carefully. Push the adjusting screw in all the way, applying force on the screw-driver, and tighten the screw while still applying pressure to it.

5. Replace the push-button and insert the proper station call-letters.

Corresponding settings may be made for the rest of the push-buttons.

In some receiver models, including a number of Chevrolet automobile receivers, no screw-driver need be used, since the push-buttons are round and adjustment may be made by turning the push-button itself. The procedure, however, is the same. Fig. 6 illustrates the appearance of these round, knurled push-buttons which may be adjusted manually without removing the button itself.

Section 5. ELECTRO-MECHANICAL PUSH-BUTTON TUNING

This method of automatic station selection is a combination of electrical and mechanical action. There are two general types used: The solenoid-operated and the motor-driven. Each of these will be described. These types are most frequently encountered in automobile receivers.

Section 6. SOLENOID-OPERATED PUSH-BUTTONS

This method of accomplishing push-button tuning is most popular in automobile receivers, and is also termed "relay-operated". Because different manufacturers have their own plans for the construction and setting of solenoid-operated push-buttons, and may even vary the methods from one model to the other, it is not feasible to give a clear-cut procedure for the alignment of each model of this type. However, a general picture of solenoid operated automatic tuning is illustrated in Fig. 7.

The push-buttons, located upon the car control panel, are connected to the solenoid coil through a ground connection. When it is depressed the push-button switch connects the solenoid to ground and completes the battery circuit so that the solenoid is energized. The push-button may then be released, since it merely initiates the action which is to follow.

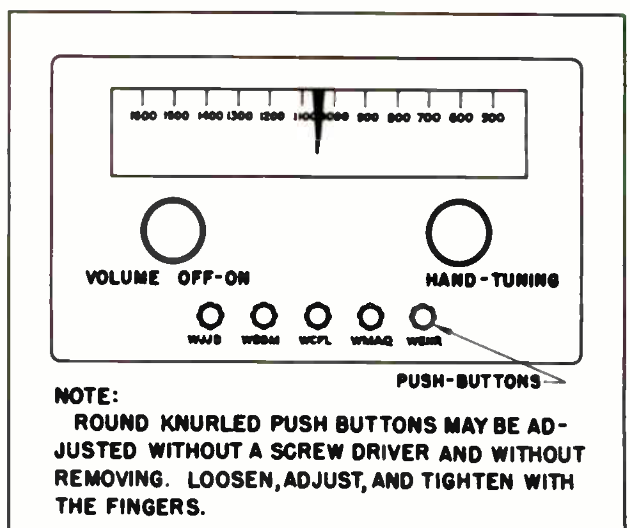


Fig. 6. These Push-Buttons Need Not be Removed for Setting to Proper Station.

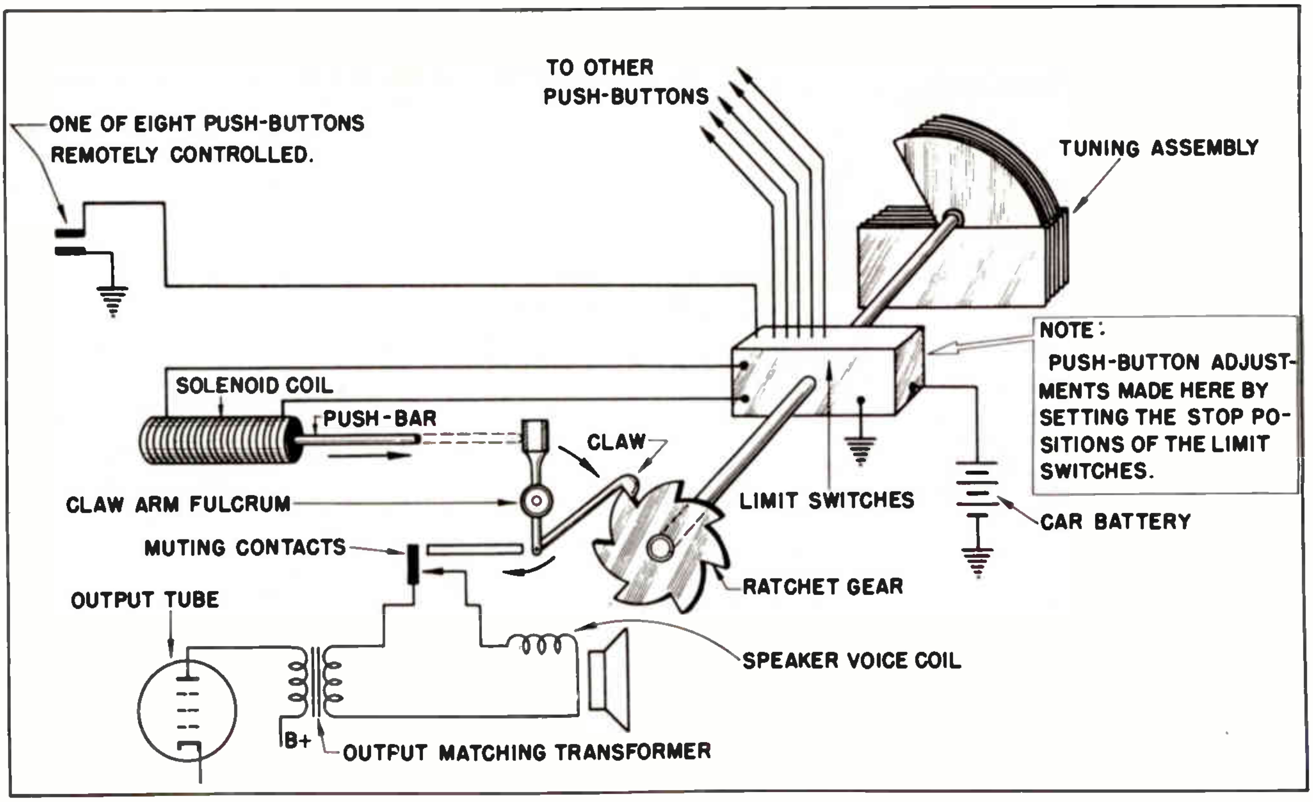


Fig.7. The Principle of a Solenoid-Operated Automatic Push-Button Tuning System.

When the solenoid is energized, a switch within the limit-switch assembly shorts out the connection to the push-button. The relay continues to repeat its operation; the shaft connected to the toothed gear turns until the limit switch corresponding to the push-button is opened by the movement of the rotating shaft. This simply means that the limit switch breaks the ground connection of the solenoid when the desired station is reached by the rotating shaft.

The claw shown in the illustration pulls the ratchet gear one position every time the solenoid is energized. When the limit switch de-energizes the solenoid, the gear remains stationary. At the same time an extension of the claw arm operates the "muting-contacts". These are a series-connected, single-pole single-throw switch which opens and closes the voice coil circuit so the speaker will be completely silent until the desired station is brought in.

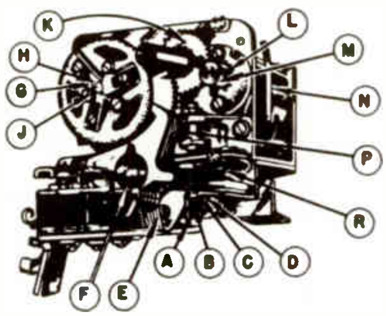
As was indicated in the illustration, setting this type of push-button system is accomplished generally by adjusting the point at which the limit switch for each station cuts off the battery current for the solenoid. Another way of setting these push-buttons is to adjust the mechanical coupling between the tuning shaft and the tuning assembly for each push-button position.

It is suggested that you secure the wiring diagram for any specific receiver under examination before attempting any adjustments. Follow the push-button setting procedure given therein. The manufacturer usually gives very complete information in his operating manuals regarding the setting, adjustment, and servicing of the push-button tuning system.

In most cases adjustments may be made from outside the receiver. Exact instructions are provided by the manufacturer. It is usually advisable to make the push-button adjustments on the test bench rather than in the car. They can be made more accurately and more easily because of the better accessibility.

Section 7. MOTOR-DRIVEN AUTOMATIC TUNING

While this type is being slowly replaced by the more modern solenoid and electrical systems, there are still many receivers of the automobile and home type which include motor driven automatic tuning. Fig. 8 shows a photograph of the Motorola Electric Automatic Tuner, an example of which would be



A. SWITCH ADJUSTMENT SCREW.
B. SWITCH ADJUSTMENT SCREW.
C. SWITCH ADJUSTMENT SCREW.
D. SWITCH ADJUSTMENT SCREW.
E. LATCH TENSION SPRING.
F. LATCH AND SHAFT ASSEMBLY.
G. LOCKING SCREW.
H. LOCKING LEVER
J. LATCH RING ASSEMBLY SCREW.
K. MANUAL TUNING GEAR AND COUPLING.
L. MOTOR PINION
M. PINION COLLAR
N. TUNING MOTOR
P. MUTING RELAY COIL
R. REVERSING SWITCH

Fig.8. A Motor-Driven Automatic Tuning Unit.
(Courtesy Motorola Radio Corp.)

their model E5T. Notice the locations and names of the parts used.

A circuit diagram showing the electrical connections in this tuner is illustrated in Fig.9. It is worthy of study. Note there is a special electro-magnet for each push-button, and that a special muting relay is also included. Another point of importance is that the motor is made reversible, and that it will therefore turn only in the direction demanded by the specific push-button pressed. This is accomplished, of course, by the action of the latch arm against the reversing switch.

To illustrate the completeness with which Motorola describes the setting of the push-buttons on this motor-driven system, we include their outline for the setting procedure.

Section 8. SETTING THE MOTOROLA AUTOMATIC TUNER

Note: Before setting any station, let the set warm up for not less than ten minutes. If you wish, you can set the automatic tuner on the bench before installing the receiver. Use a short antenna and peak the antenna trimmer to it. Then re-adjust the antenna trimmer after the installation in the car.

Important: You will note that the 9-contact plug on the end of the control-head cable has one pin that is shorter than the others. For the setting-up procedure, this plug should be inserted in its receptacle on the receiver only half-way. This will cause all the magnet terminals to be connected, but will not permit the tuning motor to run during the adjustment, since the short pin will not make contact, thereby holding the motor circuit open. The motor should not run at any time during the setting-up procedure.

1. From the set of call letter tabs provided, detach the proper ones for the six stations. The station tabs should then be inserted in the space provided in the face of station tuning buttons. Cover the tab with a small rectangular piece of celluloid. Both tabs and celluloids snap into position.
2. Loosen the automatic locking screw. This screw should be turned counter-clockwise, four or five revolutions -- far enough to assure plenty of looseness.
3. Turn the dial all the way to the low frequency end (535 k.c.).
4. Press the first button and hold it down. A faint click should be heard, indicating that the tuning magnet has attracted the latch-bar.
5. Holding the magnet energized, turn the dial manually all the way to the high frequency end (1550 k.c.) and then all the way back to the low frequency end (535 k.c.).
6. Still pressing on the button, tune in the station to be set on that button.
7. Proceed to set the remaining five stations. For each station, follow steps 3, 4, 5, and 6, as outlined above. AT NO TIME IN THE SETTING-UP PROCEDURE SHOULD THE MOTOR BE PERMITTED TO RUN.
8. Tighten the automatic locking screw very securely. Do not hold the tuning knob while locking the automatic, but allow the mechanism to turn to its natural stop.
9. Push the plug all the way into the receptacle on the receiver housing so the short motor pin will also make contact.

Section 9. TROUBLE-SHOOTING PUSH-BUTTONS

Depending upon the exact type of push-button tuning system used, the troubles in

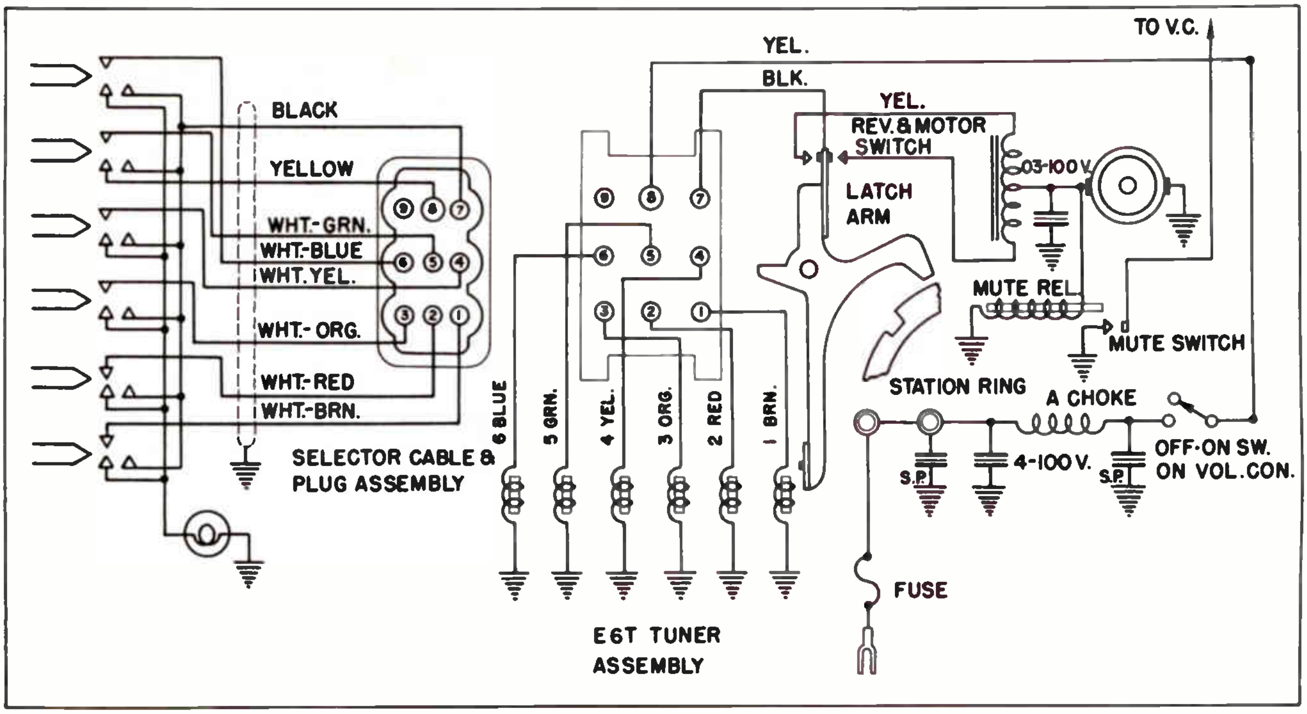


Fig.9. Circuit Diagram for the Motorola Automatic Tuning Unit. (Courtesy Motorola Radio Corp.)

a push-button system may be logically traced to their causes.

In the purely electrical type, troubles usually occur in a single push-button, and the cause may be traced by examining the action of that one. For a common trouble in this type is an open connection to a specific condenser. If the connecting wires are intact, the trouble probably lies in the sliding contacts which electrically engage this particular condenser. To correct trouble in the contacts the best plan is to clean the contacts with carbon tetrachloride or some other non-combustible solvent. This may be done by pouring a few drops of solvent upon the push-button contacts involved, and operating them vigorously several times. The station should come in clearly when the button is depressed. If it comes in intermittently, the contacts may have become soft, which means that the spring pressure against them is weak. In this case, careful bending with a sharp blade usually helps to make positive contact. Note that the trouble is immediately traced to a specific push-button by the obvious fact that all other buttons operate correctly.

If none of the push-buttons operate properly sliding contact trouble can usually be ruled out. The trouble is obviously in a circuit common to all of the buttons. Such a trouble may well lie in a lead common to all of the condensers which lead to the tuning coils of the receiver. An open ground connection between the push-button assembly and chassis ground of the receiver may be broken loose. There is also the possibility that the AVC return from the RF condensers, common to them all, may be broken loose. Visual inspection is invaluable in tracing a trouble of this type.

Drifting of the settings is probably the most common of all types of push-button tuning defects. This is easily corrected by re-setting the button or buttons involved. As a rule a receiver should have the push-button system re-adjusted once each year. Such precaution will take care of small drifts due to the slow aging of the materials from which the condenser plates and di-electrics are made.

A de-tuned push-button generally announces itself when the station allotted to it becomes weak, and is accompanied by considerable static. To check this possibility tune the same station in by manual tuning. Then compare the strength and static content of the signal. If the station is weak on its push-button, and the static is above normal, but reception is good on manual tuning, a re-adjustment of the push-button is indicated. If the signal is weak on both push-button and manual tuning, and the static level is high on both, then receiver circuit troubles are indicated. These symptoms indicate a weak RF or I-F amplifier tube, de-tuned I-F trimmers, and a shorted or open antenna.

Trouble-shooting the solenoid type of automatic push-button tuning should be done with the aid of the circuit diagram and manufacturer's notes for the receiver in question. General rules, however, may be followed.

If none of the push-buttons operate properly the solenoid winding may be open. If the receiver blows fuses when the push-buttons are pressed, the solenoid or something connected to it mechanically, may be stuck. If the solenoid keeps energizing and de-energizing, look for trouble in the limit switch assembly. A shorted ground connection within this assembly could cause the continuous operation of the solenoid.

In some of the solenoid systems cold weather may account for their failure to operate, or cause them to operate very sluggishly. While we cannot, as a rule, change the weather, there is a provision for speeding up the action of the solenoid. As indicated in the manufacturer's wiring diagram of the set, the technician may make an adjustment of the "dash-pot" brake in the solenoid assembly. This "dash-pot" is simply a piston and cylinder arrangement connected to the solenoid push-bar designed to keep the action from operating too fast. The adjustment is to increase the size of the air-escape hole by turning an adjusting screw for this purpose. If the relay acts too fast, as it may do in warm weather or when the car motor warms up, the dash-pot adjustment may be made in the opposite direction, thus slowing down the action of the solenoid.

Cable troubles between the control head and the receiver may also develop. These would include such troubles as an open wire in the cable, or the cable plug fitting too loosely into the receptacle in either the control head or the receiver housing. Visual inspection and consideration of the faulty action will readily disclose the source of such trouble.

Among the common troubles found in the motor-driven automatic push-button system are faulty and corroded contacts at the push-button, dirty or corroded motor commutator and brushes, and mechanically worn fittings. Their faults are best determined by examining the action produced, and noting if the trouble occurs on one, or on more than one, push-button. Those that are common to all of the push-buttons may be logically traced to elements common to them all, such as the motor, the reversing switch, and the power supply lines. Those which are peculiar to only one button may be located by examining the circuits of that one button in detail.

Re-setting and re-adjusting the motor-driven system is identical with the original push-button setting procedure, except that it may not have to be made on all of the buttons.

In *A-C* receivers incorporating a motor-driven push-button system, the motor is of the capacitor-start-capacitor-run type. This includes the electrolytic condenser required to shift the phase of the A-C input power for starting the motor when a button is pushed. A shorted or open electrolytic condenser here could also make the system fail to start. Another cause for failure may be open winding within the motor. Ohmmeter tests on the motor windings and the electrolytic capacitor are excellent guides in trouble-shooting this type of system. However, these motors are so ruggedly built this kind of trouble is very rare.

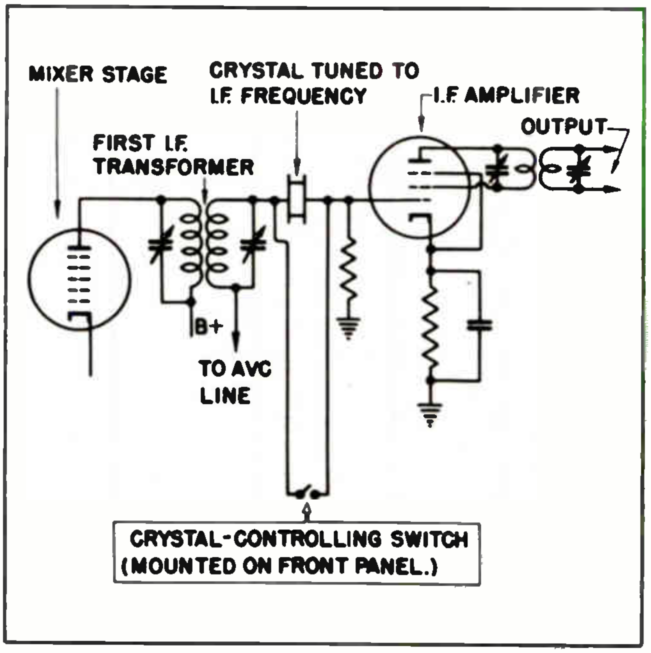


Fig. 10. Crystal-Control of an I-F Tuned Circuit. The Switch is Located on the Front Panel.

Section 10. CRYSTAL PHASING

Another form of automatically controlling the action of a circuit is known as crystal-phasing. Such a circuit uses a Piezo-electric crystal to keep the band-width of the I-F amplifier stages extremely narrow and therefore gives them extremely high gain.

Fig. 10 illustrates the application of such a crystal (made of quartz, Rochelle salts, or tourmaline) in a modern communications receiver where especially high gain is required.

The plate circuit of the mixer stage is loaded in the ordinary way with the primary of the first I-F transformer. The secondary of this transformer, however, in addition to being tuned to the I-F frequency, is connected by the phasing crystal to the grid of the first I-F amplifier. The result is that the frequency response of the crystal limits the band-width to this grid.

Since the crystal, by virtue of its very high "Q", is extremely efficient, only those frequencies of the I-F carrier which are almost exactly in agreement with the resonant frequency of the crystal will be permitted to pass through to the first I-F amplifier grid. The consequence of this arrangement is that the I-F amplifier, designed to amplify most efficiently at exactly the I-F frequency, will impart an extremely high gain to the input of the first I-F amplifier stage.

This, of course, makes the receiver more sensitive and capable of reaching out over a wider receiving range. Such high gain, and its resultant narrow band-width, are desirable where long-distance code reception is desired. In music reception, where the band-width must be wide enough to include all of the important musical harmonics (or overtones) such crystal-phasing would distort the musical signal. In order to accomodate musical signals with good fidelity, and at the same time pick up long distance signals with high sensitivity, the manually, operated crystal-controlling switch is provided.

As the diagram shows, this switch is placed on the front panel of the receiver. When high sensitivity is required, as would be the case with trans-oceanic voice or code signals, the switch is opened. This places the crystal in the circuit. When local musical signals are to be brought in by the

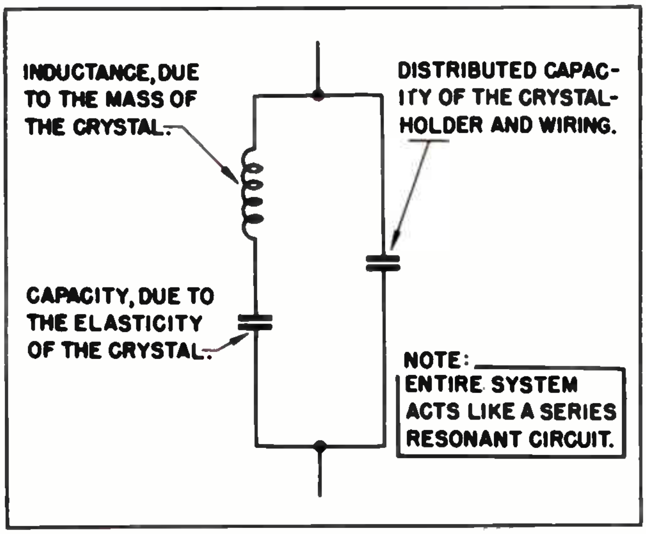


Fig.11. Equivalent Circuit of Crystal Used in Crystal-Phasing.

receiver, the operator closes the switch and shorts out the crystal. Now the "Q" of the circuit is low enough to widen the band-width and receive musical signals with good fidelity.

The equivalent electrical circuit for a Piezo-electric crystal of the type mentioned is shown in Fig. 11. The high "Q" of the crystal is possible because of the high value of *inductive reactance* as compared to resistance. Note that the entire arrangement acts like a *series resonant circuit*, providing the capacity between the holder plates is kept low in comparison with that of the crystal.

Section 11. FULLY AUTOMATIC CONTROLS

Let us now turn our attention to the group of controls which are fully automatic, and once installed, are independent of manual operation. Their response, in contrast to semi-automatic controls, is under the influence of either amplitude or frequency changes in the circuits of which they are a part.

Automatic Volume Control (AVC), and Delayed Automatic Volume Control (DAVC) have been covered elsewhere. These two circuits belong to the group of fully automatic controls, responding to changes in antenna signal strength by producing bias voltages for the tuned amplifiers which increase their gain when signal strength is low and decrease their gain when signal strength is high. They are self-operating and fully automatic.

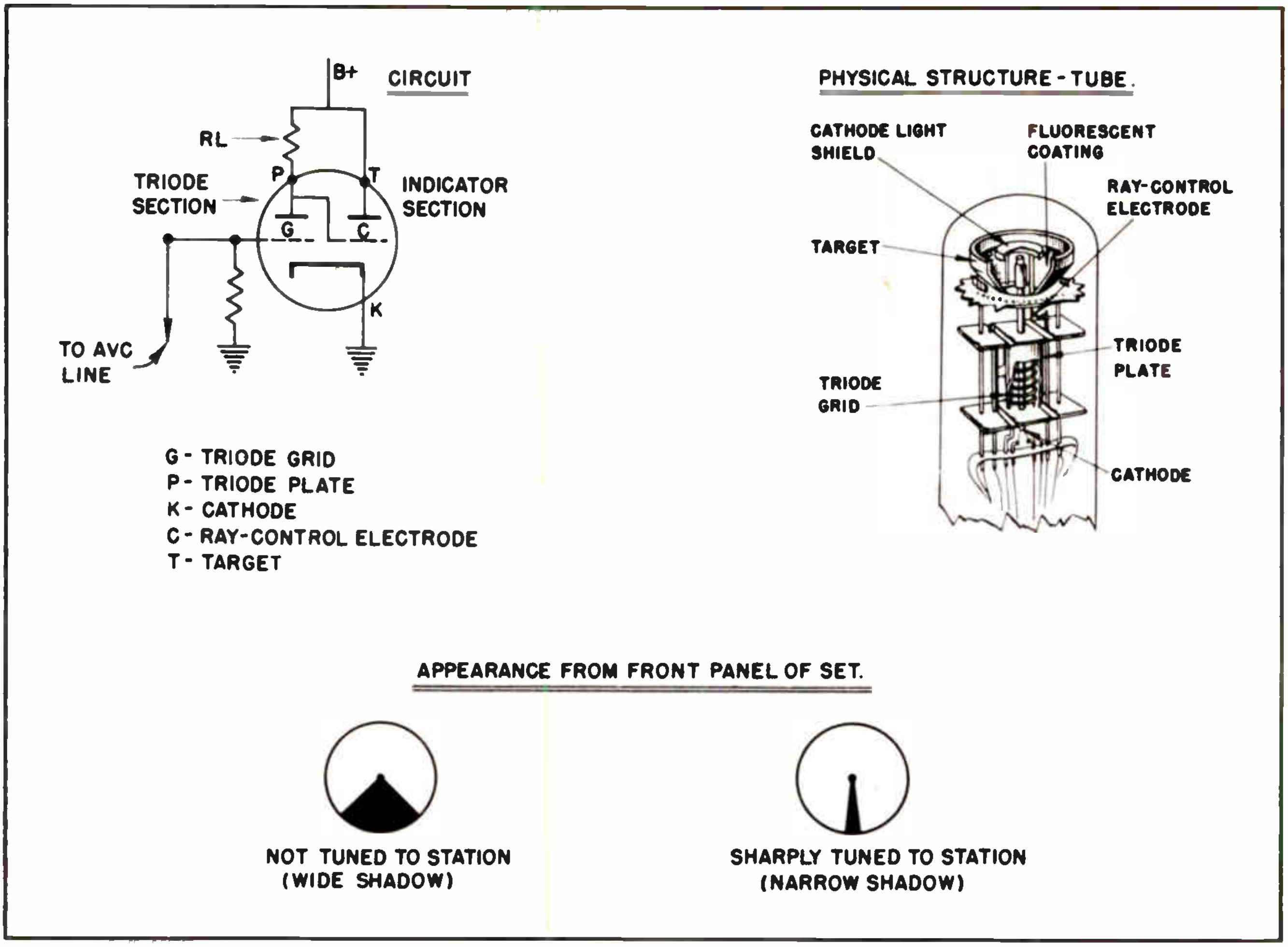


Fig.12. Principle, Construction, and Appearance of Tuning-Eye Indicator.

Section 12. THE TUNING-EYE INDICATOR

This indicator has often been referred to as the *Magic-Eye*. Its purpose is to indicate to the person who is tuning in a radio signal just where the tuning is most accurate. It is especially useful on FM and in the console type of receiver as an assistance in adjusting the push-buttons. It is also employed in recording devices, to indicate the proper degree of modulation to be used. Fig. 12 illustrates the important details of its physical and electrical structure.

The diagram illustrates that the tube -- called an *electron-ray tube* -- consists of two sections: a triode amplifier and an indicator. The indicator is visible as a ring of green fluorescent light from the top of the tube, which is mounted to expose this view from the front of the receiver. The target is coated with a sensitive surface which lights up green when electrons fall upon its surface.

The control grid of the triode section is connected to the AVC line of the receiver. Since the AVC voltage becomes more *negative* with a strong antenna signal, and therefore a strong signal voltage in the second detector stage, the triode grid of the electron-ray tube is driven more negative when a strong signal is tuned in. This negative-going voltage cuts down plate current in the triode plate circuit. The drop across the load resistor (R_L) decreases, and the plate becomes more positive.

Note that the ray-control electrode is directly attached to the triode plate. This brings the control electrode toward a more positive voltage. When the control electrode is more positive, it has a decreased repellent action on the electrons flowing near it toward the target. The effect is to narrow down the "shadow" of the control electrode, as produced by electrons falling upon it. The result is that the indicating eye narrows when a strong station is tuned in sharply by the receiver.

If the station is de-tuned, for any reason, the AVC voltage is brought to a less negative value. This permits more current to traverse the triode plate load, decreasing the plate voltage. This brings the ray-control electrode down to a more negative value. Being now more negative, the control electrode has a greater repelling action on electrons flowing near it. The result is that the shadow widens and the eye opens up. This indicates the station is not being tuned in sharply.

It is interesting that there need be no modulation on a carrier wave from a transmitting station to effect tuning-eye response. The AVC voltage is a measure of the strength of the carrier frequency at the antenna, regardless of whether the signal is being modulated at the moment or not. For a given signal strength and a set tuning position, the tuning-eye indicator will remain at a constant width.

As a monitor for the modulation level in a recording machine, on the other hand, the shadow width will vary with the momentary changes in modulation strength. This is to be expected, and the volume control of the recorder is set so that the loudest sound being recorded will *just barely* close the tuning-eye completely.

Section 13. **AUTOMATIC FREQUENCY CONTROL**

Another important member of the completely automatic controls, found in radio and television circuits, is automatic frequency control (AFC). In its essential form, this circuit consists of three parts: the frequency discriminator, the reactance tube, and the oscillator whose frequency is to be stabilized. Fig. 13 is a typical circuit of this type suitable for use in AM radio, FM, or television.

The frequency discriminator is itself a fairly elaborate circuit. In a radio receiver this would be an added circuit not ordinarily used in AM reception. In FM and television, this frequency discriminator constitutes the last I-F stage of the sound channel. It is not within the scope of this lesson to discuss the details of the discriminator. However, we may assume that its purpose is to extract the audio component of

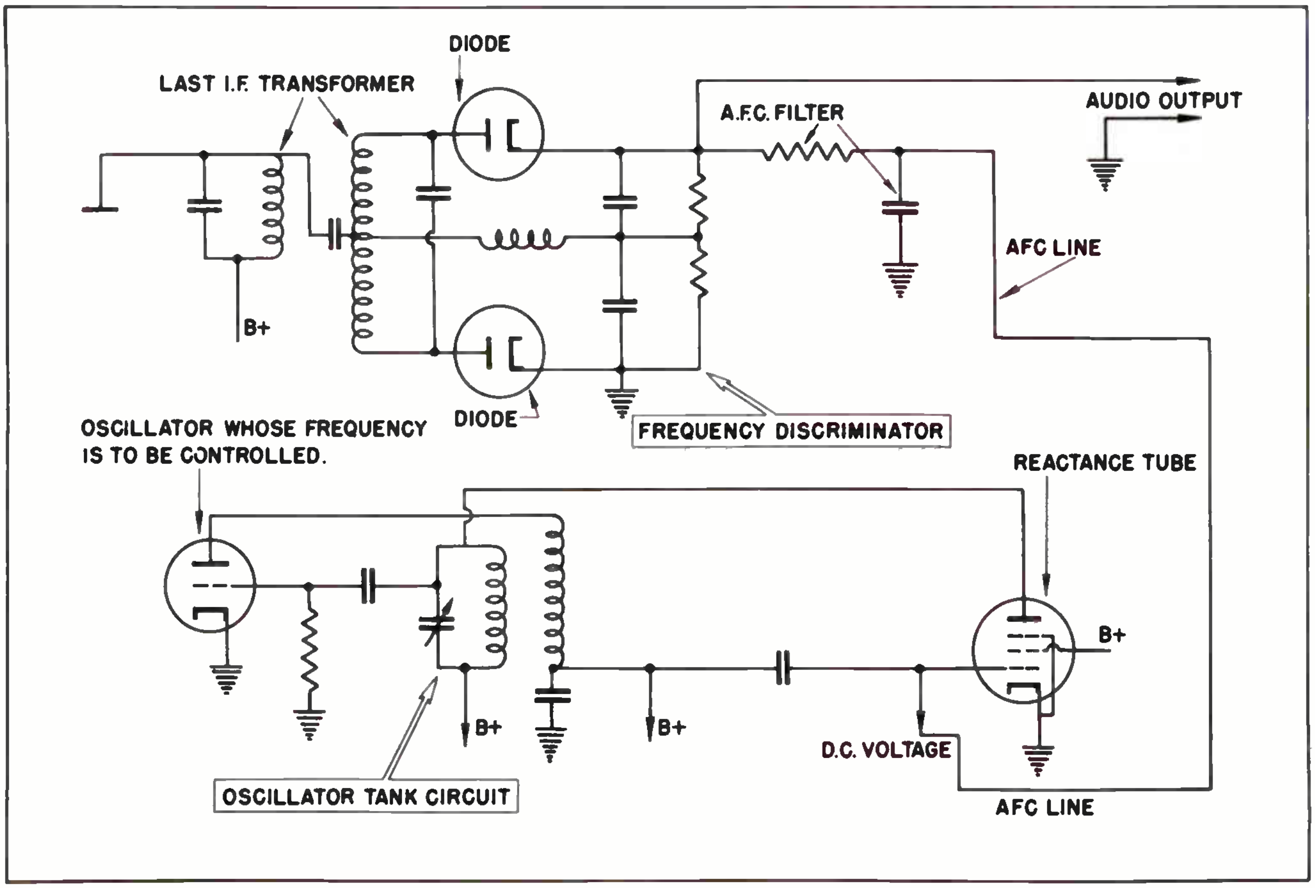


Fig.13. Basic Circuit for Automatic Frequency Control.

the FM changes in the carrier. In FM and television sound (which is also FM) these changes take place at modulation frequency. In the AM receiver, however, any frequency change is undesired, for it represents a drift of either the transmitted carrier frequency, or of the local oscillator frequency.

In order to maintain the oscillator frequency stable for any given station setting on the AM dial, it is desirable that drifts of any type be cancelled out or compensated for.

The output of the discriminator stage should have an *average* D-C output of zero volts. If the frequency of the input to this stage is audio modulated, and varies *only* in accordance with the modulation, the AFC line should be at ground potential. However, if the tuned discriminator stages are not exactly tuned to the I-F signal, the voltage at the AFC line will either increase positively or negatively, depending upon how the frequency has changed.

If the local oscillator drifts, or if the station is not tuned in exactly, the AFC line will change in potential in proportion to the drift in frequency of the oscillator. This AFC voltage, being fed to the reactance tube, will affect the grid voltage of that tube. The plate current flowing through the tube will be likewise changed, and the effect of this current when shunted across the oscillator tank circuit will be to alter its reactance. The frequency of the oscillator, however, depends upon the reactance in its tank circuit. Since this reactance has been changed, the frequency of the oscillator will change in the exact amount required to compensate for the drift. This will bring the oscillator back to its desired frequency and the AFC voltage will keep it stabilized there.

Section 14. HOW AFC WORKS

The frequency of any oscillator depends upon values of the two components which go to make up its "tuned circuit" -- the capacitor and the coil. If the values of either the coil or the capacitor are changed the frequency of the oscillator will be changed. This principle has been discussed so much in previous lessons it seems almost unnecessary to mention it again at this point.

In most oscillator circuits, or other circuits using tuned circuits, any change in the resonant frequency of the circuit is brought about by physically changing the value of one of the components. In most cases this method is entirely satisfactory, but there are some cases where it is difficult or impossible to change the physical values of the circuits. The AFC circuit is one of these cases.

In the AFC circuit it is desired to vary the value of one of the components of the oscillator tuning circuit, but it is virtually impossible to bring about such a change by any mechanical means. For this reason it is necessary to bring about the change in value by an electrical means. This is the purpose of the reactance tube. The reactance tube is intended to change the value of the reactance of the coil in the oscillator resonant circuit by adding to, or subtracting from, the reactance of the coil.

In our previous studies of coils and magnetism we learned that the reactance of a coil could be changed by the proximity of another coil. This is sometimes called reflected impedance, sometimes mutual inductance, and sometimes by other names. The main thing is that magnetic lines of force from one coil can interlink with, and affect the lines of force from a second coil. Depending upon their relationship to each other, the lines of force can either add to or oppose the lines of the other coil.

Note how the circuit in the lower part of the diagram of Fig. 13 operates. A pulse of current in the anode circuit of the oscillator tube flows through the coil in that circuit. This coil can be considered as the primary of a transformer. The current through it also affects the adjacent coil of the tuned circuit. This second coil can be considered as the secondary of a transformer. If nothing else was added to this circuit it would operate as a simple Armstrong oscillator.

But note that the pulse of current from the anode of the oscillator tube also acts to send a voltage pulse to the control grid of the reactance tube. The current from the anode of the reactance tube flows through the tuned circuit and acts to interfere with the operation of the circuit. The pulses from the reactance tube can increase or decrease the frequency of the oscillator depending upon whether the pulses from that tube are weak or strong. Now the strength of the pulses from the reactance tube depends very largely upon the bias on the tube.

From a study of the diagram you will see that the bias on the tube is variable -- it depends upon the strength of the voltage received from the discriminator.

We can now see that the frequency of the oscillator can be increased or decreased as the result of the biasing voltage generated in the discriminator circuit. If the receiver is tuned a little off the desired frequency the discriminator will develop a voltage which will act to change the frequency of the oscillator just enough to bring it into step. If the tuning happens to be a little off in the other direction the voltage will be developed in the other direction and tend to change the frequency of the oscillator in the other direction.

The net effect is that if the receiver is tuned approximately correct the AFC circuit will step in and change the frequency of the oscillator just enough to bring in the station right on the nose.

This principle of automatic frequency control has been successfully applied to console radio receivers containing the so-called "telephone-dial" automatic tuning. In this type of circuit, the dial was rotated as a telephone dial is rotated, and it was not necessary to bring the dial to an exact position.

The AFC circuit, recognizing a discrepancy in the dial setting by the increase or decrease in AFC voltage, would then take over and alter the oscillator frequency automatically to compensate for the difference.

This same principle is utilized in television. Some television receivers are not equipped with a front-panel "fine-tuning" control. Where such is the case, and there is no other provision for fine-tuning, an automatic frequency control system, similar to the one shown in Fig. 13, brings in the station exactly on the nose when the "coarse" tuner is brought anywhere near the station desired. The Philco model 48-1000 employs AFC and increases its effectiveness by the use of a D-C amplifier which strengthens the AFC voltage as developed in the frequency discriminator.

Automatic frequency control is used in another television application. This is the stabilization of the frequency of the horizontal sweep oscillator. Its object is to prevent "tearing" of the picture when local static is especially strong. The AFC circuit here does the job of matching the horizontal sweep oscillator output with the synchronizing pulses as received from the transmitter. Where there is any change in the oscillator output, the AFC acts to compensate for that change. Such changes will tend to occur under conditions where the incoming signal is weak compared to the local static noise level. When the synchronizing pulses are exactly in phase with the horizontal oscillator output, the reactance tube control grid is at zero potential and the oscillator frequency is left unaffected.

(Notes for Reference on the Page Following)

NOTES FOR REFERENCE

There are three types of push-button tuning systems:

Electrically operated;

Mechanically operated;

Electro-mechanically operated.

In the electrically operated type, the push-button switches *out* manual tuning condensers for the RF and oscillator circuits, and switches *in* a pair of pre-set trimmers to take their place.

In the mechanically operated system, the variable tuning condenser gang is placed in a certain precise position by mechanical gears and levers.

The electro-mechanical system utilizes a combination of both of the other types. They are generally operated by means of solenoids, relays, or motors.

The purpose of *automatic volume control* is to maintain the signal strength at the speaker constant, regardless of the signal strength at the antenna.

The purpose of *automatic frequency control* is to stabilize the output frequency of the local oscillator.

The tuning-eye indicator permits the exact tuning position for a station, either on manual tuning or automatic push-button tuning.

Visual inspection and observation of the action of a defective automatically controlled radio circuit is the best approach to locating the trouble. The voltmeter and ohmmeter are always useful in verifying a suspected trouble.

NOTES

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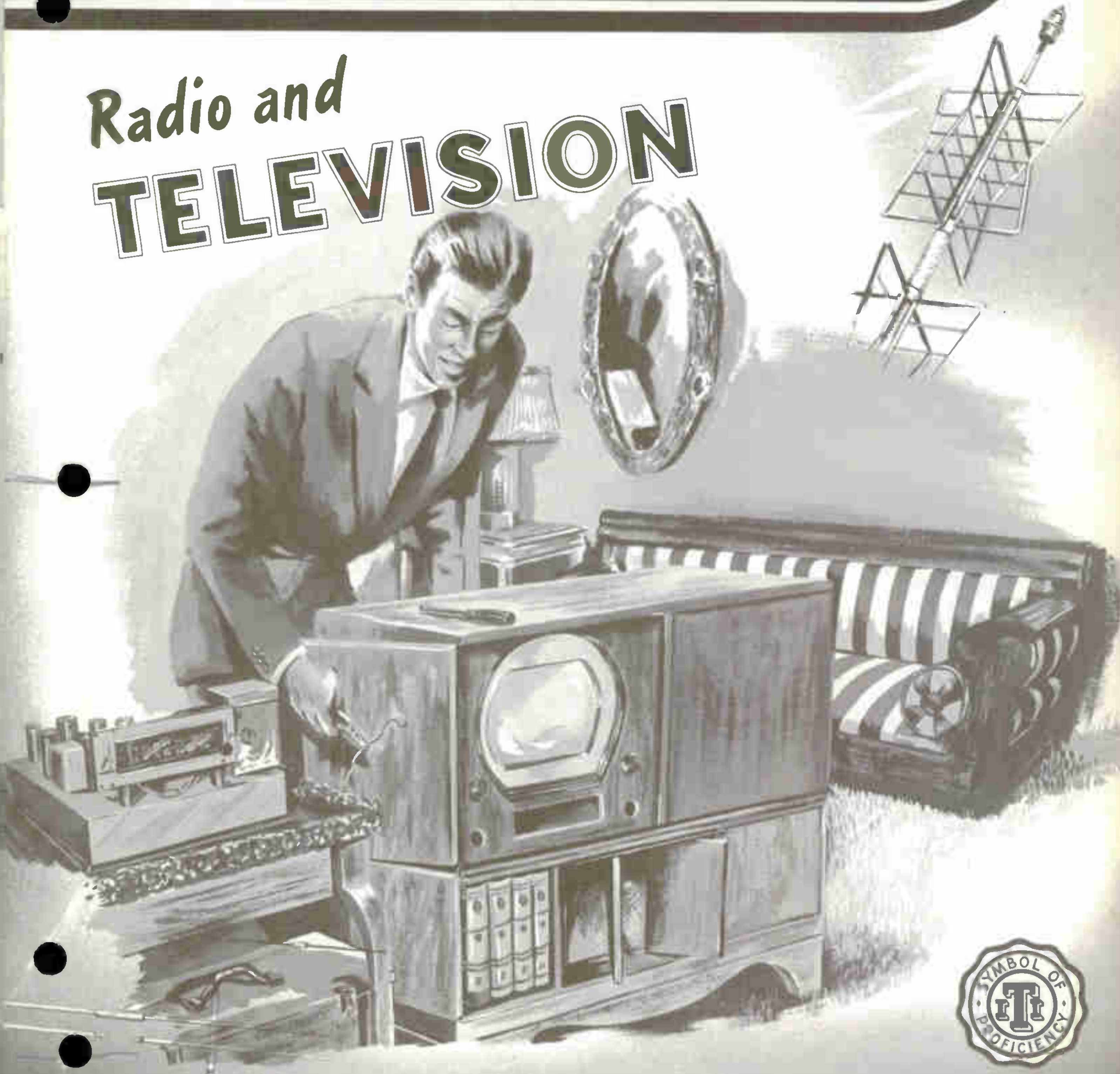

INDUSTRIAL TRAINING INSTITUTE

TCO
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TECHNICAL TRAINING SERVICE

REVIEWED - REPRINTED 1957

RADIO TELEVISION

AUTOMATIC RECORD CHANGERS

Contents: Introduction - Piezo-Electric Crystals - Temperature Co-Efficients of Crystals - Crystal-Controlled Oscillators - Crystal Mountings - The High "Q" of a Crystal - Crystals as Sound Reproducers - Automatic Record Changing - Types of Automatic Record Changers - Trouble-Shooting Automatic Changers - The RCA-Victor Record-Changer - The Webster Model 70 - The RCA "45" - Notes for Reference.

Section 1. INTRODUCTION

Since record changers are primarily mechanical devices it might seem at first thought that a knowledge of them would not be necessary in the training of a man for television work. But such a thought could be very misleading. The truth is that a knowledge of the operation of record changers is absolutely essential to the success of any radio or television repairman.

Record changers are an integral part of many radio and television receivers. This is particularly true with respect to the larger and more expensive console models. It so happens that it is the larger models which can be the source of the most profit to the successful service and repairman.

The reason for this is rather obvious when the situation is studied and analyzed. It frequently does not take any more of the serviceman's time, nor cost him any more money, to repair an expensive console model than one of the most inexpensive receivers on the market. But where the service man might hesitate to charge, and the customer balk at paying, a $15 or $20 repair bill on a $30 or $40 table model receiver, the same charge for repair work on a $400 or $500 combination would seem quite reasonable. Most of the more expensive receivers, whether radio or television or a combination of both,

Fig.1. Crystal Pick-Ups May Come in a Wide Variety of Shapes and Sizes.

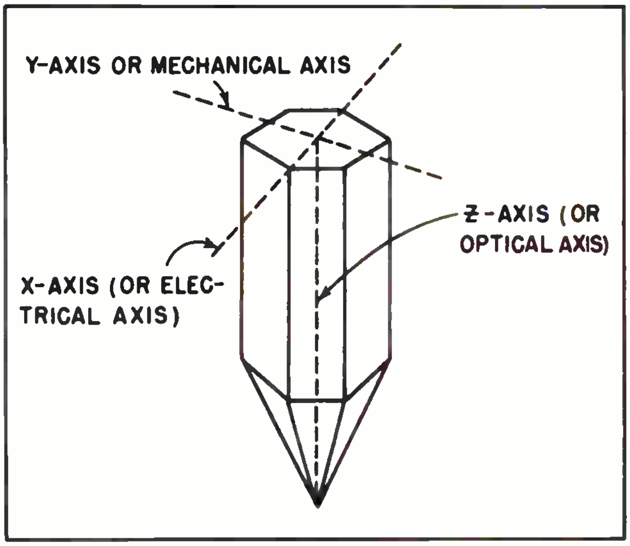

Fig.2. The Shape and Axis of a Quartz Crystal.

also includes an automatic record player. In many homes, particularly those where fine music is appreciated, the record player is often used more than the radio or the television sections. A natural result of the frequent use of the record player is that it will require reasonably frequent service. A radio and television repairman who does not understand the servicing of automatic record players is just naturally going to miss out on some of the most profitable business. It is a dead cinch that the owner of one of these expensive receivers is not going to do without the pleasure of the record player just because one particular repair shop does not know how to fix it. The owner will merely take the job somewhere else.

The history of scientific record making and reproduction of sound is intensely interesting. Unfortunately, space does not permit a full discussion of the history of this fascinating phase of acoustical science. When we compare the modern high-fidelity reproduction of music and voice which music lovers are able to enjoy today with some of the earlier techniques, a very important point emerges: except for its initial invention, most of the progress in modern record playing and reproduction has kept pace with the growth of electronic communication science.

Section 2. PIEZO-ELECTRIC CRYSTALS

Specifically, the huge popularity of modern recorded entertainment, as we know and use it today, is due to the development of almost perfect voltage and power amplifiers built around vacuum tubes. Yet, high-fidelity voltage and power amplifiers are not the only components of a modern record player. Because voltage and power amplifiers can be used to impart high gain and at the same time lose none of the fidelity of a musical tone, another important component may be substituted for the earlier methods: the crystal reproducer. Several examples of crystal phonograph pick-up units are shown in Fig. 1.

One peculiar property of crystals makes them adaptable for use as phonograph reproducers. It is known as the Piezo-electric effect. This property is such that if a crystal is physically disturbed (as by a sharp blow), it will produce an electrical voltage. This action is also reversible. If an electrical voltage is applied to opposite surfaces of a crystal, the *physical* structure of the crystal will undergo a distortion in its shape.

Only certain kinds of crystal materials possess this property. These are primarily quartz, Rochelle Salts, and tourmaline. The galena "crystal", used in the old type of crystal detector, is not of this type. The two types of crystals used in Radio-electronic work should not be confused. The galena crystal is a rectifier. The quartz crystal is Piezo-electric.

Even quartz, Rochelle Salts, and tourmaline display the Piezo-electric property in varying degrees. For example, Rochelle Salts are the most efficient, but the least durable, of this family of crystals. Quartz has

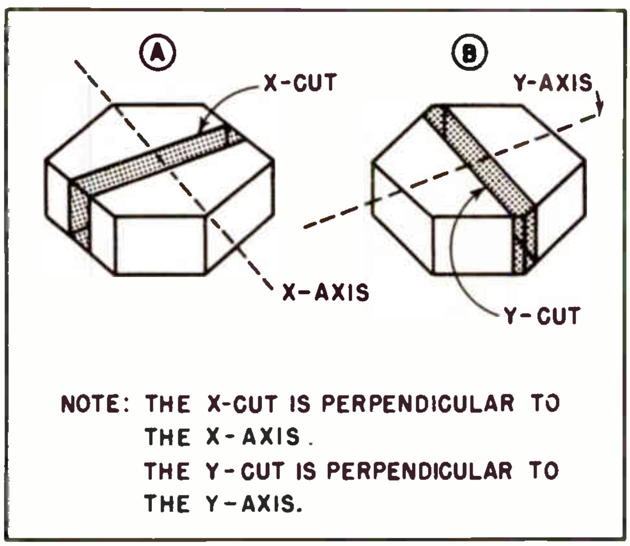

Fig.3. X-Cut and Y-Cut in the Quartz Crystal.

a smaller electrical output for a given physical force applied, but is insoluble in water and therefore more durable than Rochelle Salts. Tourmaline, with the lowest voltage output of all of them, is physically stronger than the other two and may be cut into very thin sections without danger of fracture or punctures under fairly strong voltages.

Voltage outputs from these crystals may vary between a small fraction of a volt to several hundred volts under various conditions of applied vibrations.

In order to be of use to us, the crystal must be processed from its native condition. In nature, quartz crystals occur in hexagonal shapes, with pointed ends, as illustrated in Fig. 2. Seldom does the crystal, as it occurs in nature, take on perfectly geometrical shape; often it does not have the two pointed ends. Yet each crystal is surprisingly like all the others.

A line drawn down the very center of the crystal, as shown in Fig. 2, is known as the Z-axis; also as the optical axis.

Now, if thick slices are cut from the natural crystal, as indicated in Fig. 3-A, hexagonal slabs will be obtained. These slabs can then be cut again, in the manner shown by the shading in Fig. 3-A. The line connecting two opposite points of the hexagon constitute the crystal's X-axis. If a slice is cut across -- perpendicular to -- this axis, the slice is known as an X-cut crystal.

The Y-axis of the crystal is a line perpendicular to two opposite flat surfaces, as in Fig. 3-B. A slice cut across this line is known as a Y-cut crystal. An example is the shaded portion of Fig. 3-B. We may conclude, therefore, that the cut of a crystal is determined by which axis is bisected by the cut. This, of course, excludes the Z-axis.

After these cuts have been made, the crystals appear as shown in Fig. 4. The dimensions may be described as follows: The thickness of the crystal is the distance along the axis which is cut. The *width* is the distance along the opposite axis. For instance, in Fig. 4, the width of either cut is the distance along the opposite axis, while the thickness of either cut is that amount of the cut axis contained between its two flattest sides.

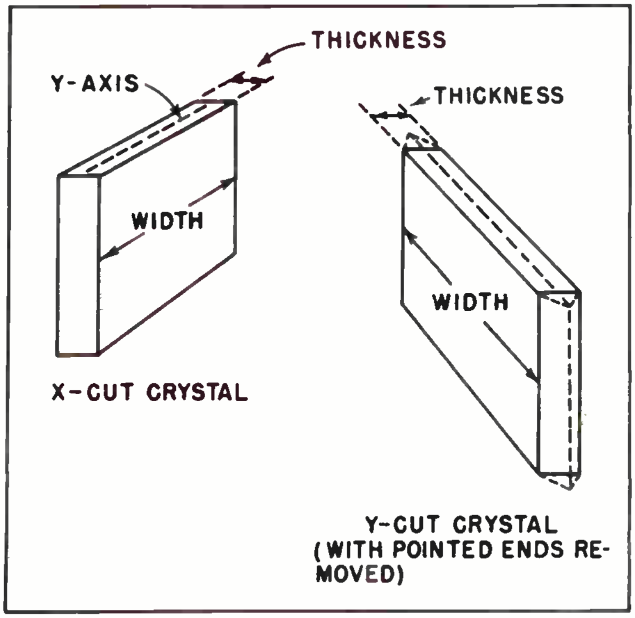

Fig.4. Physical Dimensions of the X-Cut and Y-Cut Crystals.

The Y-cut is also known as a 30-degree cut. Like everything else in nature, these cuts of crystals have a certain mechanical resonance. This mechanical resonance corresponds to a certain electrical resonance as well. While the exact manner of physical vibration of a crystal is extremely complicated, and may consist of a related family of resonant frequencies, its resonance under normal conditions may be approximately found by the following formulas:

For X-cut crystals:

$$F = \frac{2.86 \times 10^6}{T}$$

For Y-cut crystals:

$$F = \frac{1.96 \times 10^6}{T}$$

where "F" is the frequency in cycles per second and "T" is the thickness in millimeters.

Section 3. TEMPERATURE CO-EFFICIENTS OF CRYSTALS

A major application of Piezo-electric crystals in the field of radio is the control of a constant frequency output by a radio transmitter. Since by law the transmitter may not deviate from its nominal frequency more than a specified margin, the frequency-regulating characteristics of the Piezo-

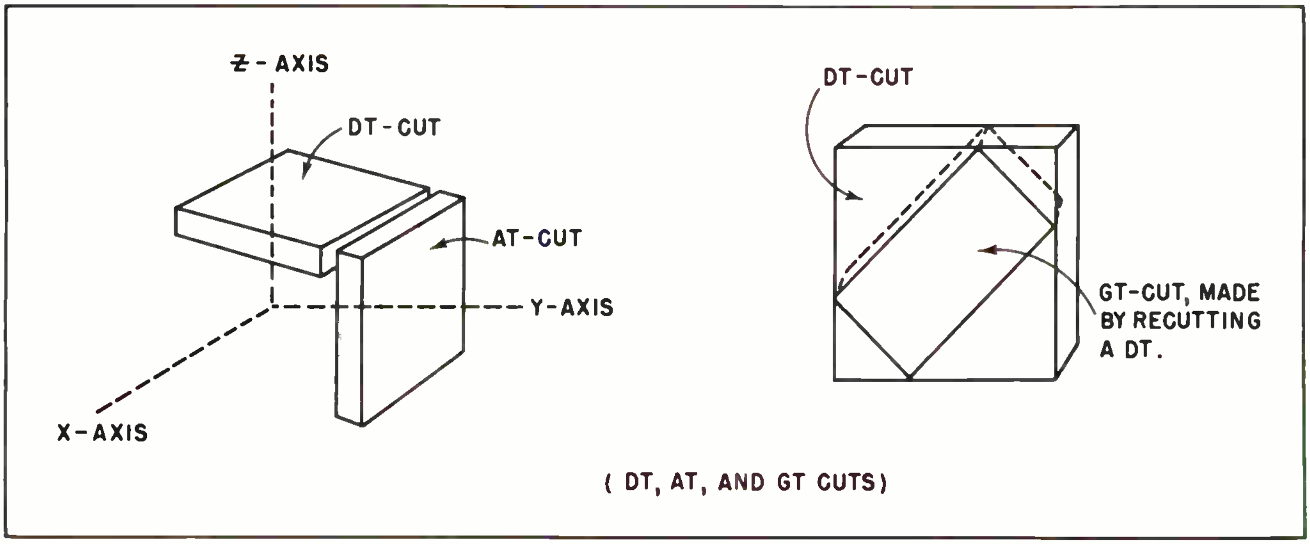

Fig.5. The AT, DT, and GT Crystal Cuts.

electric crystal are well adapted to this purpose. Crystal-controlled oscillators for radio transmitters will be discussed in later paragraphs of this lesson. There is a point, however, that may be mentioned here.

The frequency with which a certain crystal will oscillate when placed into a vacuum-tube circuit in the proper way will be determined in part by the temperature of the crystal. Those crystals which increase their frequency with an increase to temperature are said to have a positive temperature co-efficient. All X-cut crystals have positive temperature co-efficients.

Those crystals which decrease their frequency with an increase in temperature are said to have a negative temperature co-efficient. Y-cut crystals may have temperature co-efficients which are positive, negative, or zero, depending upon how the Y-cut crystal is placed in its holder and on its relative physical dimensions. For this reason, oscillators being controlled by a Y-cut crystal are unstable and result in sudden jumps of frequency which are near to each other. It is evident that the Y-cut is not suitable for use as a controlling agent for an oscillator required to remain within certain narrow frequency limits.

The X-cut is somewhat more suitable for use as a frequency-controlling agent. However, since its temperature co-efficient is always positive, the X-cut crystal needs a thermostatically-controlled oven to maintain its temperature at a constant value. New advances in crystal-cutting have recently been made. In order to secure a cut with a zero temperature co-efficient, and hence a more stable oscillator, crystals have been made with cuts known as DT, AT, and GT. Fig. 5 shows these cuts relative to the X, Y, and Z axis. Note that the DT and AT cuts are at right angles to each other, and that the GT cut is the result of re-cutting a DT crystal at an oblique angle.

These zero temperature co-efficients, represented by DT, AT, and GT cuts still must be thermostatically controlled, since the co-efficient of these crystals is zero for one temperature only. When the temperature increases or decreases, the co-efficient likewise changes. However, they are much more easily controlled by thermostatic ovens and as a result find their best applications in controlling the oscillator frequencies of commercial broadcasting transmitters.

Section 4. **CRYSTAL-CONTROLLED OSCILLATORS**

Just how the crystal may be applied to the control of vacuum-tube oscillators is illustrated in Fig. 6. This was also discussed in a previous lesson. As is shown by the equivalent circuit in the diagram, the crystal merely takes the place of the grid coil-and-condenser combination in a tuned-plate-tuned-grid oscillator employing a triode tube. Notice that in the equivalent circuit the grid tank circuit is not shown as variable. This corresponds to the relatively fixed capacity and inductance in the crystal, which contains both capacitive and inductive effects.

While certain values may affect the frequency of the equivalent circuit, the

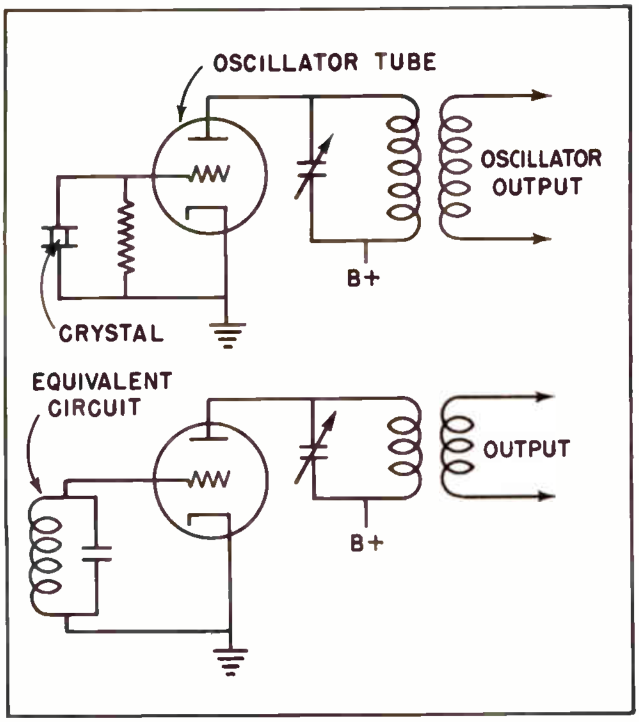

Fig. 6. Basic Circuit for an Oscillator Controlled by a Crystal in the Grid Circuit. Note the Equivalent Electrical Circuit.

crystal frequency is constant for any given crystal cut, dimensions, and temperature. The exact electrical characteristics of the crystal are indicated in Fig. 7. C_c is the electrical capacity of the crystal, represented by the elasticity (or compliance) of its structure. R is the resistive effect and represents the friction of its molecules while they are in a state of oscillation. L represents the mass (or inertia) of the crystal material and is determined chiefly by the weight contained within its physical dimensions. C_h is the natural capacity of the crystal-holder itself, since the entire assembly is built with the crystal lying between two conducting metallic plates, thus conforming to the definition of a condenser.

The total effect, therefore, of a crystal mounted in this way and connected to the grid of a triode oscillator, is that the values of inductance, resistance, and capacitance represented by the crystal and its holder will serve a resonant function in exactly the same manner as a coil and condenser placed in the same circuit. The advantages of the crystal are noteworthy:

1. The crystal accurately controls the output frequency of the oscillator.
2. The ratio of inductive reactance to resistance is very high, meaning that the crystal has a very high "Q", this, in turn, resulting in extremely sharp tuning.

The disadvantage of the crystal in comparison with the coil-and-condenser combination, is that the crystal resonance is not suited to variability. For this reason, a transmitter whose frequency is to be changed from time to time, as in the case of many amateur transmitters, must be provided with several crystals, one for each frequency desired. The inductance- or capacity-tuned transmitter, on the other hand, may be varied in a continuous manner by a manual control, without the need for replacing crystals.

For the majority of commercial transmitters, however, since they are required to transmit within narrow limits at one frequency only, the crystal-oscillator is made to order.

Section 5. **CRYSTAL MOUNTINGS**

In general, there are two ways to physically mount the frequency-controlling crystal for satisfactory operation. These are illustrated in Fig. 8.

Fig. 8-A shows the crystal mounted with the upper and lower holder plates in contact with the crystal faces. This method is common, and suitable for all cuts of crystals.

Fig. 8-B shows an alternative method of mounting the crystal, with an air-gap between the upper face of the crystal and the upper crystal-holding plate.

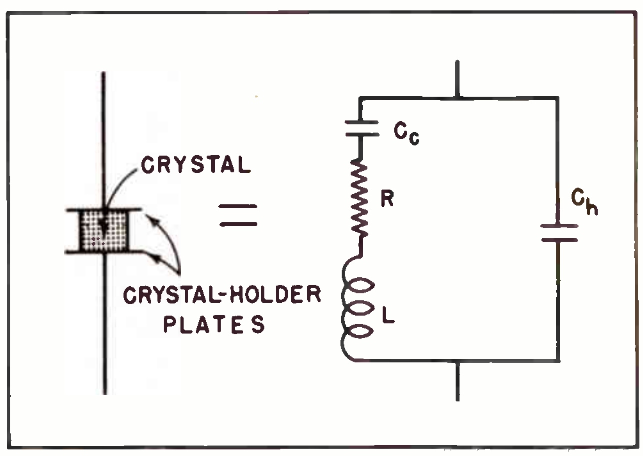

Fig. 7. Equivalent Circuit of the Crystal, Including the Capacity of the Crystal-Holder Plates.

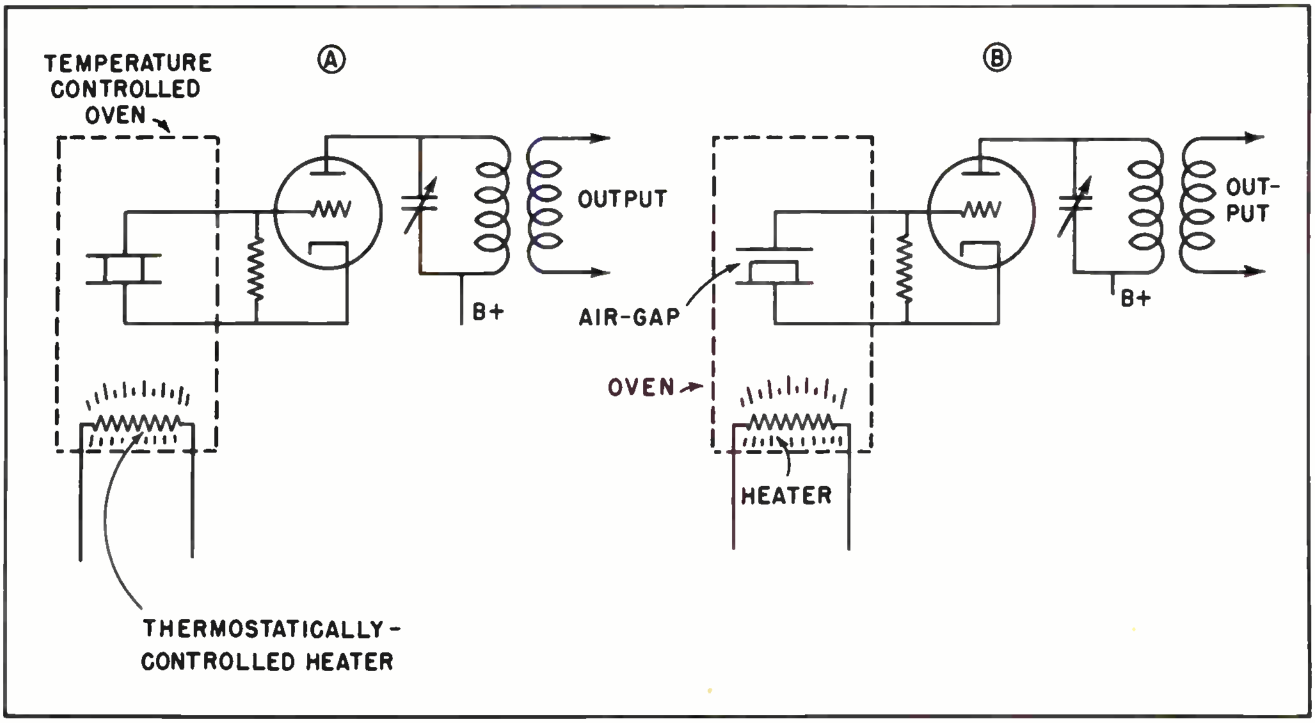

Fig.8. Two Methods of Mounting Oscillating Crystals Within Temperature Controlled Ovens.

To understand the advantages of the air-gap mounting over the rigid mounting, we must look for a moment at the manner in which crystals are cut to resonate at a desired frequency,

We have previously seen formulas which tell us that the resonant frequency of a crystal is dependent upon the physical size; that is, upon its width and thickness. Let us keep in mind that the temperature of a crystal also determines the exact frequency.

When a crystal is cut from a raw specimen, its size can be only approximately determined by the cutting tools. However, in order to more accurately fix the physical thickness and width, a grinding process is applied. Micrometer checks of the grinding procedure are likewise only approximately accurate, and it is evident that a more precise test be applied. To do this, the crystal is placed in operation in a test-oscillator circuit to check its exact frequency output. Moreover, this test is made with the very same crystal-holding plates that will be used when the crystal is permanently installed.

If the crystal, so tested, produces a frequency below the required value, more grinding then may be done, after which it is again tested. This process is repeated by the manufacturer until the required frequency is obtained. If the crystal is over-ground, it is discarded for the frequency for which it was originally cut and assigned to be ground to a higher frequency bracket.

We may now re-examine the two types of mounting, with the view toward comparative advantages.

Since the crystal is ground to a specified frequency, and this frequency changes with temperature, what would happen if the temperature of operation was different from the temperature of manufacture? This is an important question, in the light of the rigid requirements placed upon frequency range of a transmitter by the Federal Communications Commission.

We can readily see that in order to control the crystal resonance at a required point, some type of compensating process must be employed while the crystal is in use.

If the crystal is mounted in the manner shown by Fig. 8-A, we may create slight frequency changes, to compensate for drifting, by changing the temperature of the oven containing the crystal. Even when changed, this temperature is held constant by a thermostatic control, so that it will not drift from its new value. This becomes therefore an effective way of setting the crystal frequency at the exact required point, and, once being set at this point, of maintaining it without variation, as required.

The air-gap method, shown by Fig. 8-B, is even better, since the temperature control of the oven may be used, and, in addition, the size of the air-gap may also be precisely varied to change the net capacity of the crystal and its holder. This, of course, will alter the resonance, and therefore enable the operator to determine the exact frequency of the transmitter output, as required.

The air-gap mounting has the disadvantage, however, of being suitable only to low temperature co-efficient crystals, including the AT, DT, and GT cuts. In an air-gap mounting, both X-cut and Y-cut crystals have a marked tendency to jump abruptly from one frequency to another and hence do not lend themselves to accurate correction of drifts.

Section 6. THE HIGH "Q" OF A CRYSTAL

Resonant circuits are typified by several characteristics. First, there is the resonant frequency to which the circuit is tuned. Secondly, we classify all tuned circuits as either parallel or series resonant circuits. Thirdly, a resonant circuit may be examined from the point of its narrowness, more commonly described as "band-width".

This characteristic of a resonant circuit is known as its "Q" and determines the sharpness with which it can be tuned. "Q" is defined as the ratio of reactance in the circuit to resistance. In symbols, the "Q" of a circuit is given by:

$$Q = \frac{X_L}{R}$$

where X_L is the inductive reactance and R the ohmic resistance of the circuit components.

Since the crystal contains the effects of inductance and resistance, it, too, may be found to have a "Q". In fact, the "Q" of a crystal is extremely high, seldom being below 10,000, and sometimes, in special cases, rising to the value of over 300,000. Even at its minimum, the "Q" of a crystal circuit is enormously greater than even the very best of the high grade coil-and-condenser combinations.

As far as operating efficiency is concerned, it means that almost all of the power of the transmitter may be directed to the proper frequency and little lost in the useless fringes. This leaves the maximum amount of power to be utilized by the transmitted wave and its modulation side-bands, and hence makes the transmitter more efficient.

Fig. 9 shows the frequency response curves of two tuned circuits, and compares their outputs at resonance. It can be readily seen that the high "Q" crystal is unquestionably better than the low "Q" condenser and coil circuit.

The preceding discussion indicates the greatest practical application of crystal

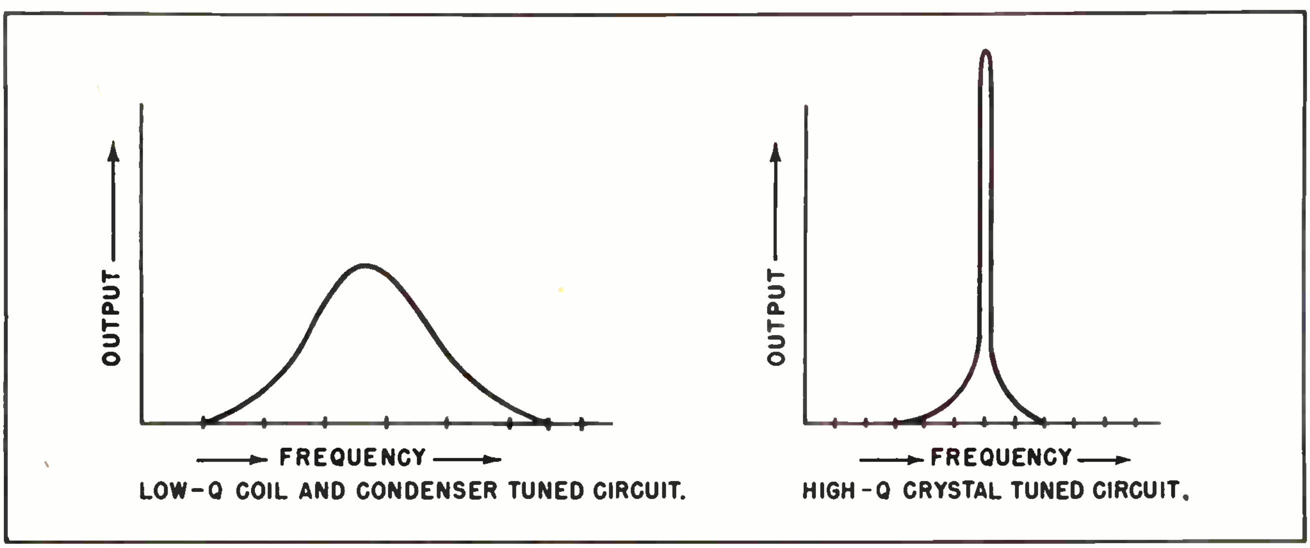

Fig.9. Frequency Response Curve of the High-Q Crystal Compared to the Ordinary Electrical Resonant Circuit.

oscillator control is in commercial, amateur, and communications transmitters. But crystal oscillators may be put to other useful purposes: calibration of audio and radio signal generators, multivibrators, and relaxation (saw-tooth) oscillators. The crystal oscillator also finds wide acceptance in multiple signal transmission, over wires and cables, which permits many simultaneous -- but non-interfering -- signals to be carried by a conductor. This is the principle known as Carrier Current Transmission and is used wherever conversation traffic on an existing line becomes heavy. Telephone companies, of course, use crystals in sending hundreds of messages over one pair of wires at the same time without any of them interfering with, or being interfered by, any other. It is evident that the saving of time, labor, and materials is enormous when such wonders can be achieved by crystals used as oscillators.

Section 7. CRYSTALS AS SOUND REPRODUCERS

Equally important to the electronic technician is the property which crystals possess to convert sound energy into electrical impulses. This, together with the reverse property of converting electrical impulses into sound energy, is due to the Piezo-electric effect inherent in crystals and mentioned previously in connection with phonograph pick-ups. It is this last use which should properly occupy our attention in this particular lesson.

In order to produce a series of voltage changes between opposite faces of a crystal, the crystal must be cut in a certain way and mechanical vibrations must be applied from the correct angle.

The X-axis are the electrical axis of a crystal; the Y-axis are mechanical. This means that if mechanical pressure or vibration is applied across the mechanical (Y) axis, an electrical voltage will be produced across the electrical (X) axis. This combination of circumstances is put to use in the phonograph pick-up. If the crystal is mounted between a pair of parallel supporting plates so that these contact the flat faces of an X-cut, then mechanical stress or vibration along the Y-axis will generate a voltage between the supporting plates.

This voltage may be led through suitable conductors to an external amplifying circuit. The crystal pick-up unit is constructed in this manner, with the desirable result that when the needle passes over the modulation "bumps" as it tracks the record-groove, the frequency and amplitude of these bumps are transmitted through the needle to the crystal and there applied as a torsion (twisting) along the Y-axis. The plates of the holder then pick up the resulting voltage changes, which correspond almost exactly to the frequency and amplitude changes of the record modulation. The amplifier to which this signal voltage is fed is ready and able to build it up, at audio frequency, to any required degree. The basic circuit for this is shown in Fig. 10.

The basic requirements for an electronic record-player of the simplest type is shown

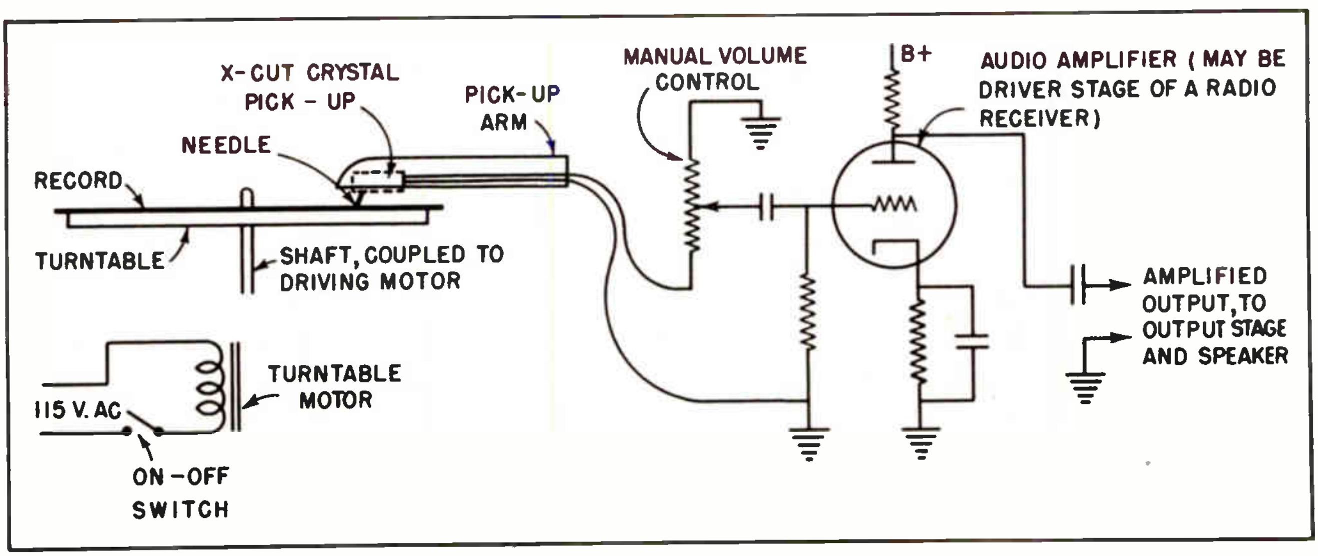

Fig. 10. Basic Principle in Coupling the Crystal Phonograph Pick-Up to an Audio Amplifier.

in the diagram. The turntable motor is operated from commercial 115-volt power (almost always A-C) and is controlled by a manual switch. The phonograph crystal pick-up is mounted in the head of a tone-arm, and the record is set in rotary motion while the needle tracks the record-groove. The vibration of the needle, caused by the modulation on the record, is converted by the crystal into electrical impulses of audio frequency. The signal is fed to the amplifier where its volume is controlled by the manual volume control. The loudness of the signal at the speaker will of course depend upon the setting of this control, which can be adjusted to suit the needs of the listener.

In the case of a radio-phonograph combination, using this simple record player, the crystal output is fed to the driver grid through the same volume control used in radio reception. A single-pole-double-throw switch will make the necessary changes.

In this simple record player, the record must be placed on the turntable manually, the tone-arm is put in place on the edge of the record manually, and the record must be stopped manually. In other words, there is nothing automatic about this type of record player. It finds use, however, in small units designed for manual record-playing, including novelty units especially designed for children's enjoyment of recorded entertainment.

Modern electronic record players, of course, go quite a bit farther than the basic record-player. Today it is possible for a listener to set a load of favorite records on an automatic record changer, then listen to several hours of uninterrupted music without leaving his chair.

Many varieties of automatic record players are on the market, each one representing a fine job of engineering skill. It is with the operation, servicing, and adjustment of these automatic record changers with which we are now concerned.

Section 8. **AUTOMATIC RECORD CHANGING**

Any automatic record-changer can do automatically what otherwise would have to be done manually. Taken chronologically, these steps are:

1. Place a record upon the turntable.
2. Set the tone-arm to the exact spot on the edge of the record.
3. Start the turntable motor.
4. Wait for the record to be played completely.
5. Repeat the above operations until the last record is played.
6. Turn off the record-player.

All automatic record-changers do not perform all of these steps. For instance, some changers do not stop the turntable during the record-changing cycle. Others will not bring the entire mechanism to a stop after the last record is played.

However, some record-changers do much more than the above list indicates. These additional tasks are:

1. By the press of a button, *reject* any record before it has completely played.
2. To play records of intermixed sizes, such as ten-inch and twelve-inch standard records in any order.
3. To play records at different speeds, such as 78 r.p.m., 33 1/3 r.p.m., and 45 r.p.m. on the same turntable.
4. To play first the *top* and then the *bottom* of the same record.
5. To permit manual operation at any time.

It is easy, first of all, to see that certain record-changers, designed for a specific use, will differ in their details of operation from all others. There is, however, a basis of classification of all types of record-changers which will help us in our study.

Section 9. **TYPES OF AUTOMATIC RECORD-CHANGERS**

I. *The two-post type.* This group is typified by the fact that there are two posts, in addition to the central spindle, on the assembly. A model of this group is shown in Fig. 11, with the turntable removed to expose the view of the turntable driving mechanism. Note the terms used to describe the components, for they are standard for all types of record changers. This changer, a popular Zenith model, will play ten 12-inch records or twelve 10-inch records

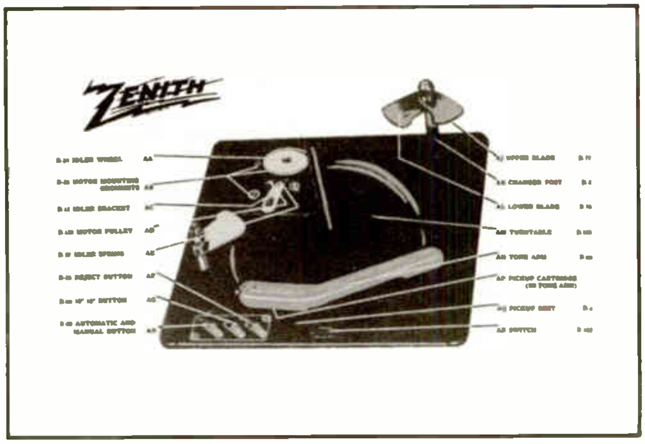

Fig.11. Location and Identification of Parts in a Two-Post Automatic Record-Changer.
(Courtesy Zenith Radio Corp.)

without reloading. However, it does not mix the two sizes.

In this two-post type, the loaded records rest upon the lower blades of each of the two changer posts. When the tone-arm is drawn toward the center of the record, an automatic trip, not shown in the illustration, initiates the changing cycle. This brings the tone-arm out from under the stack, and turns both the changer post assemblies so that a record is *sliced* from the bottom of the stack. The slicing is accomplished when the upper blades of each post move inward so that the under surface of the second lowest record is supported before the lower blades permit the lowest record to drop. A geared mechanism below the turntable plate now sets the tone-arm down on the record so the needle is at the very edge of the record and will engage the record groove as the record turns. In the meantime, the changer post assembly returns to its initial position and the weight of the record stack is shifted from the upper to the lower blades. When this record has played through, the action will be repeated.

Note also the automatic-manual button. This permits the user to select whichever of the two types of service he desires. When in the manual position, there will be no tripping of the cycling mechanism, and there will be no automatic changing.

The "on-off" button for the electric motor is located adjacent to the selector button, together with a third button used for the purpose of setting the mechanism for a given record size.

The turntable (removed in the illustration) is connected to the motor by an idler wheel assembly which uses a rubber tire on the outside surface of the idler wheel to act as a friction gear between the motor shaft and the inner rim of the turntable which is shaped to fit the idler wheel.

II. *The three-post type.* This automatic record-changer group has been widely used in the past, and there are many of them still in service. The model shown in Fig. 12 is a Stromberg-Carlson product. This "deluxe" record-changer plays sixteen 10" records, twelve 12" records, or fourteen 10" and 12" intermixed -- all on the same set-up. There are three posts, one being hidden behind the record stack in the illustration. Each of the three posts consists of two plates; the lower one on which the records rest is the shelf-plate; the upper one is the selector plate which takes from the bottom of the stack the next record to be played and releases it to fall upon the turntable.

The difference between the two-post and three-post types is primarily one of easier operation and prevention of record-breaking. The three-post type uses the slicing principle employed by the two-post type; the only difference being that it has one more additional slicer which is synchronized with the other two to make sure the record is released by all three at the same time. This prevents the record from falling obliquely, and from "chewing up" the center hole in the record.

The changing cycle is approximately the same, except for mechanical detail, as in the two-post type. A manual-automatic switch is provided so the user may select the type of service desired. Since this changer mixes both 10" and 12" records in one set-up, there is no need for the record size selector.

An additional feature of this model is that when the last record has been played, the mechanism will automatically turn completely off and the tone-arm will be brought back to its rest position.

III. *The single-post type.* This group of automatic record changers is becoming increasingly popular. An example is shown in Fig. 13. This is a modern Emerson three-speed model accomodating all of the new types of records. It will automatically play ten 12", either standard or long-playing records; twelve 10", either standard or

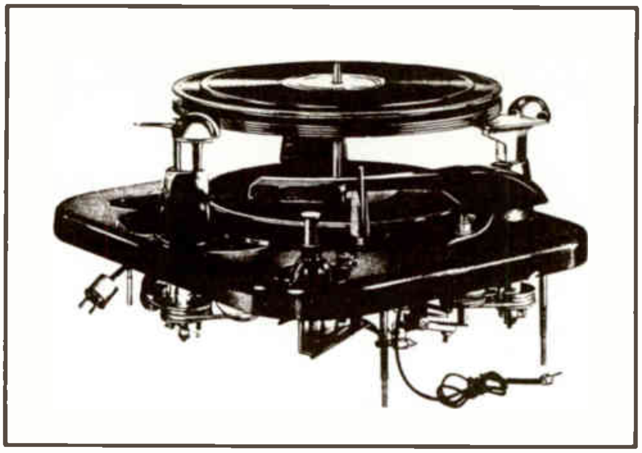

Fig.12. A Three-Post Automatic Record-Changer That Mixes 10" and 12" Sizes in One Set-Up.
(Courtesy Stromberg-Carlson Mfg. Co.)

long-playing records; any assortment of ten 12" and 10" intermixed, or twelve 7" long-playing or fine-groove records. (The fine-groove records turn at 45 r.p.m.)

However, manufacturer's notes inform the user that standard, long-playing, and fine-groove records cannot be played in one set-up, since the motor speed must be changed for each type. The motor speed control knob is shown in the illustration.

Here the changing cycle is initiated when the tone-arm is drawn toward the center by the record grooving. This actuates a *velocity trip* (rather than a ratchet trip). The velocity trip is activated when the needle, and the tone-arm, leave the closely spaced record grooves and track the widely spaced grooves near the center of the record. This sudden increase in speed of lateral motion of the tone-arm operates the trip mechanism located below the turntable plate. Note that the record spindle is offset at about its midpoint. The trip mechanism, after bringing the tone-arm out from under the record stack, activates a cam in the record support post. This cam pushes the next record to be played from the bottom of the stack. It is pushed past the offset in the spindle. This permits the record to drop, guided by the lower shaft of the spindle, onto the turntable.

The cycle continues, setting the tone-arm in the correct position at the record edge to engage the starting grooves of the record. This completes the cycle. In the meantime, while this record is being played, the cams beneath the record support knob are measuring the size of the next record to be played and pre-setting the indexing apparatus for the correct set-down point of the tone-arm on the *following* record.

The chief difference between the slicer-type, double- and three-post changer on the one hand, and the single-post type on the other, is the way the records are selected individually and dropped to the turntable. Because of their greater simplicity, the single-post models are lighter in weight, less complex, and therefore are, in general, easier to trouble-shoot.

The tendency today in automatic record-changers, as well as in most other equipment, is toward greater simplicity of construction and operation. Yet they are designed to give greater latitude in accomplishment. That this holds true in automatic record changers is evident when we consider the wide-variety of special cases which an automatic record-changer of modern design will accomodate. This includes three-speed changers, twin crystal pick-up units, and intermixing.

Section 10. TROUBLE-SHOOTING AUTOMATIC-CHANGERS

The wide variety of present-day automatic record-changers, their many special features and peculiarities, and their numerous differences makes it impossible to set down a specific procedure for trouble-shooting each of the many models. There are, however, a number of general trouble-shooting

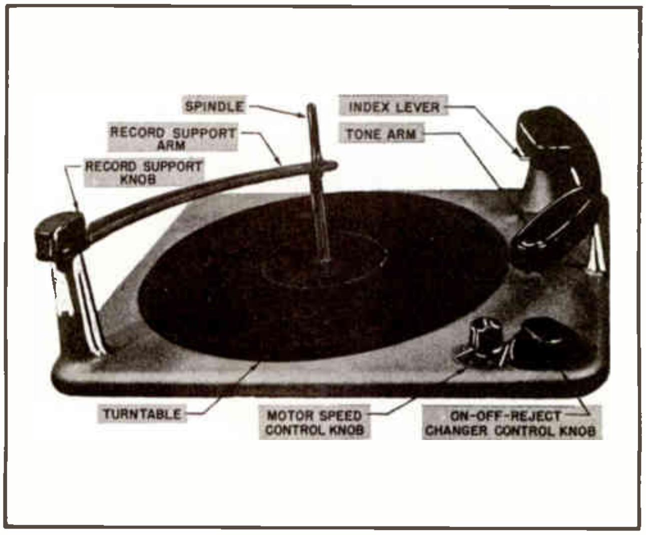

Fig.13. A Modern Single-Post Automatic Record Changer.
(Courtesy Emerson Radio Corp.)

principles that may be outlined. These will serve as a guide in repairing and adjusting any particular make and model. Keep in mind that this is only a *guide*, and that in case of doubt about any particular make and model, the manufacturer's servicing instructions should be consulted for that particular model.

Modern record-changer manufacturers are justly proud of the high quality of their record-changers, and of the fact that they supply full information to electronic technicians regarding the details of each of their products. They spare practically no expense in the preparation of their service manuals. In most cases, they are quick to oblige the technician by sending at little or no cost a complete manual for any make or model number inquired about.

From the point of view of accurate and speedy trouble-shooting, a good rule to follow is: If the trouble in a record-changer is not obvious from superficial investigation, procure the manufacturer's service manual as soon as possible. This manual, written about a single specific model, is the final authority on that piece of equipment.

As a general guide to shooting trouble in an automatic record-changer, the following procedure will facilitate the approach to the problem:

1. Examine the action of the record-changer, noting exactly, in what manner the mechanism fails to accomplish its job. Failures may be grouped into various classes.

   a. Is the trouble electrical or mechanical? If electrical, is the trouble in a signal circuit or in a power circuit? Signal troubles originate in defective crystals, disconnected or faulty wiring, corroded or broken selector switches. Notice if the turntable motor turns, and if the changer mechanism is placed into operation either by the tone-arm being drawn toward the center of the record, or by pressing the "reject" button.

   b. If the trouble is mechanical, note exactly in what manner it fails. Does the cycling apparatus start the changer? Is the indexing of the needle correct on the outside edge of the record? Does it fall off the outer edge after being set down? Does it start too far in, thus skipping the first few grooves?

   c. Does the radio with which the changer is associated produce a signal? If it does, does the phonograph signal come through on all speeds of the record changer?

2. When the specific trouble is *identified*, look for the most likely cause. Examples are:

   a. If the radio plays, and the record changer properly operates but *does not deliver a signal*, then trouble is indicated in the crystal, the connecting leads to the crystal, or the selector switch.

   b. If the music comes through on both radio and phonograph, but the tone-arm is set down too far out from the record, look for trouble in the mechanical adjustment of the indexing system.

   c. If records can be played manually, but the record selector fails to separate the records and drop them properly, trouble should be sought in quarters pertaining to the selecting and dropping mechanism. This may include a bent spindle, de-synchronized record pushing cams, or the record stack support keeping the stack at a mis-adjusted angle.

   d. If the records play, but the mechanism fails to initiate the changing cycle, investigate the tripping mechanism. This is usually of the velocity (or acceleration) type described above, and could be due to bent, mis-adjusted, and otherwise defective trip mechanism components.

A list of troubles could be extended to cover a five-hundred page book. The point to be stressed is that once the *exact nature* of the failure is determined, its *probable cause* may be suggested by examination of the components involved.

3. Having determined where the fault lies, determine the correction necessary to rectify the trouble. Try, if possible, to understand *why* this trouble occurred.

4. Make the correction, adjustment, or repair, and test the operation of the unit under all operating conditions; that is, with various size records, and using all the speeds provided for by the equipment.

Many trouble-shooting problems in automatic record-changers require the utmost skill in observation. In order to observe with the required degree of accuracy, it is necessary that the changer, removed from the cabinet, be placed in a position suitable for observation. A good light is highly important.

Fig. 14 indicates how this may be accomplished on an ordinary workbench. Set the mechanism on four fairly tall supporting blocks, one at each corner. Make sure the supports are solid and stable, to avoid tipping. A bright, shaded lamp at the lowest level can be brought near enough to illuminate the mechanism under the turntable plate while observation is taking place. The need for this arrangement is evident.

We may turn the changer over while working on it or while examining it, but it will not operate properly in this reversed position. Tracing down the trouble is a matter of studying the mechanism in operation, and it will have to be watched from underneath while it is actually in operation.

Some technicians place a mirror on the bench just below the changer. This permits them to watch the mechanism in operation through the mirror reflection. If the technician can remember that in a mirror left and right are reversed, he can interpret his observations and maintain a comfortable body position at the same time.

It is often necessary, even with the aid of the manufacturer's service manual, to study the action of a defective record-changer for several hours before its trouble can be determined. This time is well spent, and customers are willing to pay for it -- provided the job is well done when it is finished and is guaranteed to them.

Studying the operation of a defective record-changer is profitable in more ways than one. While the manufacturer's service manual is admirably complete, there are always some possible troubles in the mechanism which cannot be anticipated, even by the man who designed the equipment. Studying the operation of a defective unit is the only chance the technician has to determine the trouble. Besides, and this is important, it will increase his experience and better fit him for trouble-shooting the *next* record-changer he is called upon to repair. Whenever a given make and model is repaired, that experience is beyond price. There is no substitute for experience and self-reliance.

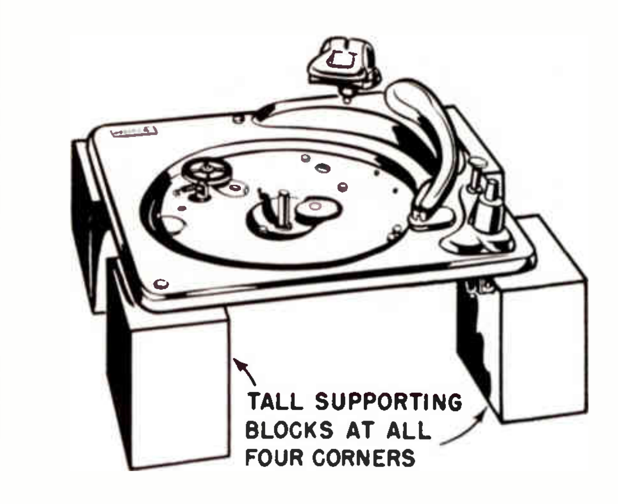

Fig. 14. Convenient Arrangement for Testing a Changer in Operating Position on the Workbench. (Courtesy Webster-Chicago)

There is another encouraging point worth remembering: knowing one particular record-changer thoroughly will tell you what to expect in most others. The makes and models need not necessarily be the same. Knowledge of one model familiarizes the technician with the general duties and component purposes of all record changers. He may have to study out the *details* of how the basic requirements are accomplished in different models, but the basic requirements generally correspond in identical fashion.

With this in mind, let us direct our attention to several typical record-changers and determine their method of operation and servicing procedures.

Section 11. THE RCA-VICTOR RECORD-CHANGER

Fig. 15 is a photograph of the RCA-Victor model 960258-1 Automatic Record Changer, showing a side-view, and with several of the components identified.

This unit is of the dual-speed type, operating at 78 or 33 1/3 r.p.m. It intermixes both the 10" and 12" records, and comes to a complete stop after the last record is played. It contains an automatic trip of the acceleration (or velocity) type.

Fig. 16 is a detailed view of the tone-arm fulcrum assembly, with its parts named. Fig. 17 shows the underside of the turntable plate and identifies the principal levers exposed to view.

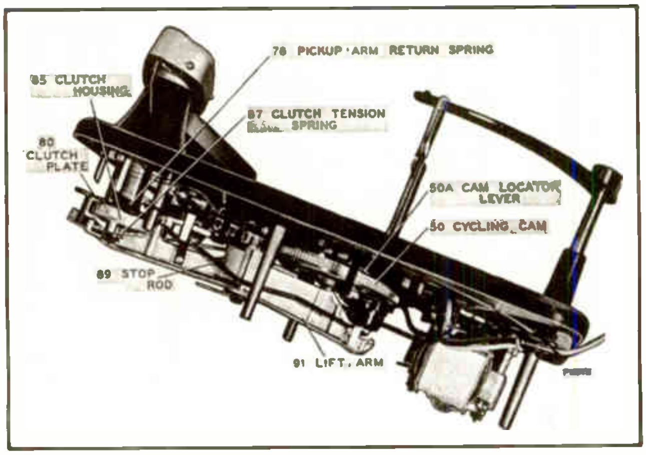

Fig. 15. Underside View of the RCA-Victor Automatic Record-Changer. (Courtesy RCA-Victor)

Fig. 18 is a view of the top side of this changer, with the turntable removed to show what lies beneath.

The service manual supplied by RCA-Victor for this model gives the following functions and notes on the principal levers shown in Figs. 15 through 18.

Control lever (59-A). The function of the control lever is to actuate both the reject rod (40) and the power switch (66). It is also engaged by the stop-rod (89), causing the mechanism to stop automatically after the last selection has been played.

Trip slide, (71). The trip slide consists of a long, thin piece of brass which actuates the lower trip dog (60) to start automatic tripping.

Stop rod (89). The stop rod consists of a long rod running lengthwise along the side of the lift arm (91). Its function is to engage the control lever and stop the mechanism after the last selection has been completed.

Lift arm (91). Functions as a main tie between the cycling cam (50) and other parts of the mechanism. It also directs the separation of the records and the movement of the pick-up arm.

Centerpost (39). Functions as a support for the record stack and also provides a means of record separation by the mechanism inside the centerpost. (The centerpost is also called the *spindle*.)

Record support (2). Performs the function of stabilizing the stack of records. It also clamps the push-off mechanism built inside the centerpost which in turn controls the stopping of the mechanism after the last selection has been played.

Landing adjustment ring (23). Forms a clamp which is used for landing adjustment and a latch controlling the indexing of 10" and 12" records.

Reject rod (40). Forms a tie between trip dog and control lever (59-A).

Upper trip dog (52). Consists of a small piece of hardened steel mounted on the main cycling cam. The contact between the off-set on the turntable shaft and the trip dog cause the teeth of the cam and the teeth of the turntable shaft to engage, thereby starting the changing cycle.

Lower trip dog (60). The lower trip dog is in contact with the trip slide (71) when tripping. It is connected by friction to the shaft of the upper trip dog, thereby providing the necessary take-up to prevent the pick-up from skipping grooves when tripping starts.

The RCA-Victor service manual gives a detailed account, together with sketches, of the complete changing cycle of this changer, and shows the mechanical action that takes place to effect the change. These diagrams are too complete to reproduce here, as are the following ones regarding the details of

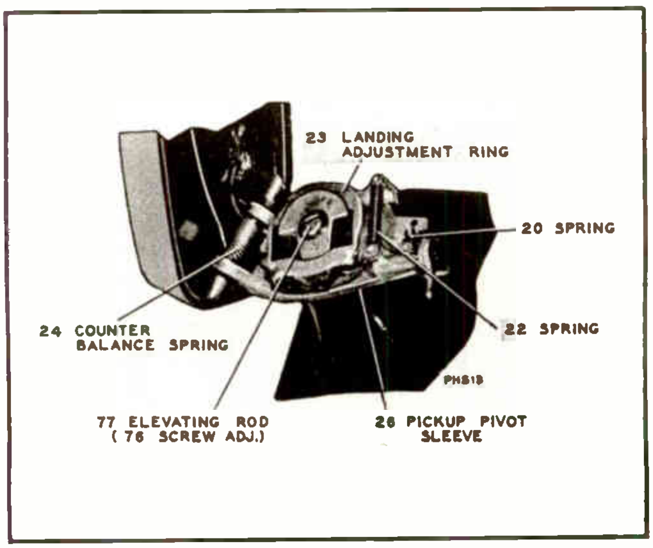

Fig. 16. Detailed View of the Fulcrum Changer. (Courtesy RCA-Victor)

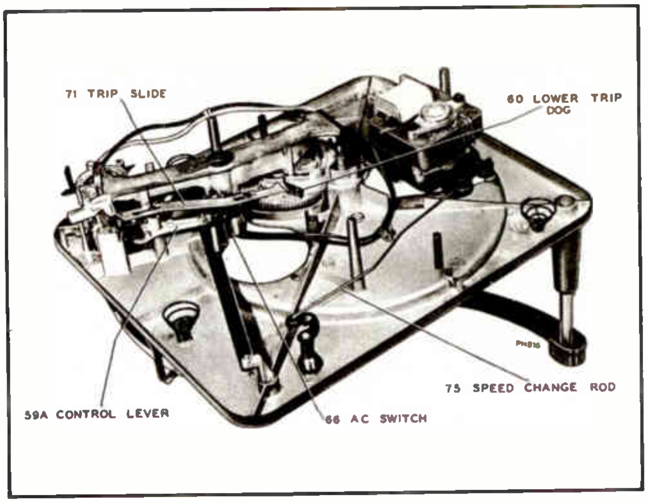

Fig.17. Another Underside View of Record-Changer.
(Courtesy RCA-Victor)

trouble-shooting this model. The trouble-shooting section provides information and correction data in the following cases of trouble:

1. The pick-up (tone-arm) skips from one groove to another.
2. Records fail to separate properly.
3. Mechanism fails to change speed when speed-selector knob is operated.

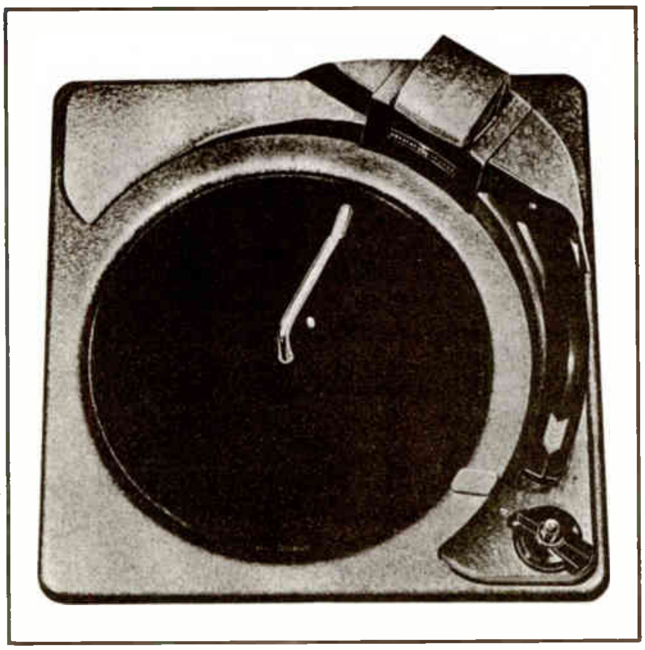

Fig.19. Top View of the Webster Model 70 Automatic Record Changer.
(Courtesy Webster-Chicago)

4. Pick-up fails to land properly.
5. "Wow" effect, or speed variation in turntable.
6. Reject button does not function.
7. Failure to trip.
8. Pick-up fails to land properly on 10" records.
9. Pick-up fails to land properly on 12" records.
10. Trips repeatedly.
11. Trips prematurely.

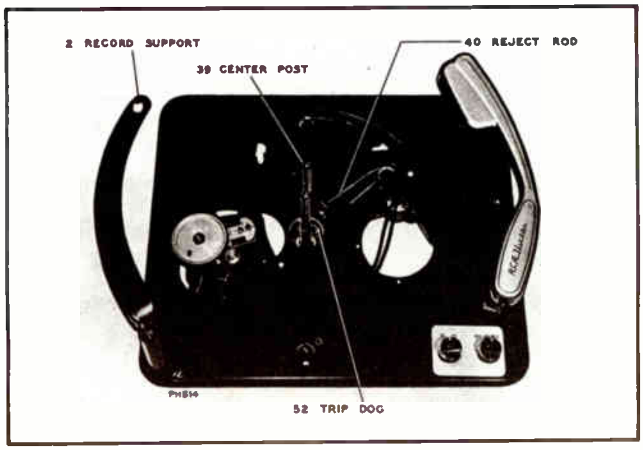

Fig.18. Top View of Automatic Changer.
(Courtesy RCA-Victor)

12. Pick-up sets down on rest instead of record.
13. Mechanism fails to stop automatically.
14. Mechanism shuts off prematurely.

The manual also supplies information and figures to be used in making all necessary adjustments and setting for proper operation.

Section 12. THE WEBSTER MODEL 70

Another popular record-changer model by a leader in the field is the Webster Model 70, a photograph of which is shown in Fig. 19. This is a single-post type, with a cushioned spindle. It provides manual record playing, and automatic playing of ten and twelve inch records intermixed. It is also suitable for home recording reproduction, and will manually play records from the outside in, the usual way, or from the inside out, as in a few special records. A special feature of this model is its retractable idler wheel, which automatically frees itself from the turntable rim when the machine is not in use. This prevents flattening of the idler wheel tire, a fault which results in "wows" due to uneven speed of the turntable. Because of its relatively simple mechanism and construction, the Webster Model 70 lends itself well to a study and location of parts.

Fig. 20 is a view of the upper turntable plate assembly. with the turntable removed to show the parts beneath. The following will serve to identify and indicate the purpose of the parts numbered in Fig. 20.

PART NUMBER	PART NAME	DESCRIPTION
1	Weight	Record Stabilizer
2	Shield	Center trim and weight assembly
4	Pick-up arm	Less crystal
6	Plate	Main base plate
7	Washer	Bearing race
8	Bearing	Ball and retainer assembly
9	Stud	Turntable shaft bearing
11	Gear	Small idler (fibre)
12	Gear	Large idler (fibre)
13	Screw	Shoulder -- idler gear mounting
14	Wheel	Idler assembly (rubber)
15	Link	Idler mounting assembly
16	Link	Connecting link and spring assembly
17	Bracket	Connecting link bracket
18	Lever	Idler release
20	Washer	Idler fibre
21	Washer	Idler felt
22	Clip	Idler retaining
23	Knob	Manual control
24	Button	ON
25	Button	OFF
27	Drive pulley	60-cycle

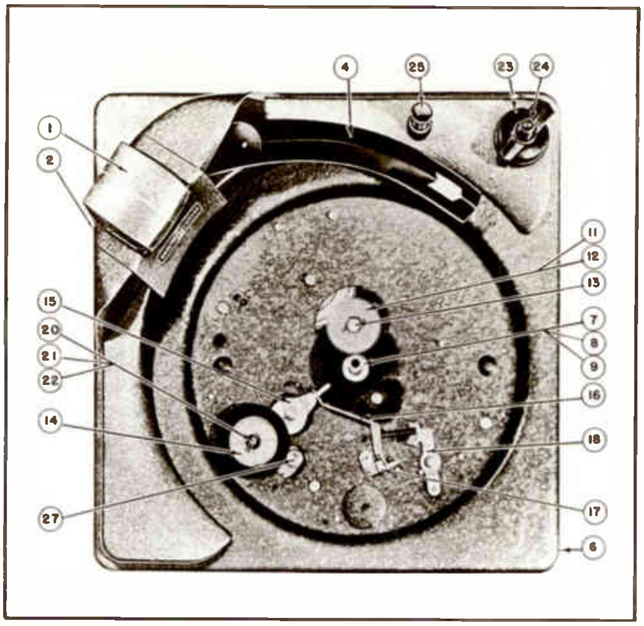

Fig. 20. This Top View of the Model 70 Helps to Locate and Identify the Parts. (Courtesy Webster-Chicago)

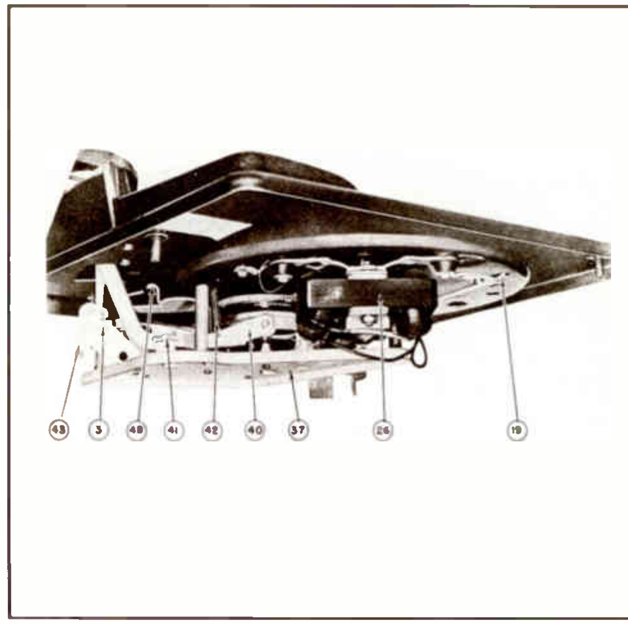

Fig. 21. Showing the Parts in a Left Side View of the Model 70. (Courtesy Webster-Chicago)

Fig. 21 shows the Webster Model 70 from the left side, with the turntable plate lifted and tilted to expose the following parts:

PART NUMBER	PART NAME	DESCRIPTION
3	Selector	Record selector and shelf assembly
19	Wire	Idler release
26	Motor assembly	50-60 cycle
37	Sub-plate	Plate and stud assembly
40	Lever	Rocker arm assembly
41	Pin	Rocker arm pivot
42	Spring	Rocker arm return
43	Lever	Index selector
48	Lever	Automatic shut-off lock

The same changer, seen from slightly below the turntable plate level, and exposing the right side of the sub-plate mechanism, is shown in Fig. 22. The parts may be identified from the table which is found on the following page.

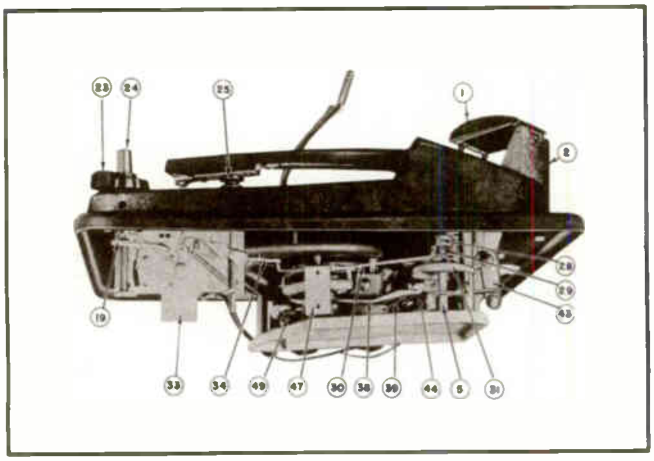

Fig.22. Showing the Parts in a Right Side View of the Model 70. (Courtesy Webster-Chicago)

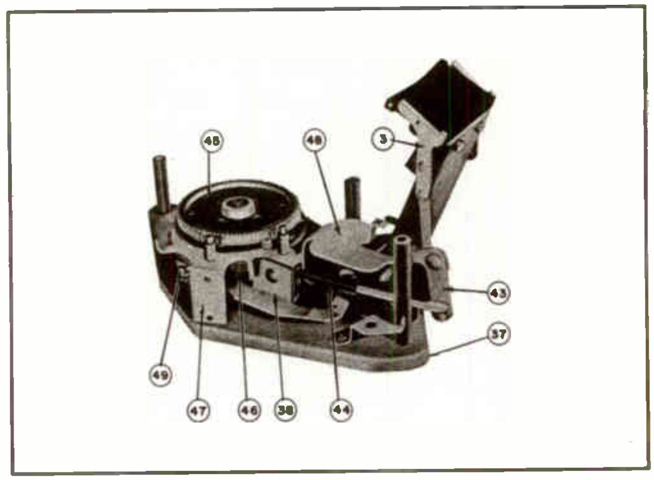

Fig.23. Showing the Parts Location in the Sub-Plate Assembly of the Model 70. (Courtesy Webster-Chicago)

PART NUMBER	PART NAME	DESCRIPTION
1	Weight	Record stabilizer
2	Escutcheon	Center trim and weight assembly
5	Shaft assembly	Pick-up arm pivot
19	Wire	Idler release
23	Knob	Manual control
24	Button	ON
25	Button	OFF
28	Lock collar	Clutch spring tension
29	Spring	Clutch tension
30	Arm	Automatic trip
31	Disc and hub assembly	Pick-up arm raising
33	Switch assembly	Less buttons
34	Manual trip	Lever and wire assembly
38	Lever assembly	Pick-up arm raising, Lever and bracket assembly
39	Spring	Raising lever tension
43	Lever	Index selector
44	Spring	Index compression
47	Trip	Velocity trip and roller assembly
49	Pin	Shut-off lock pivot

A more detailed view of the separate sub-plate, and the assembly mounted upon it, is shown by itself in Fig. 23. The parts may be identified from the following key:

PART NUMBER	PART NAME	DESCRIPTION
3	Selector	Record selector and shelf assembly
37	Sub-plate	Plate and stud assembly
38	Lever-assembly	Pick-up arm raising, Lever and bracket assembly
43	Lever	Index selector
44	Spring	Index compression
45	Gear	Main cam actuating
46	Cam	Main cam assembly
47	Trip	Velocity trip and roller assembly
48	Lever	Automatic shut-off lock
49	Pin	Shut-off lock pivot.

Lubrication points are of great importance in automatic record-changer servicing. Service manuals give this information, and specify the exact point to be lubricated, how often, and the kind of lubricant which must be used. Fig. 24 shows a Model M-12 C, Philco automatic record-changer in two views, with lubrication information. This Philco model is a multiple speed unit, playing both the standard 78 r.p.m. records of both sizes and the long-playing 33 1/3 r.p.m. records of both sizes. Note the *two* tone-arm assemblies in the top view of Fig. 24. The one at the left is a Philco Balanced Fidelity reproducer used for long-playing records, and applies the extremely low needle pressure of 1/5 ounce.

Section 13. THE RCA "45"

As a final example of modern-day record-changers, let us direct our attention to the 45 r.p.m. automatic units produced by RCA-Victor and illustrated in Figs. 25 and 26.

The RCA model 45-J (Fig. 25) consists of the record-changer, pick-up, cabinet, and manual volume control. It does not contain an amplifier system or speaker. It is designed chiefly to play through an already existing audio amplifier, such as are found in radio and television receivers, or in standard record players. It can be plugged into any audio amplifier by the use of a shielded cable and plug assembly supplied. Or it can be placed on top of a receiver, or nearby as shown in Figs. 29 and 30.

The RCA model 45-EY is the same record changing unit, but includes a two-stage amplifier and rectifier system, obviating the need for plugging it into another amplifier. The tube complement is as follows: 1-12AV6, 1-50C5, and 1-35W4. While the amplifier would operate on A-C or D-C, the motor is an A-C motor and thus the entire unit is limited to A-C input power from the wall receptacle. (See Fig. 26.)

Fig. 27 shows a cross-sectional view of this "world's fastest and smallest" automatic record-changer. Several of the important parts are identified, and the illustration provides a good idea of the compactness and simplicity of the unit.

Fig. 28 is another view of the RCA-45, showing how the records are selected by the

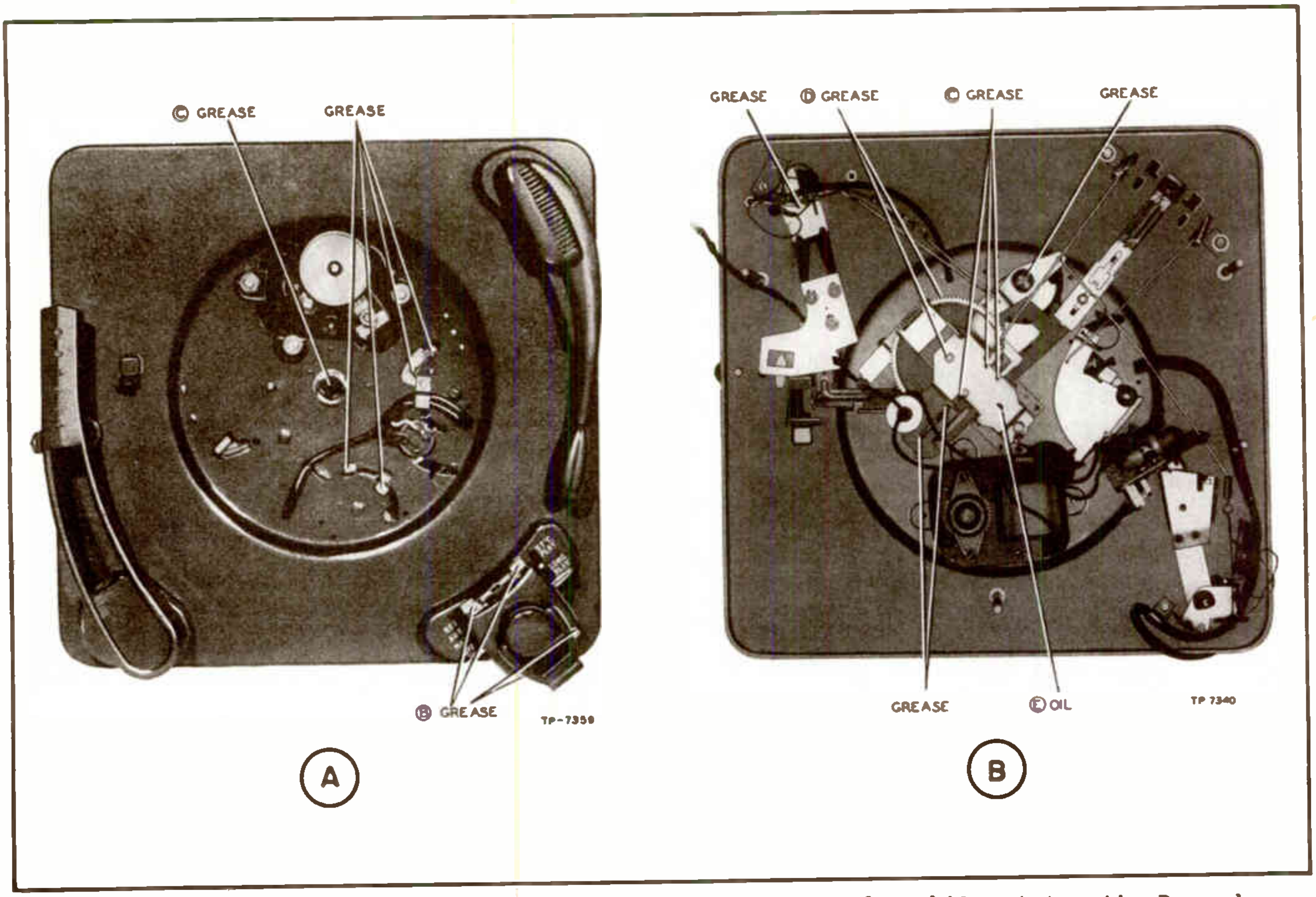

Fig.24. A. Lubrication Points Accessible From the Top of a Philco Automatic Record-Changer. B. Lubrication Points Accessible From the Bottom of the Unit. (Courtesy Philco Radio Corp.)

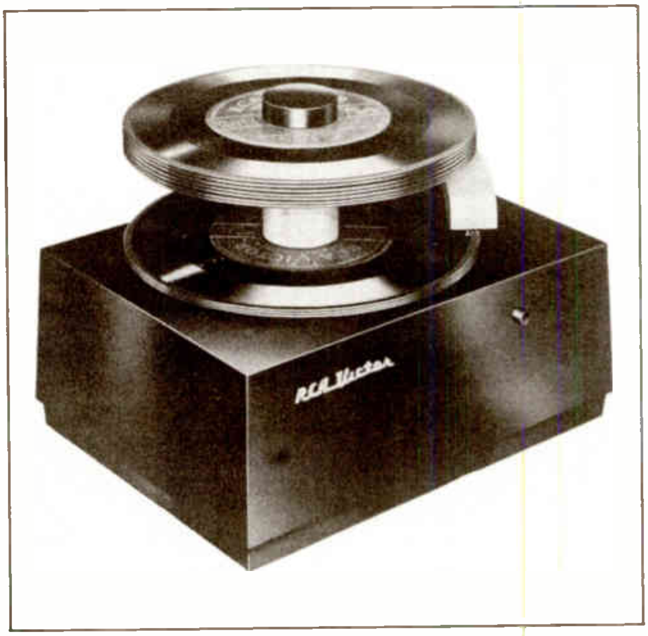

Fig.25. Photograph of the RCA Model 45-J Automatic Record Player. The Records are 7" in Diameter. (Courtesy RCA-Victor)

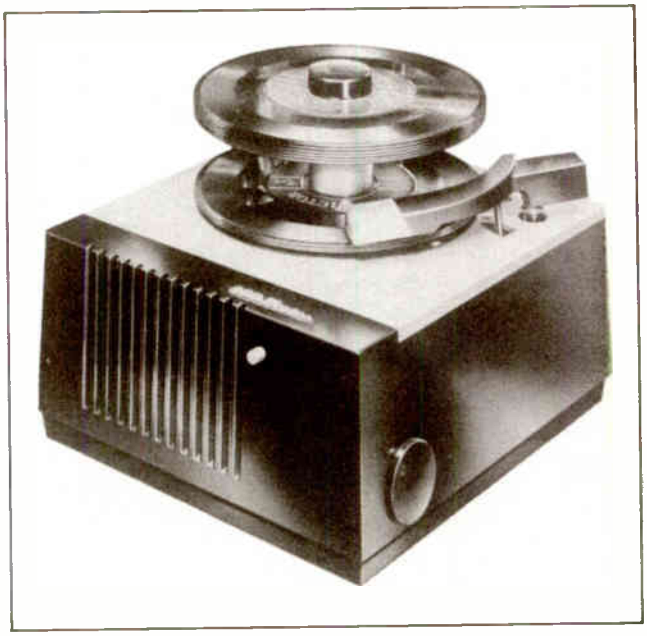

Fig.26. The RCA-45EY, an Automatic Changer Supplied With Its Own Audio Amplifier. (Courtesy RCA-Victor)

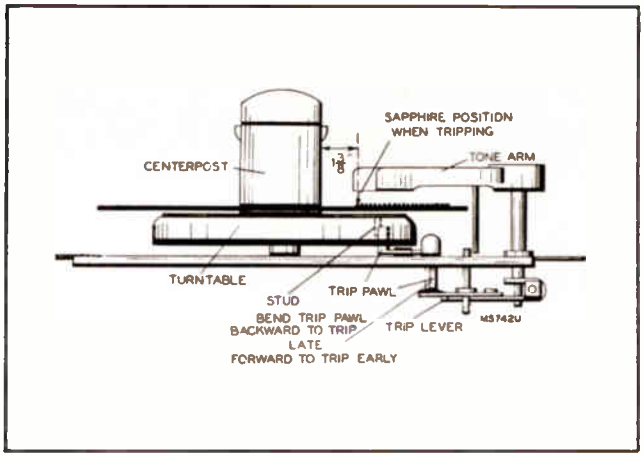

Fig.27. Cross-Sectional View of the RCA 45 R.P.M. Automatic Record Changer. (Courtesy RCA-Victor)

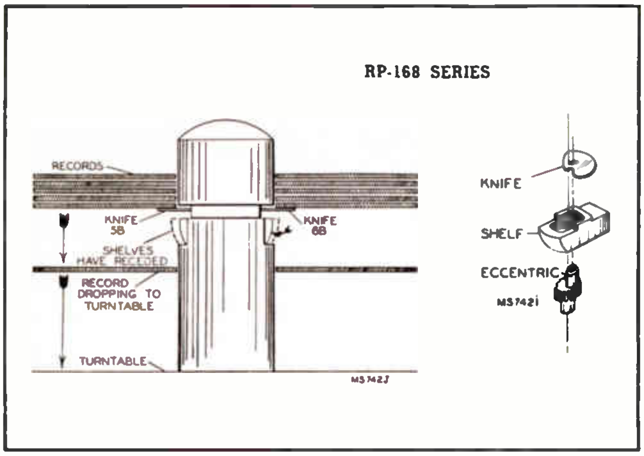

Fig.28. Record Selecting Action of the RCA-45. Note, There Are No Side Posts. (Courtesy RCA-Victor)

knife-and-shelf assembly attached to the center post. Note that there are no side posts in this unit, and hence no need for slicing the edges of the records in the changing cycle.

Fig. 27 indicates the adjustment to be made to synchronize the tripping mechanism with the correct phase of the changing cycle. A detailed view of the knife-shelf-eccentric assembly is also shown in Fig. 28.

Fig.29. How the RCA-45 Can Be Set On Top of Television Receiver. (Courtesy RCA-Victor)

Fig.30. Another Method of Using the RCA-45 With a Television Receiver. (Courtesy RCA-Victor)

Both the RCA-45-EY and 45-J units play 7" micro-groove records. These records are unique in that their grooves are close together, and terminate about halfway between the outer rim of the record and the center. The advantage is that the record modulation is always being picked up from a groove in the record which is traveling at a rate faster than that at the center of the record. This minimizes distortion in reproduction.

NOTES FOR REFERENCE

Crystals are widely used in the field of radio communications as controlling agents for the oscillators of radio transmitters.

They are also of extreme usefulness in record reproduction. In this application, their Piezo-electric properties are exploited.

The Piezo-electric effects found in such crystals as quartz, Rochelle Salts, and tourmaline are such that when electrical energy is applied along their X-axis, mechanical vibrations occur along their Y-axis. Conversely, when mechanical vibrations are applied along their Y-axis, electrical voltages occur across their X-axis.

The modern phonograph pick-up is usually a crystal, although in some cases it may be a low-impedance coil.

The voltage output from a crystal pick-up is very low, seldom greater than one volt, and often but a fraction of a volt.

The frequency with which a crystal will oscillate is determined by the kind of cut, the width, the thickness, and the temperature.

X-cut crystals have a positive temperature co-efficient. Y-cut crystals may be negative, zero, or positive.

AT, DT, and GT cuts have very low temperature co-efficients and are therefore most suitable for use in oscillator control.

The advantage of crystal-controlling an oscillator is that the frequency is essentially constant and the band-width is narrow.

Crystals used as oscillator controls may be mounted in two ways: with or without an air gap. For certain cuts, the air-gap permits fine tuning adjustments.

Automatic record-changers may be classified into three groups: the single-post type, the double-post type, and the three-post type. The first is the most popular, but there are many of the others still in service.

Record-changers may play records automatically in many different combinations.

Some play only the standard 78 r.p.m. records of the 10" and 12" sizes. This is known as a single speed changer.

Some play both the standard 78 r.p.m. of both sizes and the long-playing 33 1/3 r.p.m. records of both sizes. This is a dual-speed unit.

Some play both sizes of the 78 r.p.m. records, both sizes of the 33 1/3 r.p.m. records, and also the 7" 45 r.p.m. records; a triple speed unit.

Record-changer troubles may take on a variety of forms. To facilitate the approach to the trouble, first classify it as: electrical power, electrical signal, mechanical signal (crystal and needle), and mechanical operation.

The final authority for trouble-shooting any specific make and model of an automatic record-changer is the manufacturer's service manual for the unit. This manual will be sent to the electronics technician by the manufacturer, upon request, if the model number is specified.

Take the time necessary to *study out* record-changer trouble. Set it up conveniently, and watch it carefully under good light. Sooner or later the trouble will reveal itself in the exact operational failure.

There is no substitute for *experience* in record-changer trouble-shooting and repair.

NOTES

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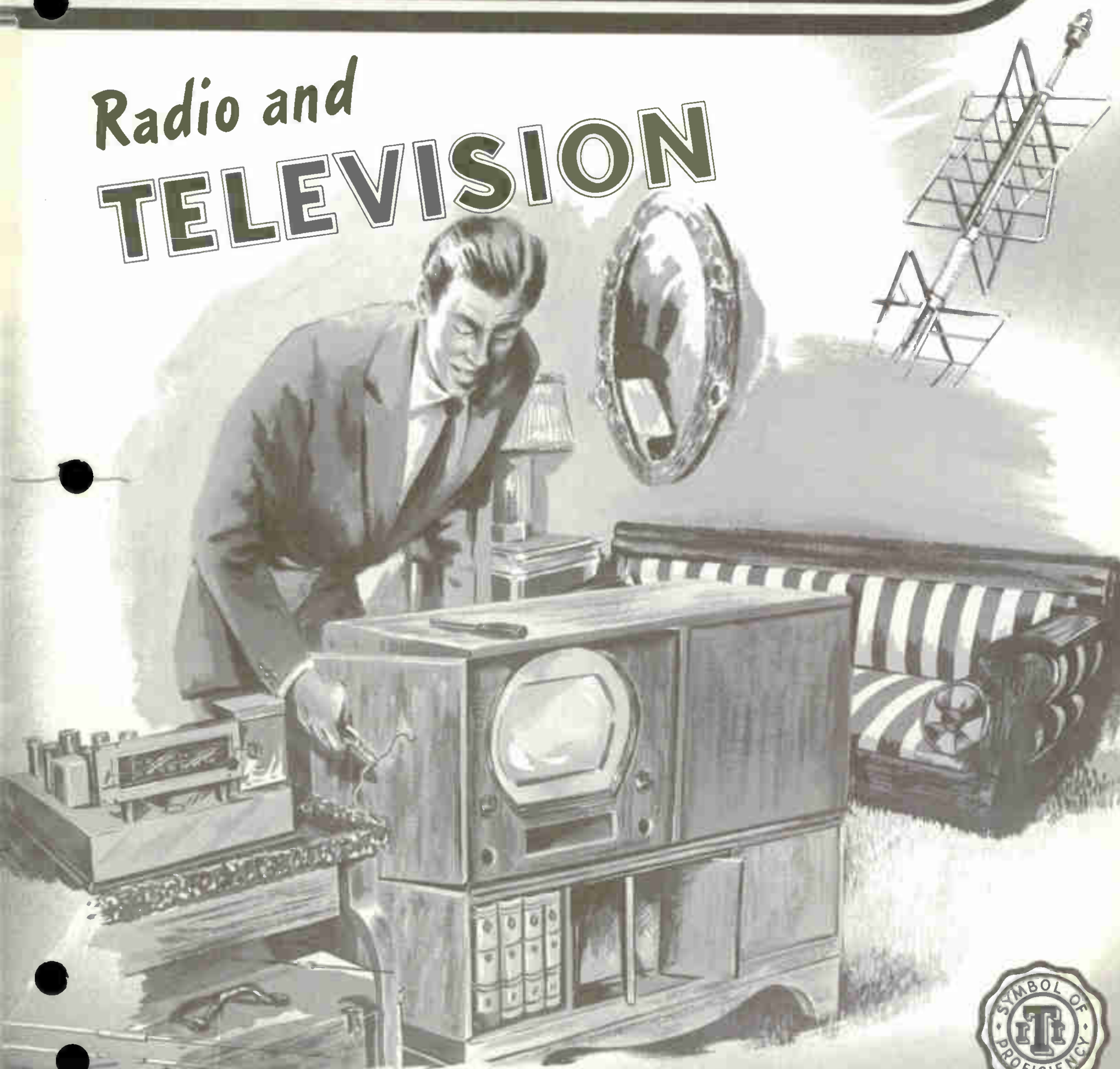

INDUSTRIAL TRAINING INSTITUTE

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TECHNICAL TRAINING SERVICE

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RADIO TELEVISION

FREQUENCY MODULATION

Contents: Introduction - Modulation and Demodulation - Modulating the AM and FM Carriers - Percentage of Modulation - The FM Transmitter - Frequency Deviation - Deviation Ratio - The Coverage Range of Frequency-Modulation - AM and FM Stations - FM Receiving Systems - Combination AM-FM Receivers - FM in Television Receivers - Notes for Reference.

Section 1. INTRODUCTION

In some of our previous lessons we have discussed at considerable length the subjects of modulation and demodulation. We described the method which is commonly used to impress the audio signals created by voice and music onto the high radio frequencies created by electronic oscillators. Our past discussions have all revolved around the method of modulation which is commonly known as Amplitude Modulation. This is the system of modulation used by all the older radio broadcast stations. It is also the system which is used to modulate the video carrier of television signals.

In amplitude modulation we cause the carrier signal to transmit the intelligence of the spoken word, or of music, or of any thing else we want to send through space. We cause the carrier signal to do this through the medium of increasing or decreasing the strength of the carrier in such a manner as to conform with the audible frequencies of the intelligence we want to transmit. To put this in other words: Audio signals are carried by the high frequency radio signals because the *amplitude* of the carrier signal is varied at a frequency which corresponds with that of the original audio signals.

In addition to the method of varying the *amplitude* of a carrier to conform to an audio signal impressed upon it, there is another method of modulation in common use. This second method is called *Frequency Modulation*. Instead of varying the amplitude of the carrier wave to conform with the frequency of the modulating audio signal, the frequency of the carrier is actually varied. It is the purpose of this lesson, and those which immediately follow, to describe the operation of the Frequency method of modulation. The difference between the amplitude method of modulation and the frequency method of modulation will be pointed out, and those circuits which are found only in FM will be discussed in detail.

Section 2. MODULATION AND DEMODULATION

We are already familiar with the amplitude-modulated radio-borne signal and the methods used in the receiver to recover the audio

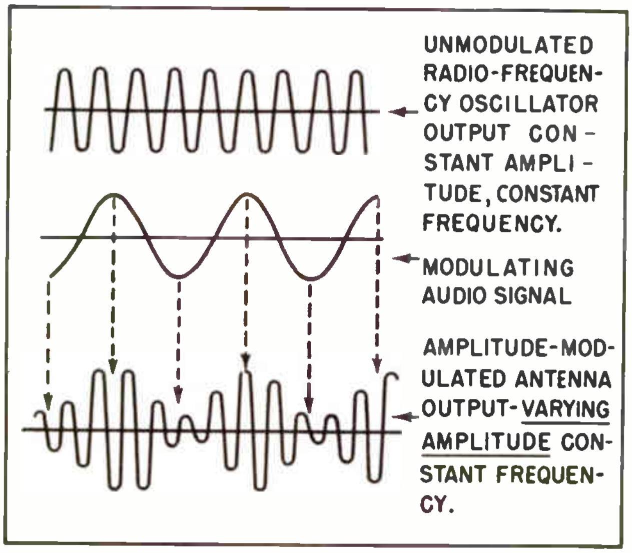

Fig. 1. Wave Forms of the Amplitude-Modulated Signal.

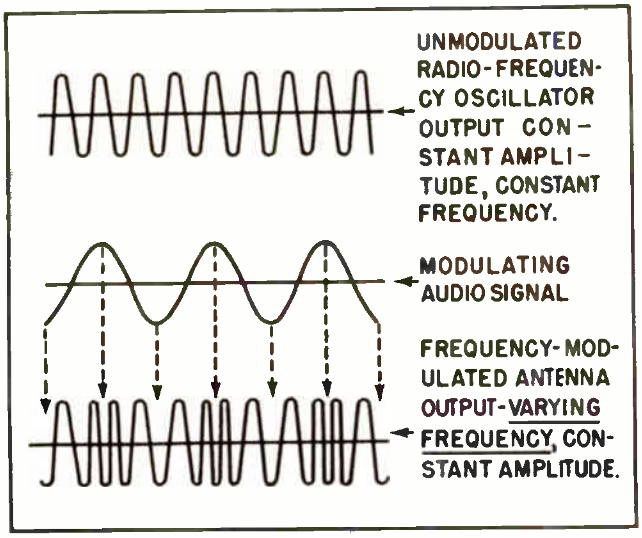

Fig.2. Wave Forms of the Frequency-Modulated Signal.

component thru the process of demodulation, or detection. Fig. 1 shows the essential points regarding the wave-form of an amplitude-modulated signal. This reminds us that: Amplitude-Modulation means changing the amplitude of a radio-frequency carrier in accordance with an audio or video signal, while leaving the frequency constant.

In contrast to amplitude modulation, we can formulate a definition of Frequency-Modulation: Frequency-Modulation means *changing the frequency of a radio-frequency carrier* in accordance with an audio or video signal, while leaving the amplitude constant.

Fig. 2 illustrates the wave-form of a frequency-modulated radio signal. A comparison with Fig. 1 will readily show that the definitions of AM and FM clearly distinguish between these two methods of transmitting a signal by means of a radio carrier. Notice that the wording of these two definitions is identical, with the exception that the terms "frequency" and "amplitude" are interchanged.

It is significant to know that both the AM and FM carriers are capable of transmission through space at the speed of light. Also, they are both capable of bearing with them through space, the audio or video component of a signal whose destination is meant to be some point remote from the transmitter. In these characteristics AM and FM are alike. They differ, however, in certain other important respects. Their chief differences occur on the basis of the following classifications:

The methods used in modulating the carrier are different.

The methods used in demodulating, or detecting, the signal are different.

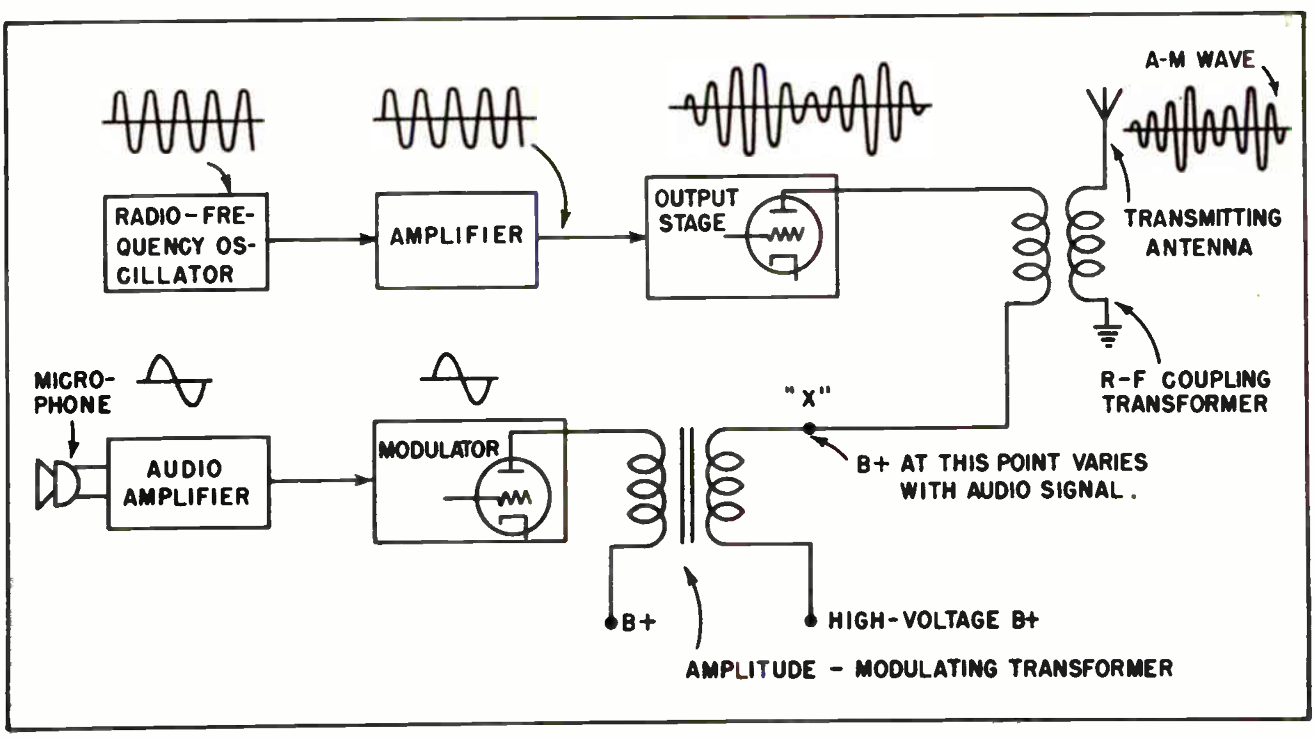

Fig.3. Block Diagram and Wave Forms of an AM Transmitting System.

The frequencies of their carriers are usually different.

Their bandwidths are different.

Their effective coverage ranges are different.

Before discussing its peculiarities and applications, let us first examine the advantages of Frequency Modulation over Amplitude Modulation.

The FM signal is practically noise-free. Under most conditions, man-made and natural static will not affect FM. That this is a distinct advantage is readily apparent to anyone. The FM signal, possessing wide bandwidths, is capable of reproducing virtually all the important tones of a musical signal. FM, therefore, is superior to AM in the fidelity with which it brings in an audio signal.

Section 3. MODULATING THE AM AND FM CARRIERS

While these lessons are not primarily concerned with the techniques of transmitting AM and FM signals, but rather with the apparatus capable of receiving them, it improves our understanding of receiving circuits if we know the processes involved in creating and shaping the transmitted signal.

The AM Transmitter. Fig. 3 shows the block diagram of a basic AM transmitter unit, and indicates the nature of the wave-forms at various points. A radio-frequency oscillator, tuned to oscillate at a convenient R-F rate, produces a frequency at a constant rate and with a constant amplitude. This wave-form is re-enforced in the amplifier stage that follows the oscillator. If there were no modulating components, the output stage would accept this constant-frequency-constant-amplitude wave and feed it to the antenna. From the antenna it would be carried through by means of radiation in all directions with the speed of light. This would constitute the unmodulated carrier wave, which is shown in Fig. 4-A. But, just because it is unmodulated, it does not carry any actual "intelligence" -- it carries no message of any kind. We shall now see how the signal is inserted into the unmodulated carrier, thus making it a modulated carrier.

The microphone is impressed with the sound energy representing the intelligence to be

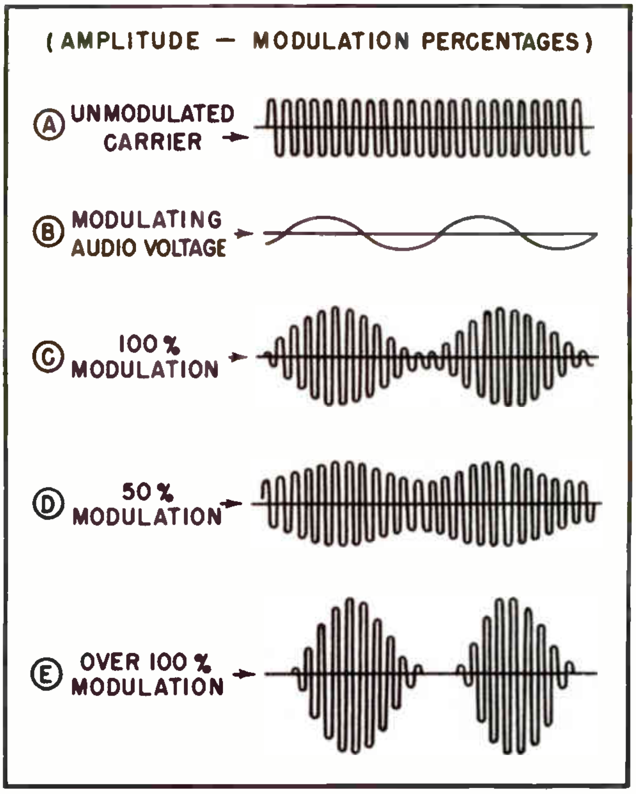

Fig. 4. Meaning of "Percentage of Modulation" in the AM Signal.

transmitted. (See Fig. 3.) The microphone, being a device which converts sound energy into electrical impulses, feeds its signal to an ordinary audio amplifier. Here the signal is strengthened by the vacuum-tube amplifier and then fed to the modulator. This stage is the key to the entire process of Amplitude-Modulation.

Note that the primary of the modulating transformer is supplied with current changes which conform to the sound which actuated the microphone. The secondary of this transformer will, therefore, be the source of a voltage which likewise conforms to the actuating sound. We already know that an induced secondary voltage must be alternating in character. This means that in addition to the high-voltage B-plus delivered to the transmitter output plate through the secondary winding of the modulating transformer, an alternating voltage is also present, as illustrated in Fig. 4-B. The result is that during one half-cycle of audio signal voltage, the alternating component will add to the D-C component of the output plate voltage; during the other half-cycle, the audio signal voltage will subtract from the D-C component. Point "X" of Fig. 3, therefore, will at one instant carry the sum of the A-C and D-C voltages, and a half-cycle later will carry the difference between the A-C and D-C voltages.

Now, since the amplitude of the output of any amplifier is dependent upon the value of B-plus applied to its plate at any instant, the amplitude of the heretofore unmodulated oscillator frequency will be changed in accordance with the audio signal, but its frequency will remain constant. This condition, by definition, is amplitude-modulation. This has been discussed in somewhat more detail in an earlier lesson, but a partial review is worthwhile at this time. The R-F coupling transformer between the output stage and the antenna is to transfer the energy released by the output tube to the radiated wave in free space.

Section 4. PERCENTAGE OF MODULATION

We may measure the extent (or percentage) of modulation present in a given AM carrier. Depending upon the relation between the carrier amplitude and the modulating voltage in the transmitter (at point *"X"* in Fig. 3), several modulation conditions are possible. If, for instance, the half-cycle of negative voltage at point *"X"* is strong enough to completely cancel out the high-voltage B-plus, so that their combined effect is zero at that instant, the transmitter output will be zero at the same instant and the modulation is then said to be 100%. It is evident that with 100% modulation, on the opposite (positive) half-cycle of signal voltage in the modulating transformer secondary, the voltage at point *"X"* will be twice the high-voltage B-plus. Since at that time this voltage is equal to the modulating voltage. The wave-form of an AM carrier, modulated to the extent of 100%, is shown in Fig. 4-C.

When the peak voltage across the modulating transformer secondary is sufficient to drive the carrier to only one and one-half times its unmodulated amplitude during one half-cycle of the audio signal, and to one-half the unmodulated amplitude on the opposite half-cycle, the degree of modulation is said to be fifty per-cent. A carrier modulated at 50% is shown in Fig. 4-D.

Another possible condition is for the modulation to be over 100%, an example of which is illustrated in Fig. 4-E. Here the modulating audio voltage swings far enough in the positive direction so that it more than doubles the unmodulated carrier output on that half of the audio cycle. The modulating voltage cuts-off the output tube current on the other half-cycle for a considerable interval. This represents audio distortion in the received signal and is therefore avoided in practice.

Section 5. THE FM TRANSMITTER

We are now prepared to make comparisons between the creation and shaping of the FM signal and those of the AM signal. Fig. 5 is a block diagram of a basic FM transmitter unit, and indicates the wave-forms at various points throughout the circuit.

The R-F oscillator, unless it is acted upon by a signal from the reactance modulator, will produce a self-controlled

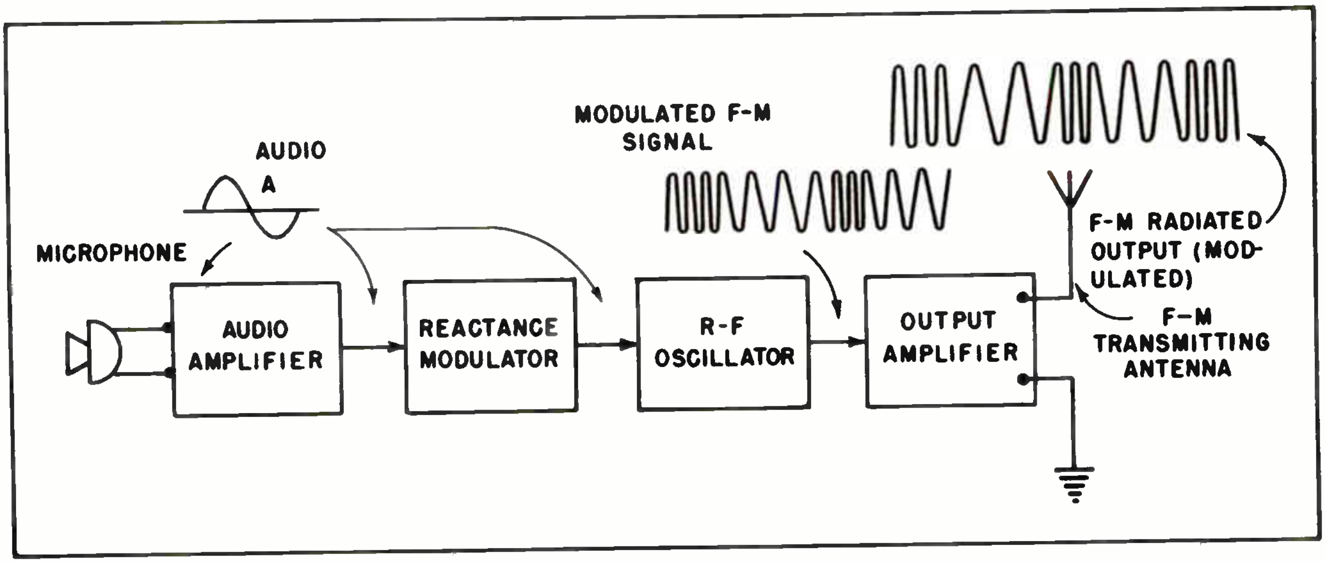

Fig.5. Basic Block Diagram of an FM Transmitter.

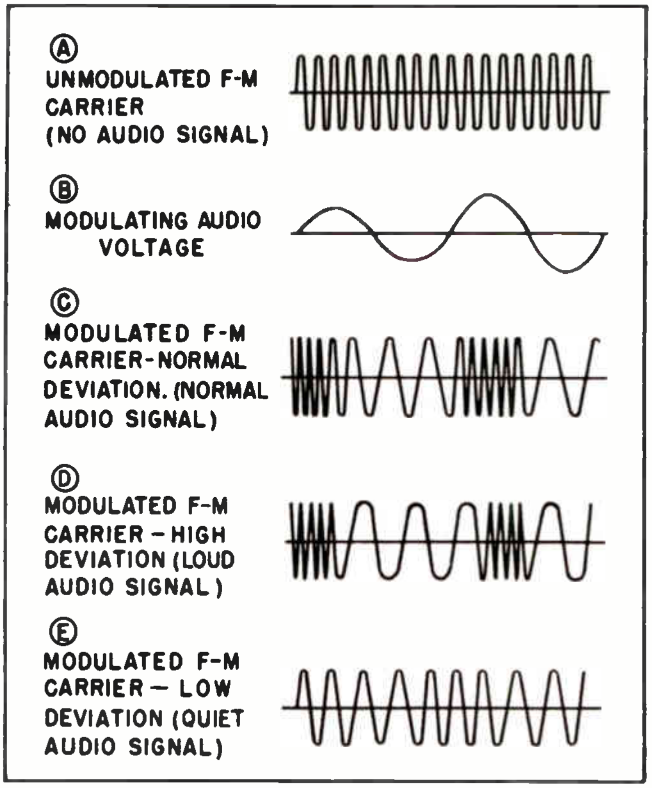

Fig.6. Showing the Meaning of "Deviation" of an FM Carrier.

oscillating output signal. This frequency, determined by the values of inductance and capacity in its tuned circuits, is fed to the output amplifier from where it is again fed to the antenna and transmitted into free space by the process of radiation. The unmodulated wave-form, identical to the AM unmodulated wave, is shown in Fig. 6-A. This is the shape of the FM wave before modulation takes place.

In FM, however, the oscillator which generates the transmitted frequency does not continue oscillating at a constant rate, as in the case of AM transmitters. The oscillator of the FM transmitter, on the contrary, is being acted upon continuously by the output of the stage immediately preceding it in Fig. 5 -- the reactance modulator stage.

Since the reactance modulator output is an electrical duplicate of the sound energy which actuates the microphone, the oscillator is being acted upon by electrical effects which correspond to the variations in microphone voltage. As we know, these variations are taking place at an audio rate. Further, the R-F oscillator circuit is so arranged that the audio voltage from the reactance modulator will change the frequency of the oscillator output in accordance with the audio signal, while leaving its amplitude constant. This condition, by definition, is Frequency-Modulation. The output amplifier accepts the frequency-modulated output from the oscillator and feeds it to the antenna for broadcasting.

In an AM transmitter, the modulator was shown to be the key stage to bring about amplitude modulation. In the FM transmitter, the reactance modulator is the corresponding key stage which brings about frequency modulation.

To better understand the wave-shaping process in FM, let us now direct our attention to the reactance modulator, a basic circuit of which is shown in Fig. 7. This circuit is similar to the one used for automatic frequency control employed in some radio and television receivers. The AFC, which is used to stabilize the frequency of the local oscillator by cancelling out drifts due to changing local conditions, has been discussed in a previous lesson. The difference is that in the reactance modulator of an FM transmitter the required effect is to produce changes in oscillator frequency at an audio rate, whereas in the AFC circuits the desired effect is to keep the oscillator frequency constant.

The action is identical, however, since a circuit which can keep a frequency constant is also capable of bringing about certain frequency changes when desired. The only difference is in the application.

Fig. 7 shows two vacuum tubes, an oscillator and a reactance modulator. These correspond to the similarly-named stages in the block diagram of Fig. 5.

The audio input, whose wave-form is to be impressed on the carrier in terms of frequency changes, is fed to the reactance modulator grid, where it undergoes amplification. The plate load of this stage is the coil of the oscillator tank circuit, whose windings are traversed by reactance tube current on its way to B-plus. Since the reactance tube load is almost purely inductive at audio frequencies, its plate current and plate voltage differ by practically a 90-degree phase difference, with the current lagging the voltage by this value. A lagging current indicates an inductive effect in the oscillator tank circuit, while a current which lags less

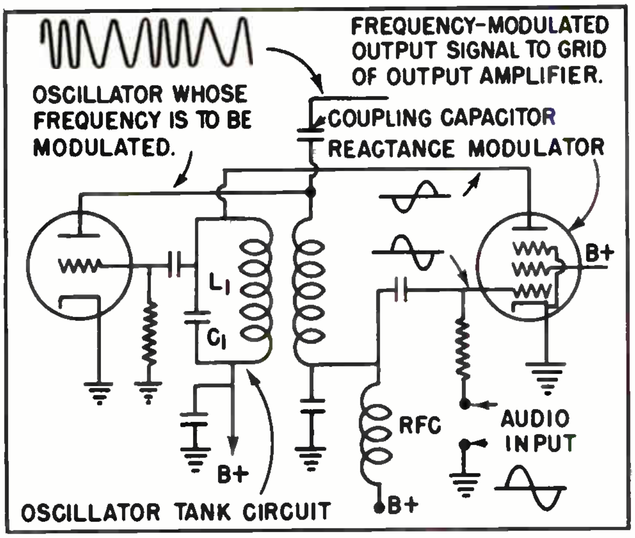

Fig.7. The Reactance Modulator and Oscillator Circuit Employed to Frequency-Modulate a Carrier.

indicates less inductance in this circuit. This "fictional" variation in tank circuit inductance, occurring in accordance with reactance tube current at audio rate, will therefore have the effect of varying the ratio of L/C in the tank circuit and will therefore change its frequency at the audio rate. It can be seen by analyzing the circuit that if the grid of the reactance modulator is made more negative the oscillator frequency will increase, and as the grid of the reactance modulator becomes more positive the oscillator frequency will decrease.

We may therefore conclude that the frequency of an oscillator so controlled is directly proportional to the negative voltage at the reactance modulator grid. Since this grid is fed with a signal which varies at audio rate, the output of the oscillator -- and also of the FM transmitter -- will be frequency-modulated at an audio rate.

Percentage of Frequency-Modulation. A glance back at Fig. 4 will recall to us that amplitude-modulated signals may occur in various percentages varying between a low percentage to over 100%, the most effective and efficient percentage being 100%. Frequency-modulation, due to the different relationship between the carrier and the modulating signal, must be viewed in another way, since the amplitude of the FM carrier is constant either with or without modulation.

In AM, the degree, or depth, of modulation is an expression of the comparison between the amplitudes of the carrier and the modulating signal. In FM, the degree, or depth, of modulation is an expression of the comparison between the frequency of the carrier and the amplitude of the modulating signal.

Section 6. FREQUENCY DEVIATION

Since in FM the amplitude of the carrier is constant, the term "modulation percentage" is meaningless if taken in a sense similar to that used in AM. We can, however, by taking the conditions into consideration, give a meaning to "modulation percentage" when applied to FM signals. These conditions are related to the maximum deviation permissible in FM transmission of signals.

If an FM transmitter is operating, let us say, at a frequency of 100 megacycles, its "resting" (or unmodulated) frequency will be 100 megacycles. During modulation, however, which will occur when sound energy strikes the microphone, the frequency of the carrier will rise and fall above and below the 100 megacycle *resting frequency*. In terms of cycles per second, this means that at one instant the carrier is above 100 megacycles and a short time later is below 100 megacycles. If the audio modulation, acting upon the resting frequency drives it first to 100.075 megacycles, then drives it down to 99.925 megacycles, we see that there is a difference between the resting carrier and the higher frequency equal to .075 megacycles, or 75 kilocycles; also, there is an equal difference between the resting carrier and the lower frequency of .075 megacycles, or 75 kilocycles. The actual result is that the carrier is seldom stable. It is being constantly driven through the frequency range of 99.925 to 100.75 megacycles at an audio rate, with the mean, or average, carrier frequency of 100 megacycles lying midway between these limits.

This difference, between the carrier's unmodulated frequency and either the upper or lower limit, is known as the frequency *deviation* of the FM signal. In the above example, the frequency deviation is 75 k.c.

Frequency deviation in FM corresponds to percentage of modulation in AM. The maximum permissible deviation in FM signals is fixed by law. This is done to prevent the lower limit of one transmitter interfering with the upper limit of another station whose allocated frequency is just below that of the first. The deviation of FM signals is also limited by practical considerations, in that the FM receiver must have a bandwidth passage capable of accepting and passing the wide range of frequencies transmitted. Failure of the receiver to do this will result in distortion of the audio signal as heard in the receiver speaker. The I-F circuits of an AM receiver need be capable of passing a bandwidth of only 10 k.c. The above example indicates the I-F of an FM receiver must be able to pass 150 k.c.

In a broad sense, then, percentage of modulation, as applied to AM transmitters, also applies to FM in the sense that in FM a practical limit -- 75 k.c. -- corresponds to 100% modulation.

Let us now refer back to Fig. 6, to see the effects of modulating over, at, and under 100% in an FM signal.

Fig. 6-A is the unmodulated FM carrier and is therefore at its resting frequency. Fig. 6-B shows the sine-wave audio signal which will eventually ride the carrier in its excursion through space. Fig. 6-C shows the carrier modulated to a "normal" degree, which is really only a matter of comparison. We may assume, however, that this represents the difference between the highest and lowest frequencies attained during the transmission of a normal level audio signal, whose deviation is approximately one-half of 75, or 37.5 k.c.

In Fig. 6-D an "over-modulated" FM carrier is shown. Here the compressions are closer together and the spread between compressions is wider. This we may interpret as a greater deviation. While this action in the transmitter will not actually distort the signal, it may extend beyond the legal limit permitted. Furthermore, a receiver not capable of handling this wide bandwidth will make the signal sound distorted after receiving it. The maximun deviation permissible is 75 k.c.

Fig. 6-E shows an example of "under-modulation" in FM. Here the highest frequency attained is not very high -- in comparison with the resting carrier -- and the lowest frequency is not very low. There is little danger in this case either of exceeding the legal deviation limit, or of causing distortion in a receiver with ordinary bandwidth characteristics, but the signal will be *quiet* when received. Deviation of the carrier here is approximately 10 k.c.

There is another, and equally important, meaning to be attached to deviation in an FM signal. We may well ask, if the faithful reproduction of an audio signal is the complete retention of frequency and amplitude changes in the audio signal, how does the FM wave carry these changes? In other words, what constitutes loudness and what constitutes pitch in the FM signal?

Referring again to the wave forms of Fig. 6, these questions may now be answered. In 6-C, with a normal level audio signal, the degree of deviation is such as to make the upper and lower frequency limits of the carrier stay well within the legal values. In other words, a deviation of approximately 37.5 k.c. means that the modulating audio level causing it is of about medium loudness.

In Fig. 6-D, where the deviation is the maximum permissible, 75 k.c., the modulating audio level is of maximum loudness. A louder modulating audio signal would overdrive the deviation limit.

In Fig. 6-E, on the other hand, where the deviation is of the order of 10 k.c., the modulating audio level is low -- that is, it represents a quiet audio signal.

With these facts in mind, we may now formulate an important statement: In FM transmission, the loudness or amplitude of the audio signal is proportional to the degree of deviation of the carrier. (By comparison, in AM transmission, the loudness of the audio signal carried is proportional to the amplitude of the carrier.)

But what about the pitch of the audio component of the FM signal? In ordinary audio considerations, the pitch of a note is defined as its frequency in cycles per second. Translated into terms of a frequency-modulated signal, pitch then becomes the number of times per second that deviation takes place. (By comparison, in AM transmission, pitch is the number of times per second that amplitude changes occur.)

The wave forms of Fig. 8 illustrate the meaning of pitch and amplitude, as referred to the audio signal component, in both the AM and FM transmitted signals.

Section 7. DEVIATION RATIO

Another term peculiar to FM only is known as the ratio of deviation, or modulation index. It is a comparison between the

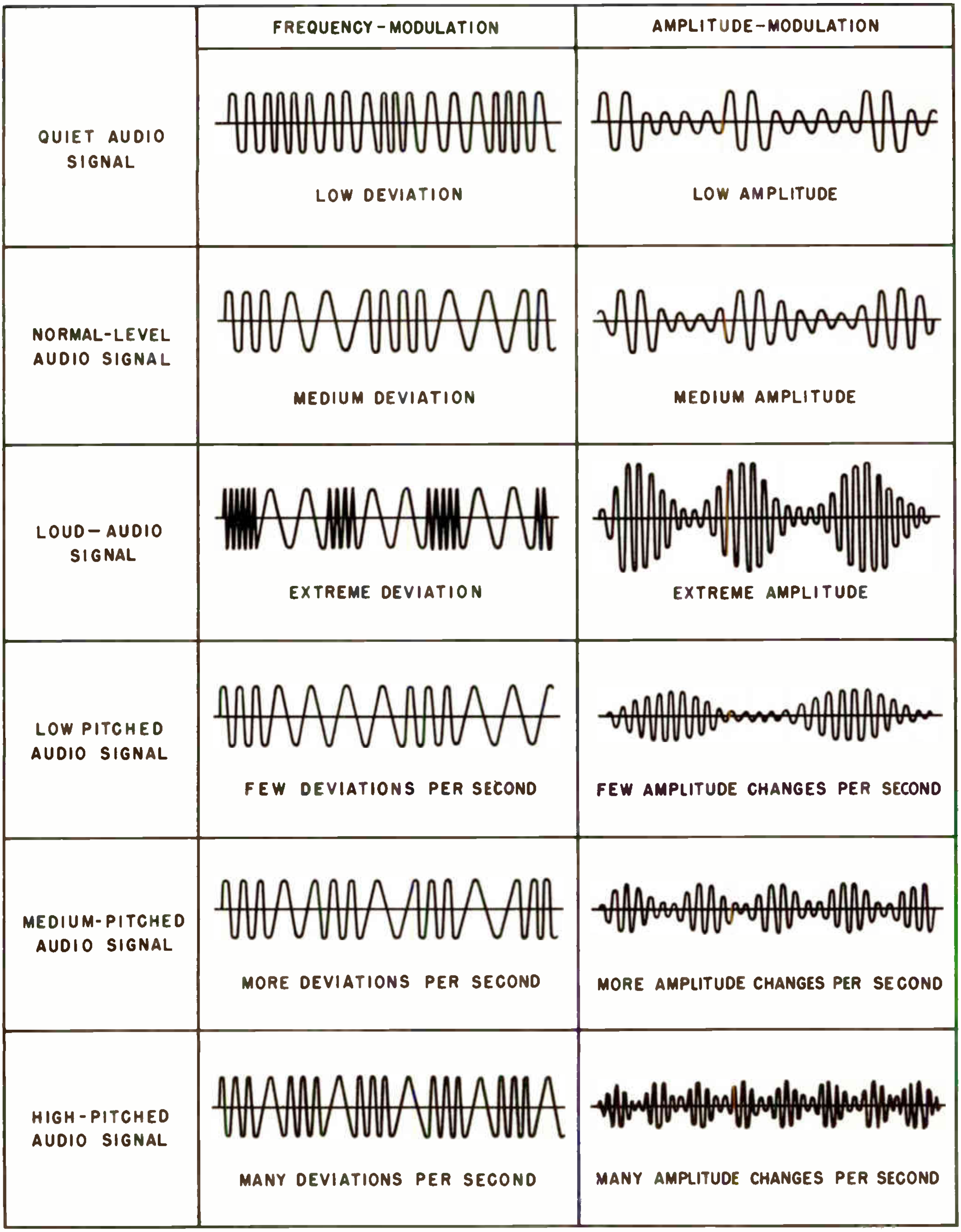

Fig. 8. This Table Compares the Effects of Amplitude and Pitch Changes in the Modulating Signal on the AM and FM Carriers.

frequency of the highest-pitched note broadcast and the maximum deviation of the carrier, and is equal to the latter divided by the former. For instance, if the maximum deviation of the carrier is 75 k.c., and the highest-pitched audio note carried by the carrier is 15 k.c. (15,000 cycles per second), then the deviation ratio, or modulation index in this example is 75,000 divided by 15,000, or 5. This is the standard deviation ratio in current use.

We shall meet deviation ratio again when we discuss the types of FM demodulators associated with the FM receiver. However, in FM transmitter considerations, it can be said that in general, a high deviation ratio for an FM signal means a lower noise level at the receiver. This is true where the FM signal strength itself is high.

When the transmitted FM signal strength is low, then a lower deviation ratio improves the signal-to-noise ratio in the receiver. In practice today the power output of FM transmitters is high, in most cases approaching the multi-kilowatt power output of the large AM transmitters. A deviation ratio of approximately 5 is therefore suitable for FM reception with a satisfactory signal-to-noise ratio.

Section 8. THE COVERAGE RANGE OF FREQUENCY-MODULATION

A peculiar combination of circumstances relating to the characteristics of the FM transmitted signal constitutes an indirect -- but effective -- reason for its short-range coverage, as compared to the long-range transmission of AM radio signals.

One of these circumstances limiting the effective range of FM signals is that the wide bandwidth normally required by FM for faithful and efficient reproduction of audio signal modulation, necessitates a high carrier deviation value. Two FM stations, due to the high deviation of the carriers, cannot be assigned frequencies that may overlap. A safe frequency difference between two adjacent FM carriers in a resting state is approximately 150 kilocycles, thus making it possible for these two stations to each have a deviation of 75 k.c. Only at the very maximum point of deviation would they meet at a frequency halfway between their respective unmodulated values.

It is evident, also, that if an FM band is to be used, it must contain all of the allotted frequencies of the stations holding FM operating licenses, and yet no two stations may be closer than 150,000 cycles to each other. These requirements can be met only if the entire FM band is placed in the very-high-frequency range; that is, above 28 megacycles. If FM stations were allocated frequencies in the regular broadcast band, the entire range from 550 k.c. to 1700 k.c. could accommodate only seven stations at most, separated from each other by intervals of 150 k.c.

The present band of commercially operated FM stations is between 88 and 108 megacycles, which is a band range of 20,000,000 cycles. At intervals of 150 k.c. apart, this band may hold as many as 120 separate FM stations, in any given locality. Other FM bands, outside of the 88-108 megacycle group, are available for special FM transmission, such as police, fire-department, taxi-cab, and other similar services. All of the FM bands, however, are in the very-high-frequency range or higher.

By itself, the wide bandwidth of FM transmission would not limit the distance its signals could travel. However, since the bands used for FM are all of the very-high-frequency range, the propagation characteristics of these frequencies are of importance.

The so-called long-waves used in AM radio, due to their wave-lengths in general follow the curvature of the earth. This occurs when the ionized layer of the earth's atmosphere acts as a reflector for radio waves of this wave-length striking it at an angle. The earth's surface, too, acts like a reflector. Together, the ionized layer and the earth form a system of "wave-mirrors" which bounce a radio signal between them until it strikes some point which may be on the opposite side of the earth. This phenomenon of the reflection of comparatively long wave-lengths around the curvature of the earth is shown in Fig. 9.

Terminology should be clarified at this point. You may wonder why we have described earth-circling radio signals as "long-wave" when it is practically common knowledge that trans-oceanic broadcasts are picked up by "short-wave". The terms "long-wave" and "short-wave" are comparative only. For instance, the short-waves on most AM receivers are shorter than broadcast band waves, but they are also longer than high frequency waves. Both broadcast and short-

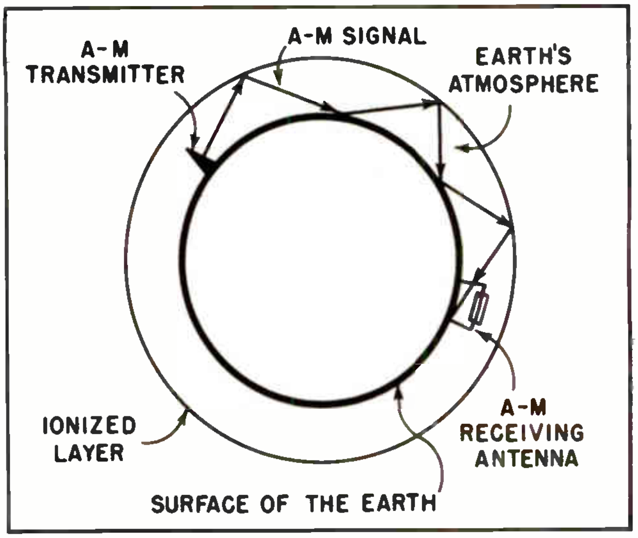

Fig. 9. How the Earth's Atmosphere Acts as a Reflector to Send a Signal Around the Curvature of the Earth.

waves are longer than very-high-frequency waves. For thé moment our discussion will infer that any wave longer than very-high-frequency, such as is used in FM transmission, are "long" waves. The illustration of Fig. 9 indicates that these waves, ordinarily used for AM transmission, are bent beyond the earth's curvature and may completely encircle the globe.

Fig. 10 shows the lack of such reflections with respect to very-high-frequencies. Instead of being bent around the curvature of the earth, a very-high-frequency wave, such as FM, when radiated upward from an antenna, will travel what is practically a straight path, cutting through the atmosphere surrounding the earth, then continues traveling through interplanetary space until it is dissipated in some remote part of the universe. Those that travel downward, however, also describing straight lines, will either strike the earth itself, or some object upon its surface. A suitable conductor erected at the receiving station constitutes the receiving antenna, which will convert the wave that strikes it into a voltage at signal frequency.

It may be seen that the F-M signal will not go beyond the horizon. The horizon, however, is far or near depending upon the position of the observer. The higher an observer is situated, the farther is his horizon. For the average FM transmitter, the horizon is usually between 50 and 60 miles away, which is the effective coverage range of the average FM transmitter. Fringe areas beyond this distance exist, of course, where the signal, though weak, may be received. Disregarding "freak" conditions, the FM stations of cities or towns beyond 100 miles from each other do not interfere.

AM transmitters, on the other hand, may interfere with each other over distances of several thousand miles.

Section 9. AM AND FM STATIONS

A great deal of confusion exists today regarding the relationship between AM and FM. Much of this confusion is brought about by such announcements as this one, during a station break: "You are listening to radio station WENR -- AM and FM." The listener is not quite certain as to which station he is listening, WENR -- AM, or WENR -- FM. Most of the time, it must be admitted, the listener does not care which station he is hearing. However, some facts pertaining to this situation may be in order.

An AM transmitter can be heard only by an AM receiver. In similar manner, an FM transmitter can be heard only by an FM receiver. Also, it is not possible, with one receiver only, to get a radio program from the same station on both AM and FM at the same time.

The call letters, such as "WENR -- AM and FM", are a short-cut way of indicating that the program sent out by the broadcasting company at that time is using two separate transmitters, one of them AM and the other

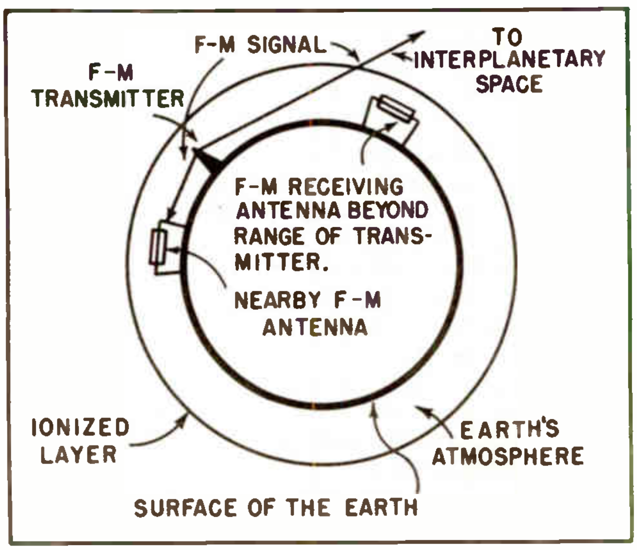

Fig. 10. Because the Ionized Layer of Air Above the Earth is Penetrated by Very High Frequency Radiation, the FM Signal is Limited to the Horizon.

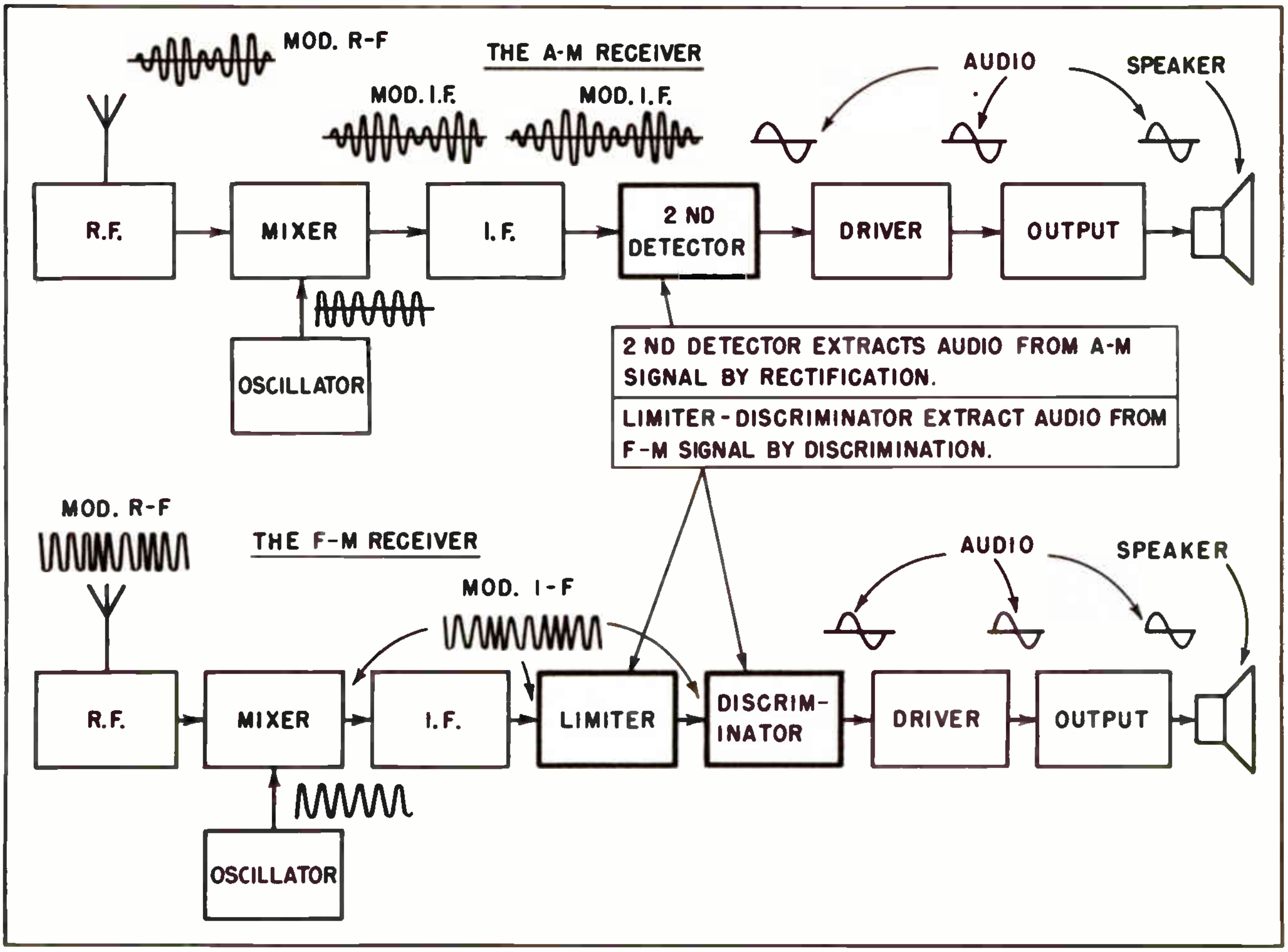

Fig. 11. Comparing the Block Diagrams of the AM and the FM receiver, and Showing Their Chief Differences.

FM. These two transmitters happen to be broadcasting the same program, but each in its own manner.

A receiver containing both an FM and an AM circuit can, at the will of the listener, be tuned to either of the two associated stations. He will, of course, hear the same program from both, if they are both transmitting the same program. Yet he will be hearing the FM station through the FM circuits of his receiver; and, when he switches over to the AM circuits of his receiver, he will hear the AM signal.

Many commercial AM transmitting stations are associated with a sister FM station. They may or may not broadcast the same program at a given time. When they are broadcasting the same program, the pair of stations is identified by the announcer adding "AM and FM" to the station call letters. When they are broadcasting separate programs, the announcer makes a separate identification of each station, and omits "AM" from the call letters of the AM station.

Section 10. **FM RECEIVING SYSTEMS**

FM receivers must be built, of course, to accept, tune, and amplify the FM transmitted signal. In this respect FM and AM receivers have a common purpose, but each accomplishes this purpose in a different way. (See Fig. 11.)

Accepting a radio-borne signal in FM is basically the same as in AM. The chief difference is that since the frequency ranges are considerably different, the tuned circuits accepting the transmitted signal from the antennas must differ widely in tuning properties. In AM broadcast receivers the R-F circuits must stay within 500-1700 kilocycles for the ordinary broadcast band. In FM broadcast receivers the R-F circuits must include resonant frequencies between 88-108 megacycles. The values of inductance and capacity in the FM tuning circuits are extremely low by comparison with those of the AM tuning circuits.

The process of heterodyning in the mixer (or first detector) stage is identical in both AM and FM receivers. Here again, since the frequencies involved in FM are much higher than those found in AM, the resonant circuits of the FM mixer and oscillator stages contain much lower values of capacitance and inductance. As in the case of the R-F stages, these are differences of degree rather than of method. The principles you have previously learned still apply, but the values with which you work are considerably different.

In like manner, the methods used in handling the I-F frequencies in AM and FM are the same, with the understandable difference in the actual values of capacity and inductance in the I-F stages of the respective receivers.

In AM receivers, the I-F frequency may be 455 k.c., 456 k.c., or 465 k.c. Some manufacturers use other I-F frequencies, but they are rare in broadcast band receivers.

In FM receivers, the I-F frequency is usually within the range of from 4-11 megacycles, with various manufacturers differing in the exact value chosen for a given model. A value of 4.5 megacycles is common, and a value of 10.7 megacycles is used in many of the newer models. As in the case of the AM receiver, I-F frequency values in an FM receiver may be determined most definitely by the manufacturer's wiring diagram of the set. In all of these comparisons (between R-F, mixer, and I-F stages) in AM and FM receivers, we have seen that the differences were of degree rather than of kind.

There is another notable difference in the tuned circuits of FM and AM receivers, also a difference in degree rather than in kind. This refers to the bandwidths present in the I-F stages. In AM intermediate stages, normal bandwidth is approximately 10 k.c. which will accept modulation sidebands within 5,000 cycles either above or below the I-F carrier. F-M intermediate stages possess bandwidth characteristics far in excess of these, and modulation bands varying by 75,000 cycles each way from the I-F carrier are readily accepted. Since the band-width of an intermediate stage is twice the permitted deviation from the carrier, the FM bandwidth amounts to 150,000 cycles. This represents a modulation percentage of 100% and forms a deviation ratio of 5 with a 15,000 cycle audio note.

The most radical departure in an FM receiver from practices used in AM receiving equipment is the way in which the audio signal component is extracted from the I-F carrier. The general procedure is indicated in Fig. 11, which shows the block diagrams of an AM receiver and an FM receiver, together with the wave-forms present at key points in their circuits.

In the AM receiver, as we have already learned, the audio component is extracted by introducing the amplitude-modulated I-F

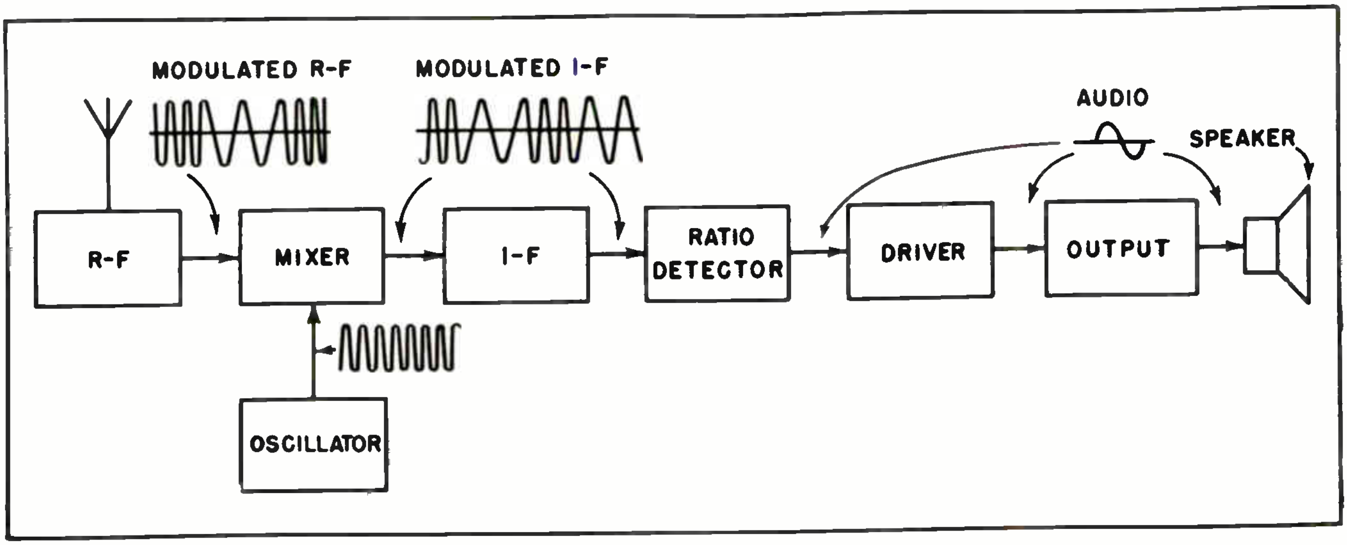

Fig. 12. If a Ratio Detector is Used in an FM Circuit, it may take the Place of the Limiter and the Discriminator.

carrier to a rectifying circuit, which clips off all of the negative loops of the wave and integrates the positive loops into the audio signal in the form of voltage changes.

In the FM receiver the audio component is extracted by introducing the frequency-modulated I-F carrier into a frequency-discriminator circuit, which accepts frequency changes and converts them to voltage changes at audio frequency.

In both cases, however, the detecting stages (those which extract the audio component of the signal) are immediately followed by the audio driver (a voltage amplifier), the power amplifier, and the loudspeaker. Here the electrical impulses are converted to sound energy and distributed throughout the room as faithful duplicates of the sound that originated the signal back at the broadcasting studio.

Note, in Fig. 11, that one of the stages of the FM system is a "limiter". This stage is peculiar to the FM receiver and has no counterpart in the AM system. Its purpose is to eliminate any form of amplitude changes in the frequency-modulated I-F carrier. Since static, both man-made and natural, represent changes in the amplitude of a carrier, the process of limiting the amplitude of the carrier will minimize -- if not completely eliminate -- the interfering effects of static. In essence, the limiter stage is an I-F amplifier tuned to the I-F frequency, but having a very low plate voltage. This low plate voltage, by methods which will be described in a subsequent lesson, serves to saturate the stage with a weak grid signal and hence does not permit great changes of amplitude to get through.

Instead of two separate stages -- the limiter and the discriminator -- many FM receivers use a single stage to limit the amplitude and extract the audio at the same time. A stage designed to accomplish this double purpose is called a *ratio detector*, and with it no limiter stage is needed. The "ratio" being detected by this stage, as the alert student will already suspect, is the "deviation ratio" mentioned earlier in this lesson.

By a special circuit, to be explained in a subsequent lesson, the ratio detector fixes the audio output at a constant value with respect to the fast-changing peaks that are caused by static. The ratio detector, however, being essentially linear with

Fig. 13. A Modern Table-Model AM-FM Receiver.

respect to the audio signal itself, will reproduce the signal with all of its natural amplitude and frequency variations. A block diagram showing the FM receiver employing a ratio detector instead of the limiter-discriminator combination, is shown in Fig. 12.

Section 11. COMBINATION AM-FM RECEIVERS

Fig. 13 is a photograph of a combination AM - FM receiver of the table-model style. That such a combination is electrically possible is evident from the block diagram of this receiver, showing how the AM and FM tuners may be individually put into service at the flip of a switch. The outputs of each of these separate tuners are selected separately for delivery to the audio section of the receiver which is common to both tuners.

The block diagram of this receiver is shown in Fig. 14. Notice that the audio section is common to both the FM and the AM tuners, and that a third position of the selector switch enables the operator to use the audio section for use with a phonograph if desired.

In practice, combination AM - FM receivers take many different physical forms. The one indicated in the block-diagram of Fig. 14, representing a table-model receiver, must be compact. In order to provide two separate tuners within one small compact receiver cabinet, it is necessary to design the parts so that the same amplifier tubes may be used on both the AM and FM tuners.

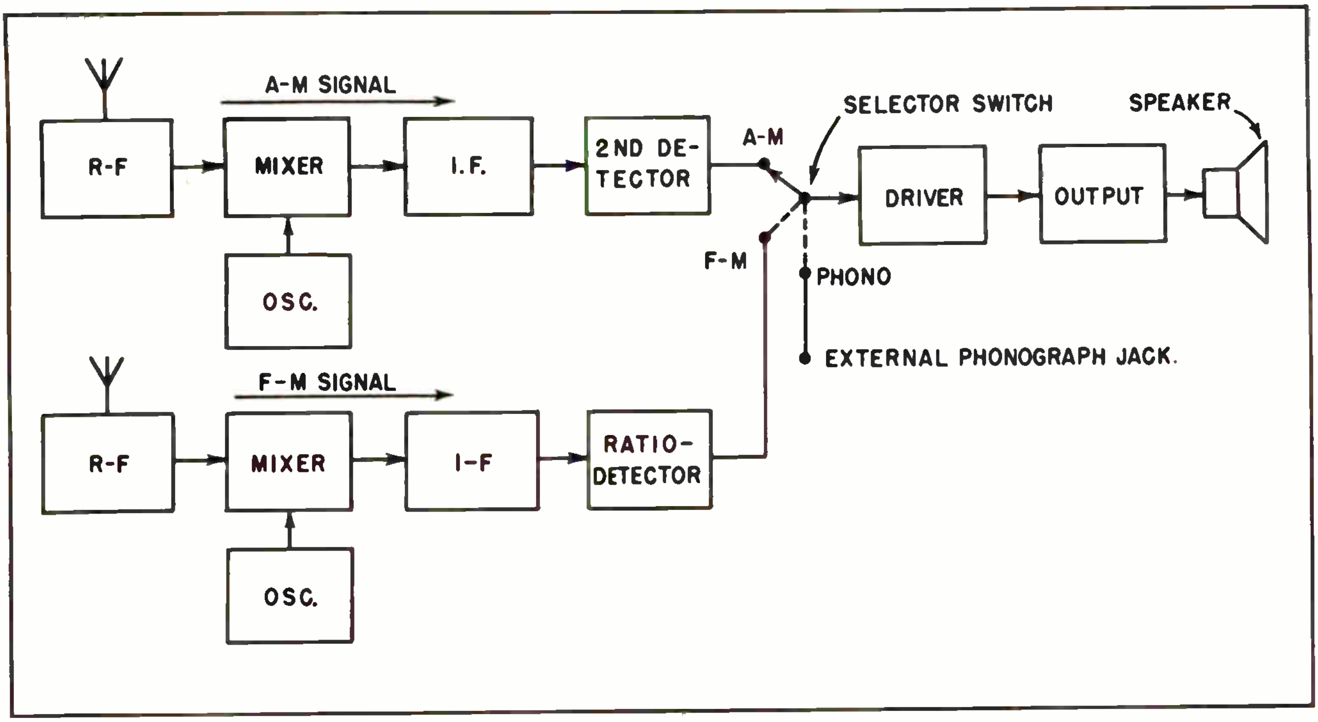

Fig. 14. How the Combination AM-FM Receiver May Switch from One Service to the Other. Note the Provision for a Phonograph Input.

This means that the tuned circuits of the R-F, oscillator, and I-F stages must be switched in and out when changing over from AM to FM or from FM back to AM.

The tendency in modern combination receivers of this type is to accomplish the switch-over from one type of reception to the other and still use as many parts as possible for both tuners. This means that the selector switch is not so simple as shown in the block diagram, but consists of several different sections, each of which is changed simultaneously with the others.

In the older types of combination FM - AM receivers, especially the console type provided with automatic record changers, there were actually two separate and independent chasses within the cabinet. This was convenient, of course, but its disadvantages were that the duplication of parts for each tuner raised the cost, weight, and space of the entire unit. Modern design has frowned upon this method, with the result that today the AM - FM combination, even with a record changer, is light, compact, and economical. Besides, a number of manufacturers have stressed the table-model combination receiver, such as the one in Fig. 13, for economical and satisfactory reception of not only the wealth of all AM programs, but of the FM programs as well.

In order to reproduce faithfully the full tones capable of transmission by FM, the audio section of a receiver must be built with care. Since FM is ideally suited to carry the overtones (harmonics) of musical signals beyond the ability of AM, the audio section should take advantage of these overtones by passing them through to the speaker without discrimination against either the high or the low notes. This requires exceptional linearity in the response characteristics of the audio section.

Manufacturers have gone to extreme lengths to improve the audio tone response of their FM receivers. As for the speaker itself, it too, should permit the faithful reproduction of all the important audio ranges. In general, large-size speakers are better responders to wide-band audio notes. However, in the design, placement and electrical characteristics of speakers, much can be done even with a small speaker whose size is necessarily limited by the cabinet in which it must be placed. If the cabinet is large enough, two or more speakers are often connected to an FM audio section. One, a small one, will respond best to the higher frequencies, while the other, a large one, will respond best to low frequencies. Their combination includes all the frequencies normally present in the transmitted signal and therefore lends an air of reality to the audio tone reproduced by this combination. Fig. 15 is a photograph of a modern AM - FM phonograph combination console receiver.

Section 12. **FM IN TELEVISION RECEIVERS**

In modern television receivers, frequency-modulation is employed to carry the audio component of the televised signal, while amplitude-modulation is used to carry the video signal. In television receivers, then, is found one of the most important applications of FM transmission and reception.

There are two general methods used in television receivers to handle the frequency-modulated sound signal. The first of these is by means of a separate sound channel designed to carry the FM sound signal through to the audio section of the receiver. This method is illustrated in the block diagram of Fig. 16.

In this diagram the transmitted signal, carrying both the audio and video components, is amplified and selected in the R-F and mixer stages. In a TV receiver, these two stages are generally called the television tuner. The output consists of two separate frequencies; one is the video at 26.6 megacycles, and the other is the sound at 22.1 megacycles. These are the result of mixing the incoming composite television signal with the local oscillator, and is accomplished by the tuner. (Note, for later reference, that the sound I-F and the video I-F differ by 4.5 megacycles.

Fig. 15. This Console Receiver is Built for AM and FM Reception, as well as Automatic Record Playing.

The I-F designed to carry the sound signal is tuned to the frequency of 22.1 megacycles. This frequency remains the same, regardless of which television channel is being used by the receiver.

The first and second audio I-F stages provide high amplification to the sound signal, and make it ready for the detecting process. This is done in the ratio detector, which also serves to limit noise in the speaker. The driver and output stages are conventional audio stages.

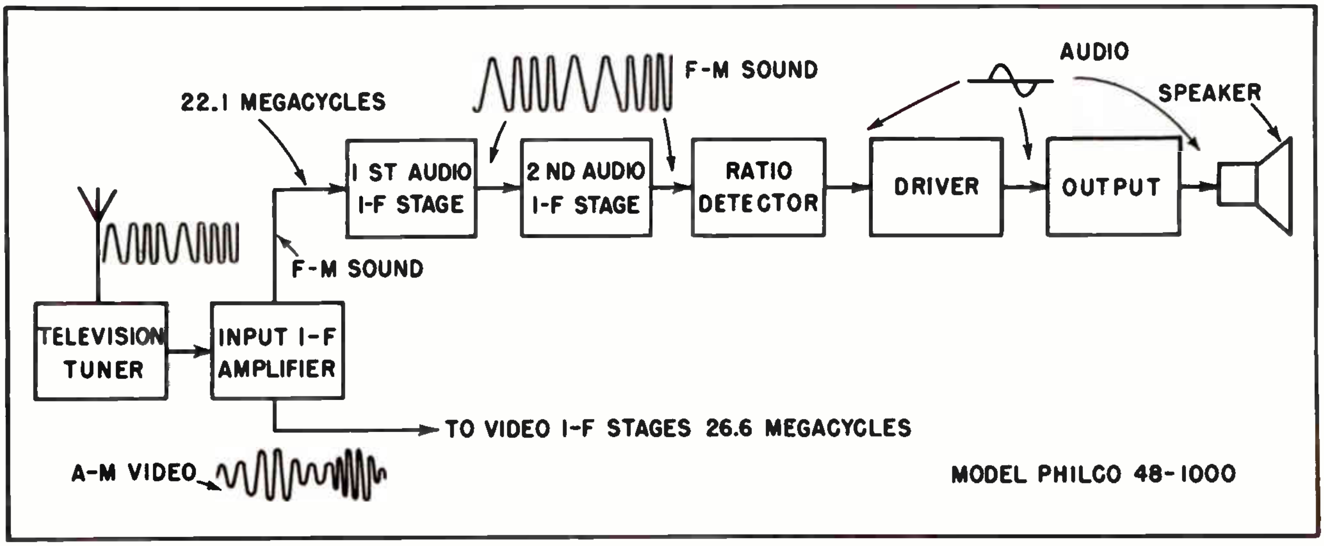

Fig. 16. Separate Sound Channel in a Television Receiver Capable of Handling the FM Sound Portion of the Television Signal.

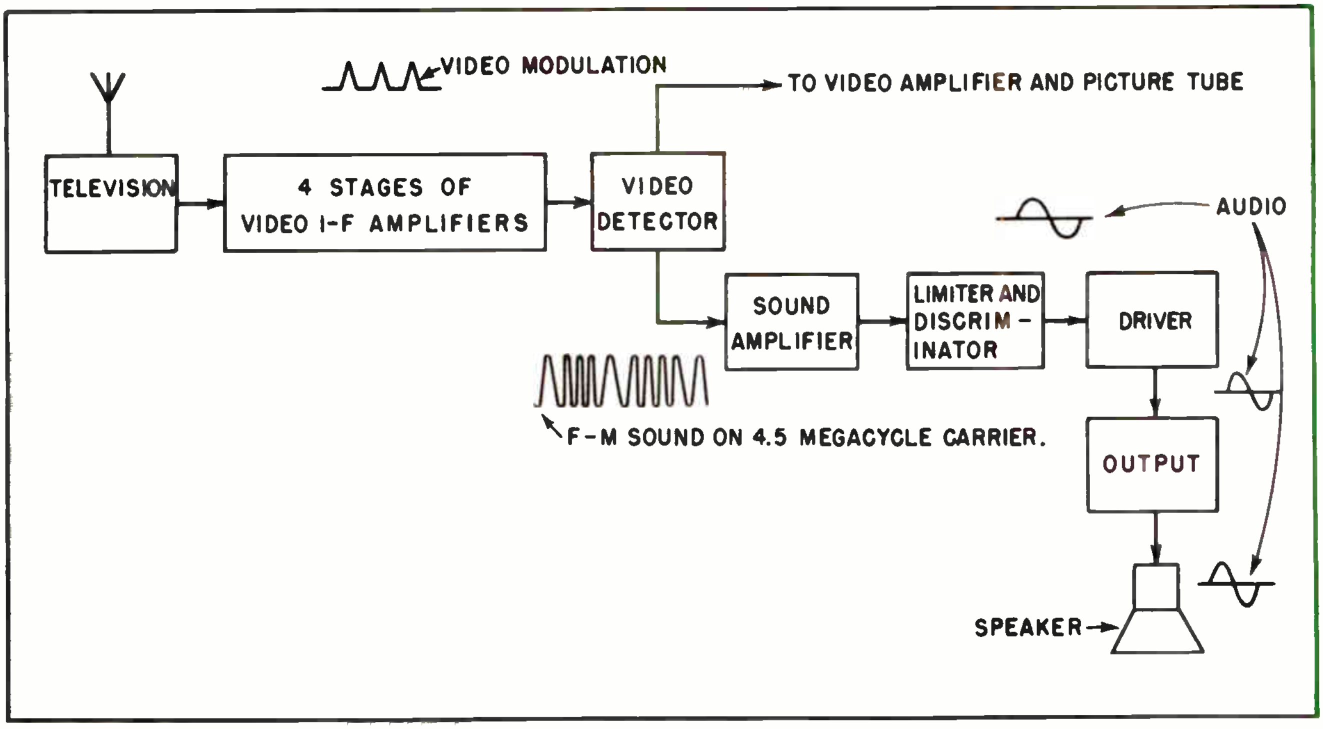

Fig.17. The FM Inter-Carrier Sound System of a Television Receiver.

This type of sound channel reception of a television signal is made possible initially by the fact that the television transmitting station actually does emit the sound and picture R-F signals at frequencies which differ by 4.5 megacycles from each other. When the composite signal arrives at the receiver, an oscillator frequency, fixed for that station, will provide beat frequencies which must also differ from each other by 4.5 megacycles.

That one equal to 26.6 megacycles is the picture I-F, and is led through suitable amplifiers and a diode detector for extraction of the video component which in further amplified form is fed as the modulating voltage to the picture tube. This portion of the circuit is not shown in Fig. 16. The details of the action of this and other television circuits will be discussed in subsequent lessons on television.

Another way of handling the sound FM signal in a television receiver is called "inter-carrier sound modulation". A block diagram of this method is shown in Fig. 17.

In the inter-carrier system, the composite television signal is picked up by the antenna, tuned, and heterodyned in the mixer stage with a local oscillator frequency. The output at this point is not two separate frequencies by themselves, but consists of a single frequency band (around 25 megacycles) that contains both the amplitude-modulation of the picture signal and the frequency-modulation of the sound signal. In addition, the synchronizing pulses are also present in the output of the tuner.

The four video I-F amplifiers are staggered in their resonance, which means that one is tuned slightly above the I-F carrier, the next slightly below it, the third slightly above, and the fourth slightly below. The advantage of this arrangement is that the I-F bandwidth may be made sufficiently wide to contain both forms of the modulation carried.

The video detector, into which the last video I-F amplifier feeds, is an amplitude-demodulator, and is designed only to extract the video content of the signal arriving at its grid. The video detector output, however, is fed to two separate circuit branches. The video signal itself goes to the video amplifier and thence to the picture tube.

However, a second output is taken from a special take-off coil tuned to 4.5 megacycles. This frequency we have previously noted to be the difference between the video and sound carriers as transmitted at the television antenna. The mixer stage, far in advance, has also produced the 4.5 megacycle difference (a beat frequency) which was placed through all the gain available in the four stages of video amplification. The sound amplifier, therefore, following the video detector, accepts a strongly reinforced sound I-F signal. After more amplification, this FM sound signal is limited, then demodulated in the limiter and discriminator circuits, fed through the driver and output stages to the speaker for conversion into sound energy.

The application of the inter-carrier sound system is another of many examples showing the ingenuity of modern engineers in adapting simple devices to complicated procedures. The results are evident in the high quality and efficiency of the modern television receiver.

NOTES FOR REFERENCE

The two general types of radio communications systems are: (1) Amplitude-modulation, in which the amplitude of the carrier is varied in accordance with a modulating signal, while the frequency is left constant. (2) Frequency-Modulation, in which the frequency of the carrier is varied in accordance with a modulating signal, while the amplitude is left constant.

Corresponding with the two types of transmitters, there are two types of receivers: AM receivers and FM receivers.

Usually an FM receiver is associated in the same set with an AM receiver. Seldom is the FM receiver built by itself, except for special communications and service purposes.

FM possesses the advantage of bringing in a signal with a minimum of noise. It is therefore used for commercially produced FM broadcasting, and in communications wherever the local noise level is abnormally high.

FM transmission and reception are limited in range. The horizon is generally the factor which establishes the limit, which is approximately 50-60 miles for a strong signal.

Methods of modulating an FM transmitter vary. The most popular method is the employment of the reactance modulator.

One of the most important applications of FM is in the sound channels of television receivers. A knowledge of FM principles and circuits is therefore of great help to anyone who plans to do television receiver servicing.

Due to the wide bandwidth permissible in FM, audio signals are reproduced in their full tone. This is a distinct advantage of FM over AM.

The present FM broadcast band lies between 88-108 megacycles. The bandwidth of each station is approximately 150 k.c.

Frequency deviation is the difference between the frequency of the resting carrier and either the upper or lower limit when modulated.

Deviation ratio is the deviation value divided by the highest-pitched audio note transmitted. The average value for the deviation ratio is 5.

In FM receivers, the audio component of the transmitted signal is extracted by a discriminator stage, or by a ratio detector. When the discriminator stage is employed, it is preceded by a limiter. The ratio detector may be used without the limiter.

An FCC regulation limits the possible drift in an FM transmitter to 2,000 cycles per second either way of the unmodulated carrier frequency. This is to prevent an FM signal from causing distortion in the receiver when the carrier frequency, for any reason, drifts slightly to one side of its allocated resting value.

The power supply of an FM receiver may be exactly the same as that in an AM receiver. The difference is only in the signal circuits, and is mostly in the demodulating stages.

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LIMITERS AND DISCRIMINATORS

Contents: Introduction - Comparison of Detector and Discriminator - Frequency-Modulated Noise Interference - RF and Oscillator-Mixer in Frequency Modulation - The I-F Amplifier in Frequency Modulation - The FM Limiter - The Frequency Discriminator - Automatic Volume Control - The Ratio Detector - Advantages of FM Radio - Notes for Reference

Section 1. INTRODUCTION

Probably the greatest physical difference between an AM receiver and one designed to receive FM signals is in the stage which performs the task of demodulation. You will recall that we devoted considerable space to the description of the demodulators used in AM receivers -- the various types of *detectors*. The action of demodulation is accomplished in a different manner in an FM receiver. The FM receiver accomplishes

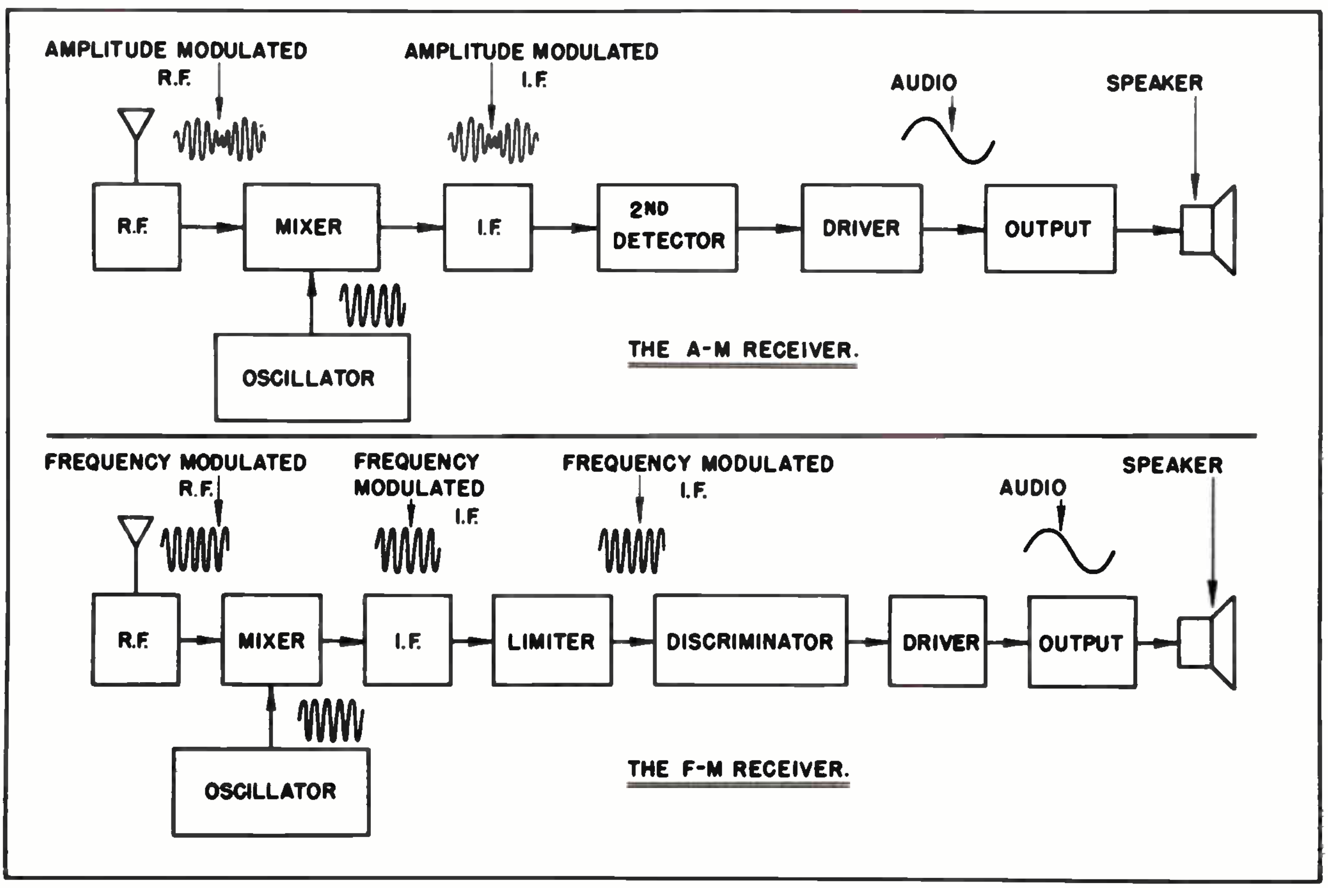

Fig.1. Comparison of the Wave-Forms in the AM and FM Receiver.

the demodulation of the received signal by means of a circuit which is called a *discriminator*. Instead of being sensitive to fluctuations in the amplitude of the signal as in the case of the AM detector, the discriminator is sensitive to *changes* in the *frequency* of the received signal. In other words, it discriminates between the various frequencies introduced to that stage, and makes known its discrimination in the form of audio frequency voltage changes.

Since the discriminator circuit is sensitive only to frequency changes it is advantageous to have the *amplitude* of the signal introduced to that stage as steady, or even, as possible. While the discriminator circuit itself is not sensitive to amplitude changes, as such, the very presence of a vacuum tube in the circuit can easily give rise to a detector action in addition to the discriminator action. If there is no variation in the amplitude of the signal which reaches the discriminator stage it is understandable that any possible detector action which might otherwise take place will be automatically avoided.

Because the intelligence carried by the received signal rests in the frequency changes, while noise in the form of sporadic static is normally carried in the form of amplitude modulations of the carried signal, it is usually advantageous to eliminate any changes in the amplitude of the signal before it reaches the discriminator stage. It follows, then, that if we can keep the amplitude of the signal at a constant value we are going to eliminate virtually all the noise which is so common to the ordinary AM radio receiver. In order to hold the amplitude of the signal to a constant value it is a common practice to precede the discriminator stage with another circuit called the *limiter*. The purpose of the limiter is to limit the amplitude of the carrier signal. If the maximum amplitude is held to a relatively low value, all voltage peaks which would normally rise above that value are automatically cut off. The amplitude of the signal may be varying constantly when it reaches the limiter stage, but after passing through the limiter the amplitude will be constant at all times.

Essentially all the limiter amounts to is an amplifier which employs a tube with a sharp cut-off characteristic. If the anode voltage on the tube is somewhat lower than normal it is possible to drive the tube to saturation quite easily. Now if the signal applied to the grid of the tube is relatively strong the tube will be driven, alternately, to cut-off, then to saturation. If the weakest signal which is applied to the grid will drive the tube either to saturation or to cut-off it will make no difference how much stronger the other signals might be -- they can drive the tube no further. This means that each positive signal on the grid will drive the tube to saturation -- a weak positive signal will drive the tube to saturation, and a strong positive signal can drive it no further. In a like manner, a weak negative signal on the grid will drive the tube to cut-off, and a strong negative signal can drive it no further. The overall result is that the amplitude of the output from the tube will maintain a constant magnitude. But the tube will have no effect on the frequency of the applied signal. The signal at the output of the tube will have the same variations in the frequency as that introduced at the grid.

Section 2. COMPARISON OF DETECTOR AND DISCRIMINATOR

In this lesson we discuss the electrical action taking place in the limiter and the discriminator stages of the FM receiver. This discussion will lead us to a third type of stage characteristic of the FM receiver -- the ratio detector.

A review of the block diagrams of the AM and the FM receiver, as illustrated in Fig. 1, will again emphasize the fact that while both are radio-borne signal receiving circuits, they accomplish their purposes in somewhat different ways. These differences are based upon the nature of modulation in the transmitted signal. The problem, then, is not: how can we arrange two kinds of receiving circuits to bring in the same signal? It is, rather: how can we arrange two kinds of receiving circuits to bring in two different types of signals?

In the AM signal, the message is carried by changes in amplitude, while the carrier frequency remains relatively constant. Changes in the frequency of an AM signal are not desirable and are to be avoided.

In the FM signal, the message is carried by changes of carrier frequency, while the amplitude remains relatively constant. Amplitude changes in an FM signal are undesirable. We are already aware that the AM signal cannot be received by FM circuits, and that the FM signal cannot be received

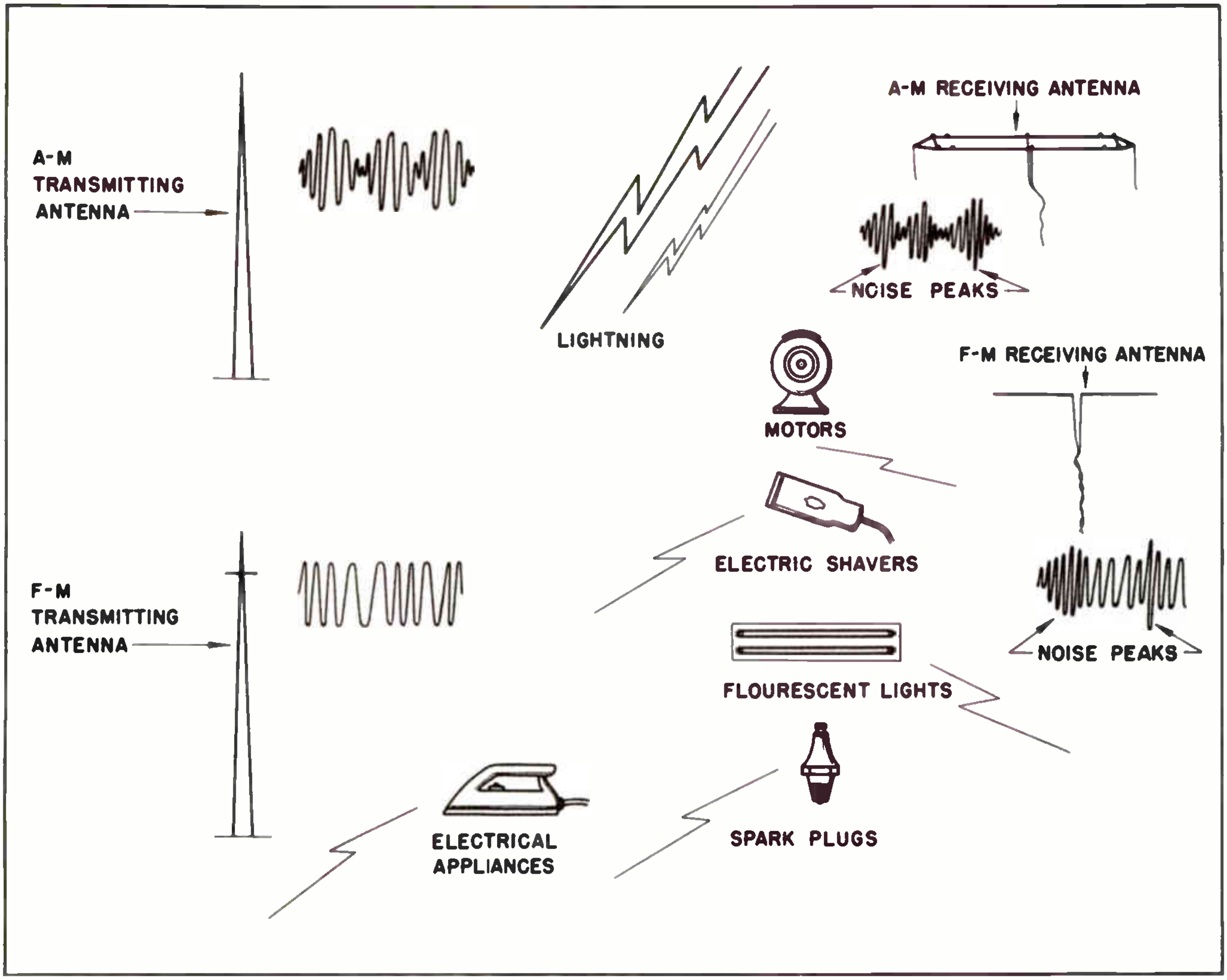

Fig.2. Much Interference is Added to the Radio Signal Between the Transmitter and Its Arrival at the Receiver.

by AM circuits. This, of course, makes them mutually exclusive; FM must have its own peculiar type of receiver while AM must likewise be received by circuits especially designed for it.

We also note that there is a combination AM-FM receiver, in which both the AM and FM receiving circuits are included. Each branch, however, is independent of the other insofar as the radio-frequencies and intermediate frequencies are concerned, but they utilize a common audio amplifier and speaker.

In these combination AM-FM receivers, the tuning dial is calibrated on a double scale, and a selector switch, operable from the front panel, effects the selection of the received programs on either the FM or the AM scale. A previous lesson has outlined and described the two methods used in modulating a radio frequency carrier with an audio signal. Let us briefly review the wave forms as they are transmitted from the AM and FM broadcasting stations, and what their characteristics are when they arrive -- an instant later -- at the receiving antenna.

Fig. 2 illustrates the nature of the FM and AM wave as they leave their respective transmitting antennas. If it were not for natural and man-made static, the wave, as it arrives at the receiving antenna, would be an exact duplicate of the wave which left the transmitter. It would be weaker, of course, due to attenuation due to distance, but the wave *form* would remain unchanged.

Further illustrated in Fig. 2 is the fact that the receiving antenna is subjected to electrical impulses other than those of the transmitted signal. There are many causes for man-made and natural static. Lightning is a major offender, among the natural causes; sun-spot activity and its associated aurora borealis (northern lights) are another source of natural static. These are generally lumped together in the category of "atmospheric interference", or just plain "atmospherics".

Among the man-made forms of static causing "noise" in a radio receiver are sparking due to electric motor brushes, automatic electrical appliances, electric shavers, fluorescent lights, neon signs, and myriads of other sparking devices. In the automobile and other mobile radio receiver, the onslaught of static due to sparking devices practically prohibited satisfactory reception until special techniques in static suppression were perfected.

Let us now examine the nature of the wave at the receiving antennas. On the AM receiving antenna, the signal is present as transmitted. In addition, there has been added to this signal the amplitude changes caused by man-made and natural static. This is represented by the swing to peak values of the alternating voltage present at the antenna, and indicated in the illustration.

Now, since the AM receiver is designed specifically to respond to changes of amplitude, it must -- by its nature -- respond to the noise peaks by a series of sharp voltage changes in the demodulated wave. This is the noise we hear in the speaker. In the AM receiver, the Automatic Volume Control circuit, described elsewhere in this series of lessons, serves the invaluable function of minimizing the noise due to static. As will be readily recalled, a strong signal at the antenna will *increase* the AVC voltage, making it more negative, and this increased negative voltage is fed to the RF and I-F grids of the receiver as an increase in bias. Since an increase in bias in a stage will reduce its over-all gain, the effect of a strong signal is to cancel out the effects of noise.

The FM receiver antenna is subjected to the same forms of static, as illustrated in the Figure. However, the FM receiver is not designed to respond to changes in amplitude, but to changes of carrier frequency. This gives a new slant to the effects of natural and man-made static in their relation to the FM receiver. Theoretically, the FM receiver should pick up no static whatever. True, there will certainly be *less* noise in an FM receiver in comparison (under similar conditions) with an AM receiver. However, there are certain reasons why static and noise suppression circuits are necessary even in the FM receiver, and the nature of the FM circuits are determined in large part by this need.

Section 3. **FREQUENCY-MODULATED NOISE INTERFERENCE**

We have heretofore referred to static and noise interference as being due to changes of *amplitude*, and this is primarily the main reason for such receiver noise. We shall now show that noise interference may also be due to changes in *frequency*.

In cities, where many television receivers are in use, most of the television antennas are mounted somewhere within a reasonable distance from a street. Automobile ignition static is within interfering range of many television receivers.

What is there about an automobile in the street that can interfere with good reception of a television program? Everyone knows that the automobile engine is driven by fuel explosions in the cylinders after being ignited by an electric spark. The spark itself is a form of radio signal, and generates a wave which is emitted from the wiring of the engine in all directions. In fact, this principle was employed in the early days of code-signal radio by the "spark-transmitter".

In the gasoline engine, the rate of occurrence of the spark is governed by the speed of the engine. Each spark is a signal in itself, and its oscillating frequency is determined by the circuit inductance and capacity through which the spark current flows.

Fig. 3 indicates the wave-forms of the total sparking effects of a gasoline engine ignition system, in a 6-cylinder car. As is evident from the Figure, each spark plug is fired from a different position of the distributor rotor. These different positions, corresponding to the firing of the cylinders, represent differing values of capacity and inductance in the spark-distributing circuits due to the varying lengths and positions of the leads and distributor parts. Moreover, during each single spark occurrence, the rotor arm (since it moves continuously) varies both capacity and inductance between the start and end of the firing interval. This, as is shown in the illustration serves to vary the resonant frequency not only

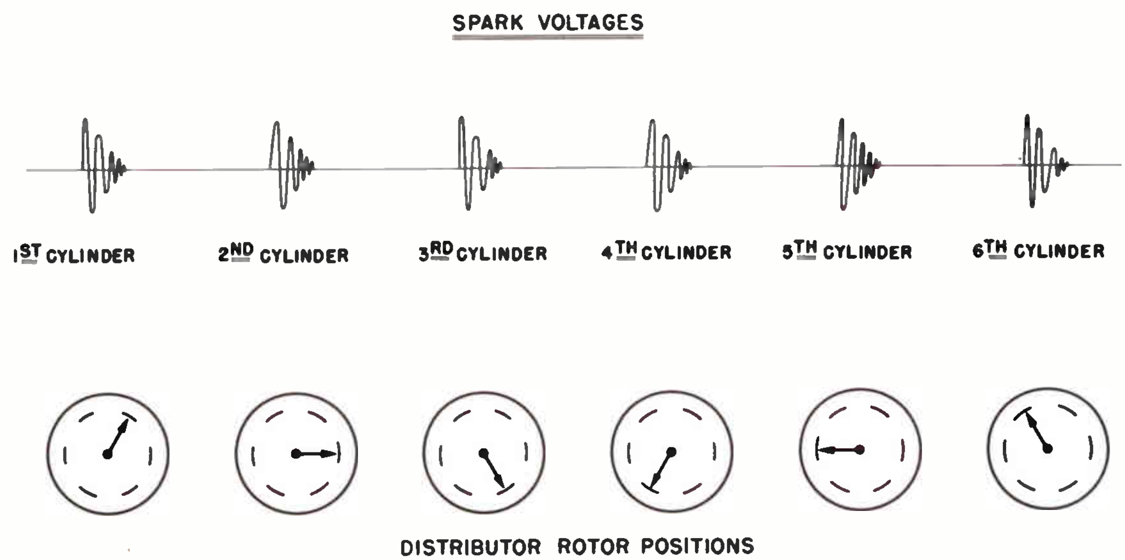

Fig.3. Generation of Frequency-Modulated Noise.

between successive firing intervals, but also *during* each firing interval.

A gross over-all frequency-determining effect, not to be disregarded, is the fact that the automobile itself is in motion, and its capacity to grounded objects is a factor that changes from instant to instant.

Amplitude changes, of course, are occurring at the same time. The initial firing peak damps out to zero value after a few oscillations, thus producing amplitude changes. Besides, there is a relatively long period between sparks, which is also a form of amplitude modulation.

The considerations we have been discussing have referred to an example of car ignition interference in television reception. While there are many other causes of such interference in television, FM and AM, this example was chosen to bring out a specific point.

The point to be emphasized here is that the sound channel of a television receiver operates on FM. Any frequency-modulated noise, therefore, which occurs on a television receiver must have its counterpart in all FM receivers. Previous mention was made to AVC in the AM receiver as an agent for reducing amplitude-modulated noise interference. We now see that the FM receiver is subject to a corresponding type of frequency-modulated interference, as well as its unavoidable share of amplitude-modulated interference. This is highly significant. Subsequent paragraphs of this lesson will show that with these noise problems in mind, the FM receiver circuit has been ingeniously and carefully designed to minimize both AM and FM interference due to man-made and natural static.

Section 4. RF AND OSCILLATOR-MIXER IN FREQUENCY-MODULATION

Before developing the theory of the special circuits involved in the FM receiver to demodulate the signal, and to reduce both AM and FM noise interference, let us examine the block diagram of the FM receiver as shown in Fig. 4. We notice that with the exception of the limiter and discriminator replacing the second detector, the system is remarkably like the AM receiver. There is also the important difference in the frequencies involved in the tuned circuits. We have chosen a typical FM transmitted signal of 100 m.c. (megacycles) as the desired signal. The oscillator is shown, at this time, to produce a frequency of 110.7 m.c. Following the same procedure as in the AM receiver, these two frequencies (100 m.c. and 110.7 m.c.) beat together in the electron stream of the mixer stage and produce their difference. This difference

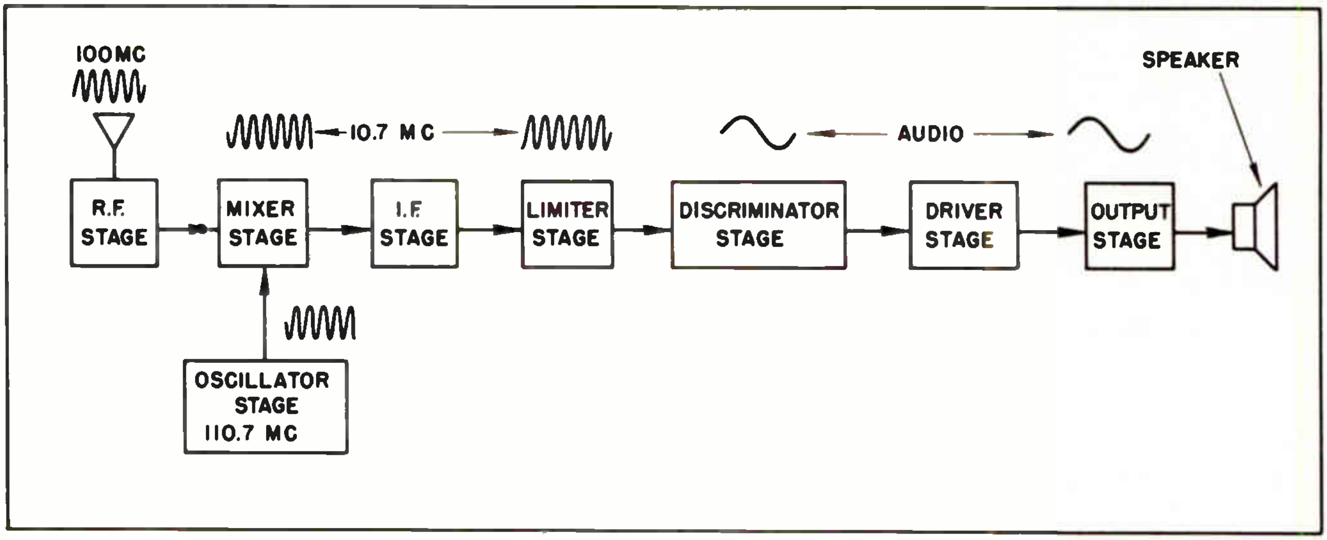

Fig.4. Block Diagram of the FM Receiver.

is readily found to be 10.7 m.c., which is the I-F frequency of the FM receiver. Besides (also following the methods of the AM receiver) the signal modulation borne through space by the FM carrier is now found to be "riding" on the I-F carrier in the form, as may be expected, of *frequency changes*.

Now, if the RF tuned circuit is manually adjusted to receive a signal at -- let us say -- 102 m.c., the oscillator resonant circuit, the capacitor of which is mechanically coupled to the RF tuner, will now produce an output of 112.7 m.c. These two frequencies will heterodyne and produce a difference which is also 10.7 m.c. In like manner, setting the RF tuning condenser to 98 m.c. will effect a capacity change in the oscillator tank that will produce an output from that source of 108.7 m.c., and their resultant difference will again be the I-F frequency of 10.7 m.c.

Let us briefly restate this action.

The purpose of the RF stage in an FM receiver, as in the AM receiver, is to select and amplify the desired radio-borne signal.

The purpose of the oscillator in an FM receiver, as in the AM receiver, is to produce a frequency with which the incoming signal may be heterodyned to produce their difference -- the I-F frequency.

The purpose of the mixer stage in an FM receiver, as in the AM receiver, is to induce the heterodyning process between the incoming signal and the oscillator output, and thus convert the modulation from the RF carrier to modulation on the I-F carrier.

Except for the magnitude of the frequencies, involved and the type of modulation employed, these purposes are the same in the FM receiver and in the AM receiver. A comparison of the frequency values is given in the following table:

	AM	FM
Typical received signal frequency	1000 kilocycles	100 megacycles
Accompanying oscillator frequency	1456 kilocycles	110.7 megacycles
Intermediate frequency difference	456 kilocycles	10.7 megacycles

The preceding table makes it clear that the oscillator frequency is made to differ from the incoming signal frequency by a value equal to the I-F frequency. This is true in both cases, FM and AM. Moreover, the oscillator frequency is higher than the incoming signal frequency in both cases.

Fig. 5 is a schematic diagram of the RF, oscillator, and mixer stages of the FM receiver. The first I-F transformer is also shown in this diagram. Except for minor differences due to the higher frequency values, the fundamental action taking place is identical in every way with that occurring in the AM receiver. The circuit shown employs a 6BA6 RF amplifier in the initial stage, followed by a 6BE6 mixer. A separate Hartley Series oscillator uses a 6C4 triode which is designed especially for FM and television applications at the high frequencies involved. These tubes are of the miniature 7-prong type, popular in modern compact receivers.

Section 5. THE I-F AMPLIFIER IN FREQUENCY-MODULATION

As the FM signal leaves the converter (mixer) stage, it has the frequency of the I-F carrier, usually 10.7 m.c., and bears the modulation of the received signal. The next step, as in the case of AM receivers, is to re-inforce the strength of the signal sufficiently to be clearly audible when it arrives at the speaker, and to further separate the desired signal from all others reaching the mixer plate. The I-F amplifier system is made to order for these tasks.

Fig. 6 is the circuit diagram of an I-F amplifier system in a modern FM receiver. Two I-F amplifier tubes are used, remote cut-off pentode type 6BA6's. This involves

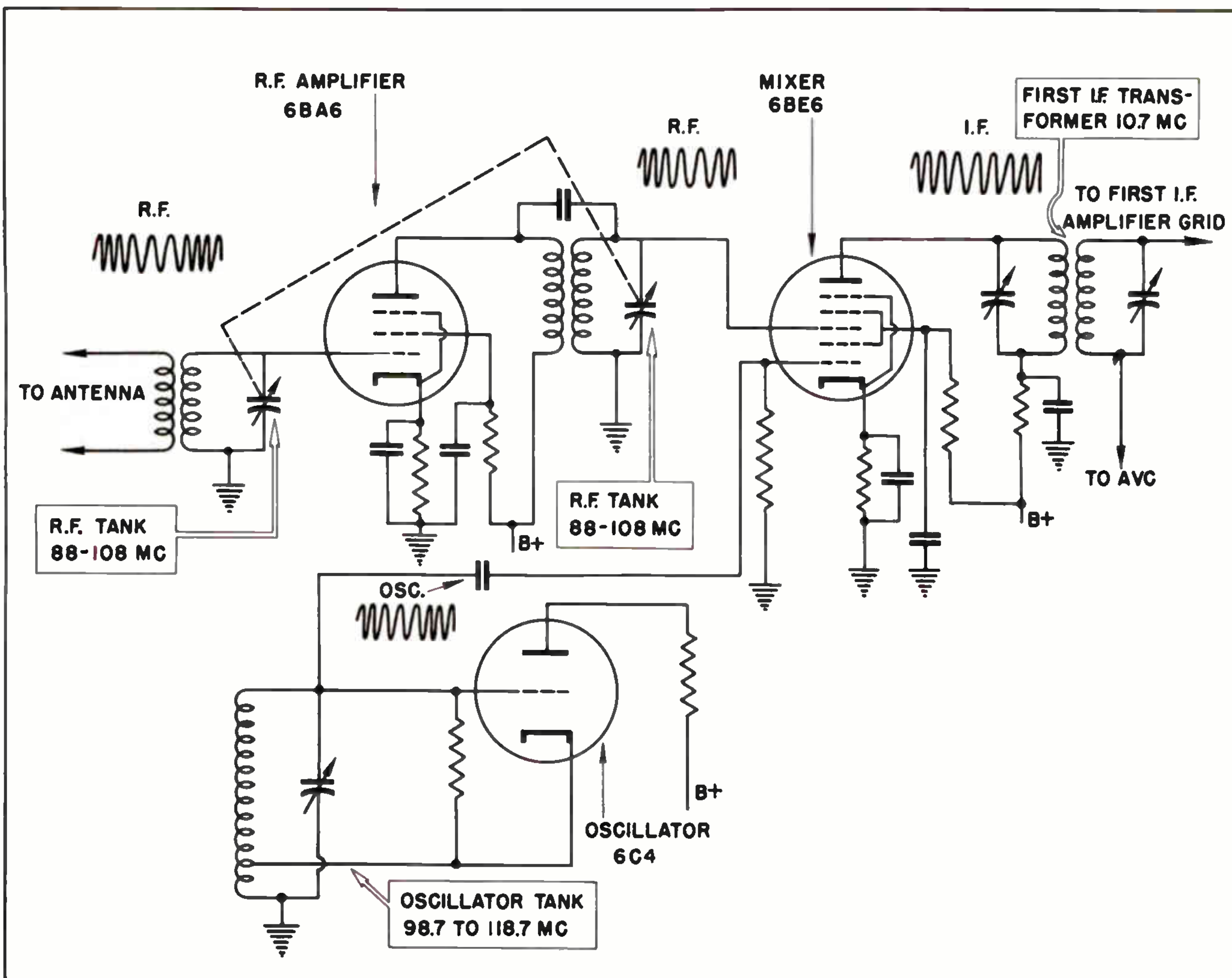

Fig. 5. The RF, Oscillator, and Mixer Stages of the FM Receiver.

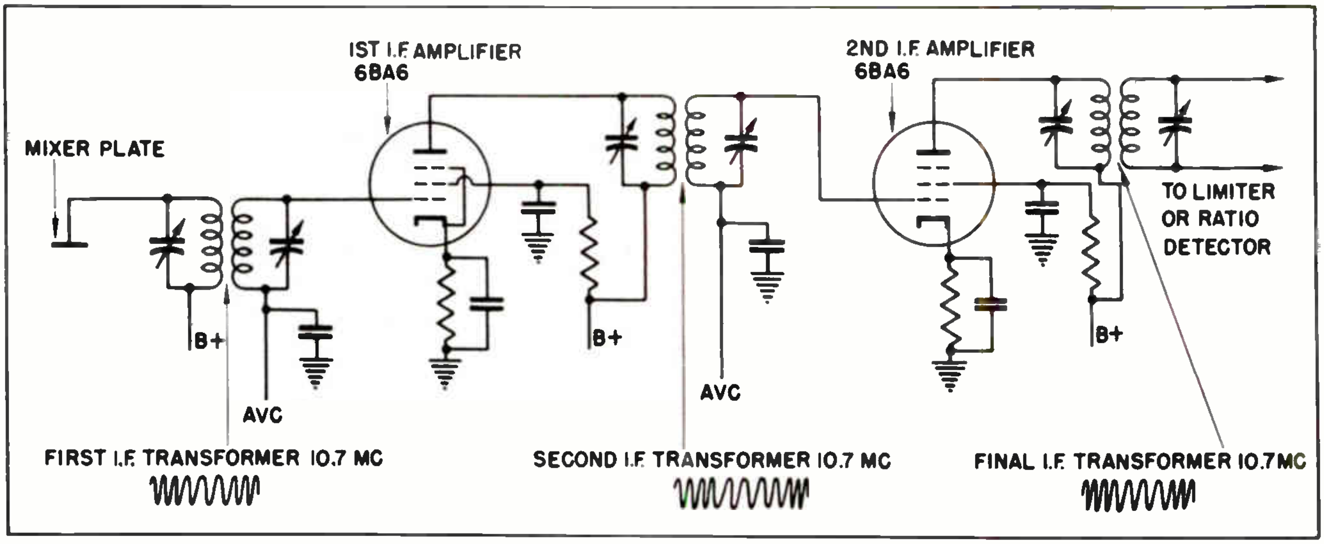

Fig.6. The I-F Amplifier System of the FM Receiver.

the use of three separate I-F transformers, all of which are tuned very near to the I-F frequency of 10.7 megacycles. The most significant characteristic of this system is its close similarity to the I-F amplifier system of the AM receiver. We should not be surprised at this fact, however, since the principles of I-F amplification and the sharp selectivity of the received signals are well known from our experience with the AM receiver. The FM receiver must also have these characteristics, and they are amply provided by a system similar to that used in AM.

While the circuit diagrams of the FM and AM intermediate stages look almost exactly alike, we may take note of certain recognized differences. As in the RF, oscillator, and mixer stages, the frequencies present in these tuned circuits are far higher than in the corresponding stages of an AM receiver. The AM intermediate tuned circuit is set at approximately 456 kilocycles. The intermediate tuned circuits of the FM receiver are usually 10.7 megacycles, or about twenty times as high.

Keeping in mind that one of the purposes of an I-F amplifier system, in any kind of radio receiver, is to provide sharp selective properties for incoming signals, and also realizing that one of the advantages of the FM receiver is its high fidelity response, we may well ask: What is the band-width of a series of tuned circuits which must be narrow enough to be highly selective, yet *at the same time* present a "flat" response to the broad range of audio components so necessary for high fidelity?

Since high fidelity pre-supposes a wide-band response, and good selectivity requires a narrow-band response, evidently some compromise must be made between the two so that both requirements will be met in a satisfactory manner. The response curves of the I-F amplifiers in an AM receiver and an FM receiver are shown in Fig. 7.

In this illustration the band-width of the AM intermediate amplifier is shown to be approximately 10 k.c. which is about 5,000 cycles either side of the resonant frequency of 456 k.c. In amplitude modulation, the audio frequencies capable of being accepted by the I-F stages are limited by their band-width. A band-width of 10 k.c. will limit the highest audio note accepted to 5,000 cycles per second. Also, it is worthy of note that the response at the edges of curve A in the Figure is less than that at the resonant value. This means that there will be some form of audio distortion in the signal, unless the response curve is made "flat" within these limits. Flatness is obtained, you will recall, by "staggering" the resonance of successive I-F tuned circuits. This was explained earlier in our lessons. Staggering cannot be carried to excess, since a response curve that is too flat will become less selective. Then adjacently assigned transmitter frequencies will overlap in the receiver.

Curve B in the Figure presents a slightly different picture. The general *shape* of the curve is the same, but the band-width is decidedly broader, totaling 150 k.c. from side to side. In the FM receiver the total band-width is limited by the greatest *deviation* in the carrier frequency. An earlier lesson explained that in order to correspond to a modulation of 100%, under present laws governing radio transmission, the maximum permissible deviation of an FM transmitter is 75,000 cycles per second either way from the carrier. But, while the band-width of an AM signal is determined by the *frequency* of the audio components, the band-width of the FM signal is determined by the *amplitude* of the audio components. Hence if the band-width of the I-F amplifying system of the FM receiver is too narrow, the high amplitudes of the modulating notes will be barred, resulting in amplitude distortion. On the other hand, a band-width which is too wide may possibly bring in the extreme deviations from an adjacent FM station.

Fortunately there is a natural reason why the FM band-width may be made fairly wide (150,000 cycles) without station overlapping. This is the result of the relationship between the "Q" of a tuned circuit and the magnitude of the frequency involved.

Several references have already been made to the "Q" of a tuned circuit. It is a figure of merit of the circuit, and is represented by the ratio of inductive reactance to resistance, or,

$$Q = \frac{X_L}{R}$$

If the Q of a tuned circuit is high, the frequency response curve rises sharply to a high peak. If the Q is low, the curve is rounded off at the top. Now, the Q of a circuit will vary with the frequency present. This is due to the fact that as the frequency increases, the effective value of the resistance also increases. It is true that the reactance of the coil also increases with an increase in frequency. However, we must keep in mind that in a resonant circuit the reactance of the coil is cancelled out by the reactance of the capacitor. This means that the resistance is increased much faster than the reactance of the coil is increased.

You may wonder how an increase in frequency through a coil will increase its effective ohmic resistance. The answer lies in the phenomenon known as "skin effect". When a solid circular-cross-sectional conductor (like a wire) is traversed by current at low frequency, the coil presents to this current a certain value of ohmic resistance represented by its conductivity, its length, and its cross-sectional area. These constitute the D-C resistance, which is measurable with an ohmmeter.

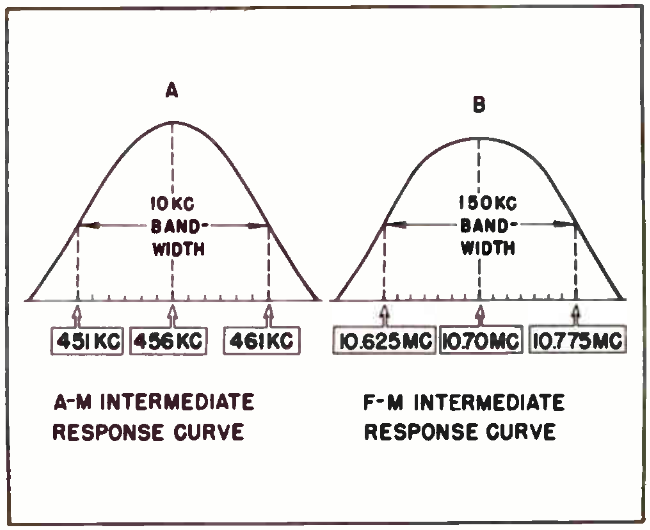

Fig. 7. Response Curves of the Intermediate Stages of the AM and FM Receiver.

With an increase to high frequency, however, another factor comes into play. Any fast-alternating current in the coil will set up magnetic fields which will oppose the initial current which caused them. This we know to be the inductive reactance of the coil.

In addition to this reactance, the field around each segment of the wire will also have its own separate effect on the current, such as to make the current flow only on the outer surface of the wire. This is because the strongest fields are set up along the central axis of the conducting wire as a virtual field center. Current through the wire will therefore take paths as far removed as possible from the field center, and still stay within the wire. The only paths fulfilling these requirements are those at the surface of the wire.

Thus the current, which at low frequency could travel through any part of the wire, is now, at high frequency, confined to the outer surface only. The net effect is the same as though the cross-sectional area of the wire had been reduced. We know that reduction of the cross-sectional area of a wire increases its ohmic resistance.

In view of the increase in resistance with an increase in frequency we can readily see that the Q of the high-frequency FM intermediate tuned circuit is considerably reduced

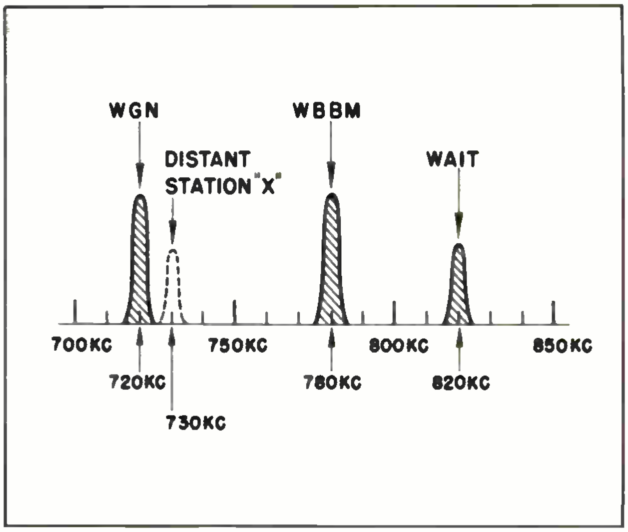

Fig.8. A Small Portion of the AM Broadcast Band.

below that of the AM intermediate tuned circuits. The effect of a lower Q, is to widen out the frequency response curve, or, to put it another way, to increase the band-width.

In FM, the band-width is therefore inherently wider than in AM circuits, and this is a desirable characteristic when we consider the wide band of frequencies required to pass through the FM circuits. To further increase the band-width the tuned circuits are often deliberately "loaded" with resistance.

Fig. 8 is a portion of the spectrum of the AM broadcast band, showing the approximate band-width of several stations. Fig. 9 is a corresponding spectrum for a portion of the FM band. In AM transmission, Fig. 8, the band-width of WBBM covers a total value of 10,000 cycles, with the peak output (representing the unmodulated carrier) at 780 k.c. The next nearest station below WBBM, *in Chicago*, is WGN, operating on the assigned frequency of 720 k.c. when unmodulated and swinging 5,000 cycles *each way* when modulated with a 5,000 cycle note. If a distant station -- let us call it "X" -- has been assigned the frequency of 730 k.c., its widest swing in the direction of WGN will be down to 725 k.c. As the diagram indicates, this is the maximum upward swing of WGN, hence the two stations cannot interfere with each other when the receiver band-width is only 10,000 cycles wide.

A corresponding situation holds true for the FM portion of the band, shown in Fig. 9, but with wider band-width characteristics. WFMF, an FM transmitter in Chicago, operates on an assigned frequency of 100.3 megacycles. This value represents its "resting" frequency when unmodulated. When modulated by the strongest audio signal permitted by law, the maximum deviation from the resting frequency is .075 m.c. below and .075 m.c. above the resting frequency. In kilocycles, this is 75 k.c.

Now, if another station operating on the FM band were assigned the resting frequency of 100.1 m.c., the band-widths of both stations could meet, should both be modulated to the absolute limit, at 100.2 m.c. However, in Chicago, no station is assigned anywhere so near as 100.1 m.c., the nearest station below WFMF being WEFM which is assigned at 99.5 m.c. as its resting frequency.

Even if a distant station "X" in some other city is assigned the frequency of 100.1 m.c., and even if either or both stations were to exceed their limits momentarily, there will still be no interference between them, since FM transmission is limited to the horizon in its effective range.

Thus while in FM transmission the band-widths are considerably wider than in AM, there is ample room in the FM spectrum to include all assigned stations with a generous margin between them.

The subject of band-widths and side-bands is covered more thoroughly in subsequent lessons of this series.

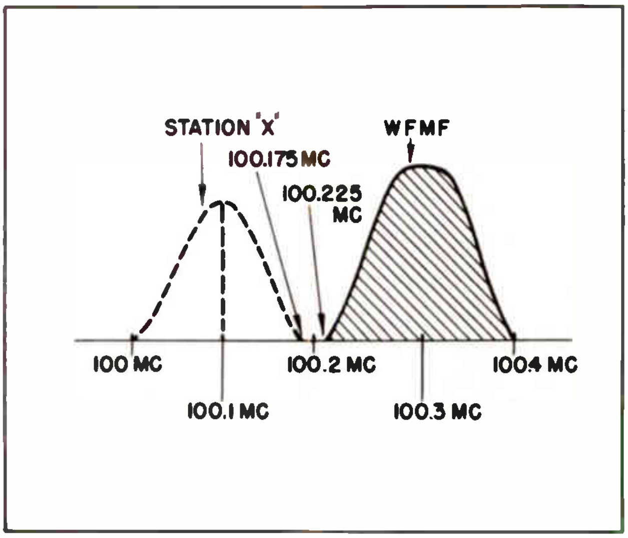

Fig.9. A Small Portion of the FM Broadcast Band.

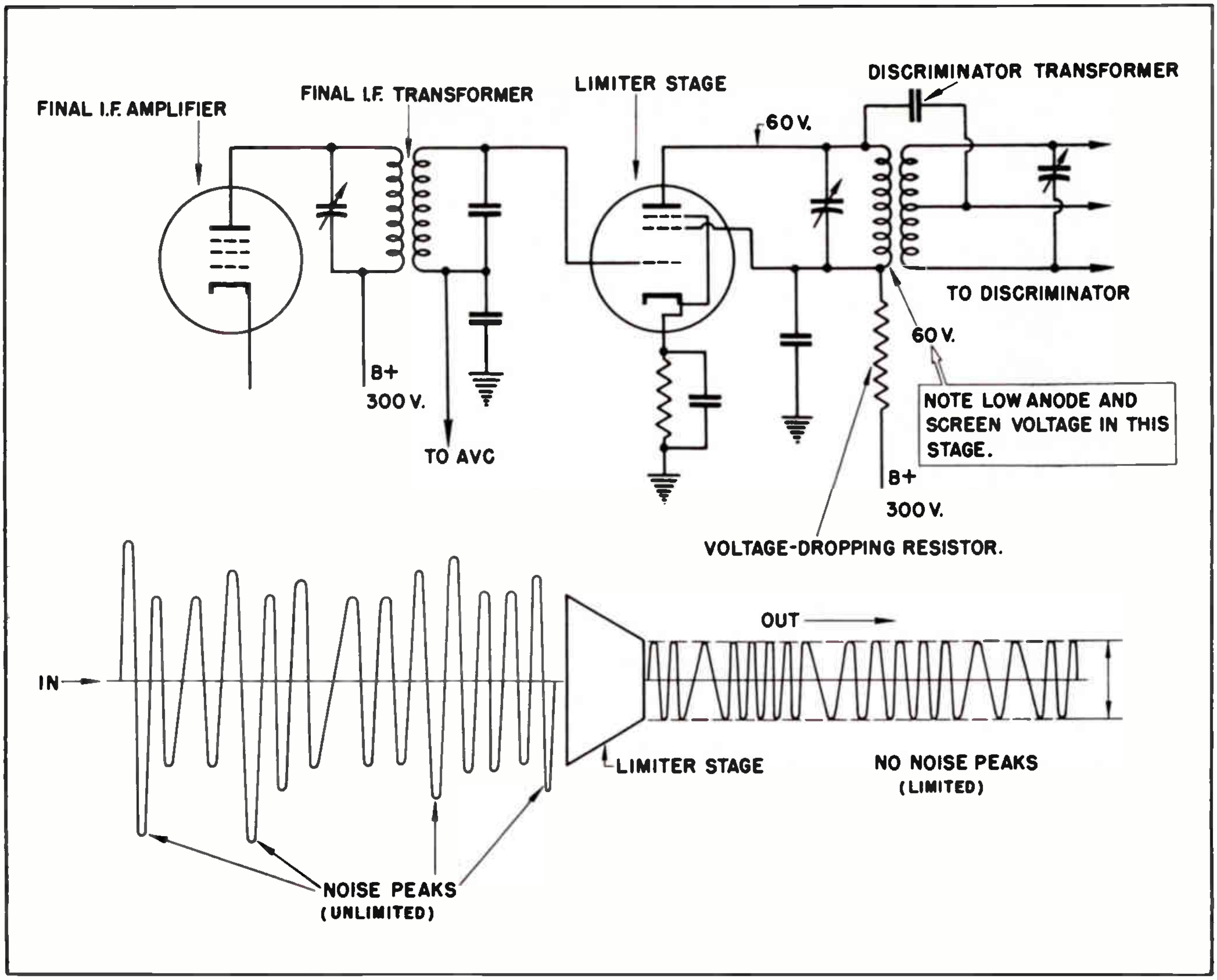

Fig.10. The Limiter Stage and Its Effect on Noise Peaks.

Section 6. THE FM LIMITER

We have seen that in FM transmission the signal at the receiving antenna is accompanied by considerable interference in the form of amplitude-modulated static noise. We have also noted (Fig. 7-B) that the intermediate amplifier system of an FM receiver does not respond in the same degree to all of the frequencies within its bandwidth, producing a higher output for the resting frequency than for those at the edges of the response curve. We are now ready to investigate the *limiter stage* of an FM receiver and show its purposes and principle of operation.

The limiter has two important purposes:

1. To reduce amplitude-modulated noise interference.
2. To flatten out the over-all intermediate amplifier response curve, and thus improve its high fidelity tone reproduction.

These purposes may be discussed as one, for the same action and the same circuit serve to accomplish both desired results.

Fig. 10 is a basic schematic diagram of an FM limiter. In the same illustration is an indication of the effects of passing a noise-modulated FM signal through a limiter stage. Let us first discuss the circuit.

Except for a few changes in the plate transformer of the limiter stage, it corresponds in most details to an ordinary I-F amplifier. One big, and significant difference, is the fact that the anode and screen potentials in the limiter stage are very low in comparison with those of the conventional

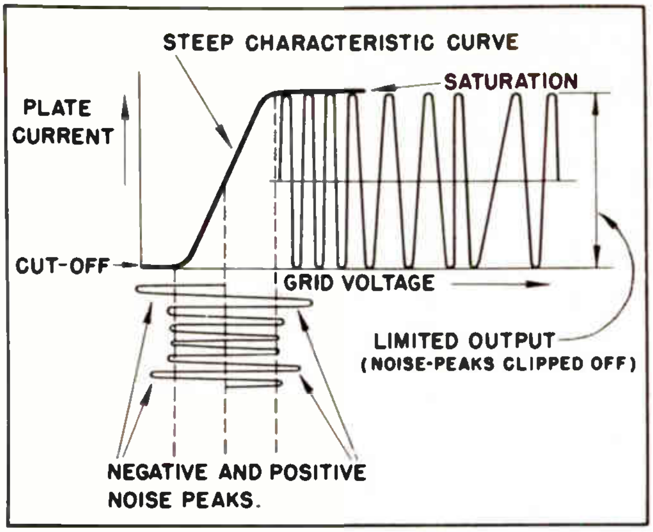

Fig.11. The Action of the Limiter Due to Low Anode and Screen Voltages.

I-F amplifier. A dropping resistor, shown in the diagram, lowers the plate and screen voltage to approximately 60 volts. The screen and plate are of course, by-passed to ground through a suitable capacitor, to avoid degenerative feedback in the stage. In the conventional I-F amplifier the plate voltage is usually around 300 volts and the screen very near to this value. What, then, is the action of such a circuit?

In the first place, it can be seen that with such a low screen and plate voltage, a small increase in grid signal voltage will saturate the tube. As indicated in Fig. 11, the effect of lowering the anode and screen voltages in a stage is to *steepen* the characteristic curve of the tube. Likewise, a small decrease in signal voltage will cut the tube off quickly. When the FM signal arrives at the grid with its accompanying amplitude-modulated noise, the plate current, swinging within the narrow limits between cut-off and saturation, will overdrive the stage to such an extent that the noise peaks can have no further effect in either increasing or decreasing the plate current.

This *limiting* value of plate current changes is responsible for the name of the stage. The action is truly a limiting effect, since the amplitude of the output signal is limited by the small grid signal voltage which so easily overdrives the tube beyond its cut-off and saturation points. If noise peaks are lost in the plate circuit of the limiter, they are effectively barred from passage through the remainder of the receiver to the loudspeaker. With the assistance of AVC in the FM receiver, noise-limiting is accomplished to a remarkable degree.

Let us now see how the same circuit and the same action will also have the effect of flattening out the response curve of the stage. Fig. 12 illustrates the principle involved. If the output from the final I-F stage is examined, it will be found to be like the dotted portion of the curve in the Figure, humped to maximum at the resonant point and considerably below maximum at the limits of deviation.

When the output of the final I-F amplifier is fed through a limiter stage, it takes on the characteristics shown in the cross-hatched portion of the curve. The curve becomes virtually flat throughout most of the band-width. Now all of the frequencies lying between the deviation limits will have practically an equal amplitude, and this means that a minimum of amplitude distortion can take place. The final result, of course, which is the object in view, is high fidelity reproduction of the audio signal when it reaches the loudspeaker.

Section 7. THE FREQUENCY DISCRIMINATOR

In FM the audio component of the signal is in the form of frequency variations of the carrier. As the I-F signal leaves the limiter, these frequency variations are those of the I-F carrier in the receiver. Up to this point in the signal circuit, the desired station signal has been selected from all others reaching the antenna, a high

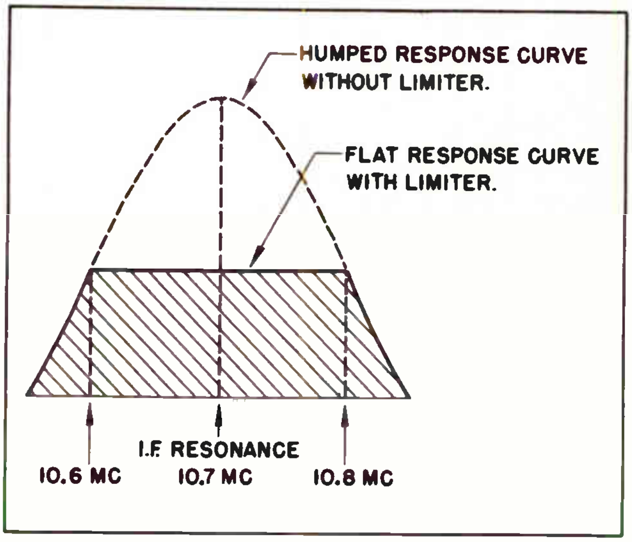

Fig.12. How the Limiter Flattens Out the Response Curve of the I-F Amplifier System.

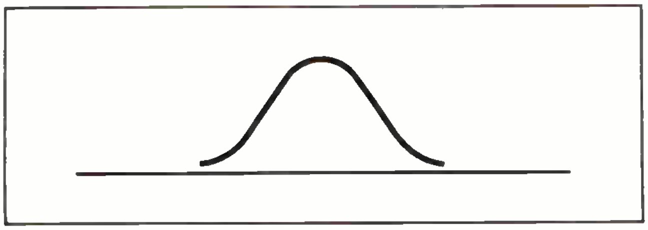

Fig. 13. Ordinary Resonance Curve.

gain has been imparted to it, its amplitude-modulated noise peaks have been clipped off, and it is ready for the process of demodulation.

Demodulation of any RF carrier consists of extracting the audio information from the high-frequency carrier. During the process of demodulation the audio signal -- also called the audio component -- is separated from the carrier which has acted to bring the signal from the transmitter to the receiver.

In previous lessons we have learned that the most common method of separating the audio information from the RF carrier is through the process of rectification. Rectifying the RF signal, and thereby extracting the audio information, works very well with amplitude modulation, or AM. But using rectification to demodulate a signal does not work so well with frequency modulation signals (FM).

An entirely different type of demodulation circuit must be used in FM. A circuit is needed which responds to changes in the carrier frequency, and by thus responding to those frequency variations can transform them into audio information.

An ordinary I-F transformer which is detuned slightly would probably be the most simple form of demodulator. To better understand how an ordinary I-F transformer could be used as an FM demodulator we will first review briefly the action of such a transformer, and its response curve.

In Fig. 13 we see the response curve of an I-F transformer, a curve which is nothing more nor less than an ordinary resonance curve. The ordinary resonance curve applies to the situation since the I-F transformer is a tuned resonant circuit.

In normal operation the I-F transformer would be adjusted so the peak of the resonance curve would represent the middle frequency of the I-F frequency. This is nothing new to you; we repeat it here solely for the purpose of review and emphasis.

Instead of the I-F transformer being adjusted so its resonant frequency corresponds to the mid-frequency of the I-F signal, suppose it is slightly detuned, as in Fig. 14. There we see the I-F frequency falls about midway of the right hand slope instead of being in the center of the resonance curve.

With such an arrangement we have a device which responds to frequency changes in the I-F signal. Any variations in the I-F frequency is quickly transformed into audible information.

To illustrate this point a little more clearly suppose we substitute some actual figures on the resonance curve of Figs. 13 and 14. We have done this in Fig. 15.

In Fig. 15 we find the I-F transformer peaked at 10.4 megacycles, but the I-F frequency applied to the transformer is actually 10.7 megacycles. This means that the mid-frequency of the I-F signal operates about midway down the slope on the right side of the resonance curve rather than at the peaked center of the curve as is normal in AM radio work.

With the mid-frequency of the I-F signal operating midway down the resonance curve slope the amplifier stage will not be operating at full efficiency. Instead, it will be operating at only about half-efficiency. This means the output of that stage will not have the amplitude it would have if the signal frequency applied to it corresponded exactly to the resonant frequency of the I-F circuit.

Thus, the normal output of this particular

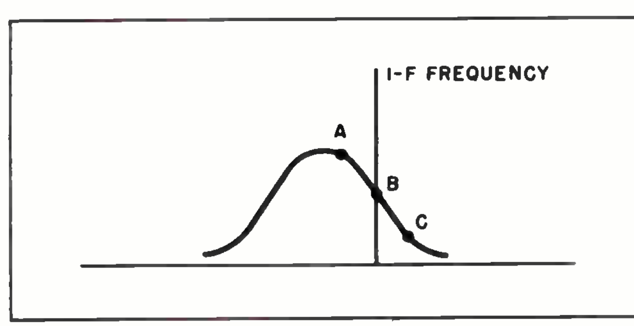

Fig. 14. A Detuned I-F Transformer. The Mid-frequency Operates Midway Down One Slope.

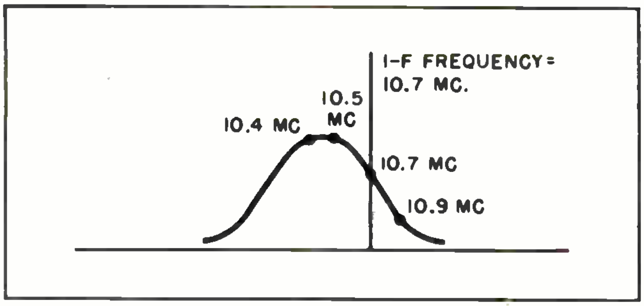

Fig.15. Frequencies Involved in a Detuned I-F Transformer with an FM Signal Impressed on It.

stage would be only about half as great as it would be if the I-F frequency corresponded to the resonant frequency of the I-F transformer.

Now, suppose the frequency of the RF carrier is varied from the normal "resting frequency", or the "mid-frequency" as it is some times called. This is the action which would occur in an amplifier circuit fed with a frequency-modulated signal.

For the sake of example we will assume an FM signal having a mid-frequency of 10.7 megacycles is fed into this circuit. While that FM signal has a mid-frequency of 10.7 megacycles it will vary somewhat from it in accordance with the modulation placed upon it. In this case we will assume the frequency of the signal varies from 10.5 megacycles, which is lower than the mid-frequency, to about 10.9 megacycles, which is above the mid-frequency.

This represents a little wider deviation than is commonly used in commercial FM broadcast work, but we have chosen the frequencies to make the point a little more clear.

When the frequency drops below 10.7 megacycles the signal is actually amplified to greater extent than when it is operating on the mid-frequency. This is because the lower the frequency drops toward 10.4 megacycles the more greatly it is amplified; being due to the fact that the nearer the frequency approaches 10.4 megacycles the closer it approaches the resonant frequency of the circuit.

On the other hand, should the frequency of the signal increase it will be amplified less than it would be at the mid-frequency. This is because any increase in the frequency causes it to drop lower on the response curve. The farther the frequency gets away from the 10.4 resonant frequency of the circuit the less the signal is amplified. And 10.9 megacycles is farther from the resonant frequency of the tuned circuit than 10.7 megacycles, the mid-frequency.

We have thus created a circuit which is clearly and definitely affected by the frequency placed upon it. Any deviation from the mid-frequency of 10.7 megacycles affects the magnitude of the amplification applied to the signal. A slightly higher frequency is not amplified quite so much as one at the mid-frequency; one at a slightly lower than the mid-frequency is amplified more than one at the mid-frequency.

Since an FM carrier frequency is deliberately modulated by the audio frequency placed upon it so the frequency varies above and below the mid-frequency, we now have a circuit which is capable of converting those frequency variations back into an audible signal.

The circuit just described here is used rather widely by radio amateurs in connection with Narrow-Band FM transmission and reception. It is preferred by them because of its simplicity.

But the circuit has some serious limitations when used in commercial work. For one thing the circuit is wide open to any AM signals at the resonant frequency which might reach it. Furthermore, either side of the slope acts equally well as a frequency iemodulator, and thus interfere with each other. These drawbacks are not serious to a skilled radio expert but they can be most undesirable in a supposedly trouble-free commercial receiver. No owner of an FM broadcast receiver wants to be troubled with constantly having to adjust the resonant frequencies.

The Travis discriminator circuit received much favorable attention at one time. A schematic diagram of the Travis discriminator circuit is shown in Fig. 16.

The Travis discriminator consists of a discriminator transformer which has one primary winding and two secondary windings. One of the secondary windings is tuned to a frequency slightly higher than the mid-frequency of the I-F modulated frequency, and the other secondary winding is tuned to a

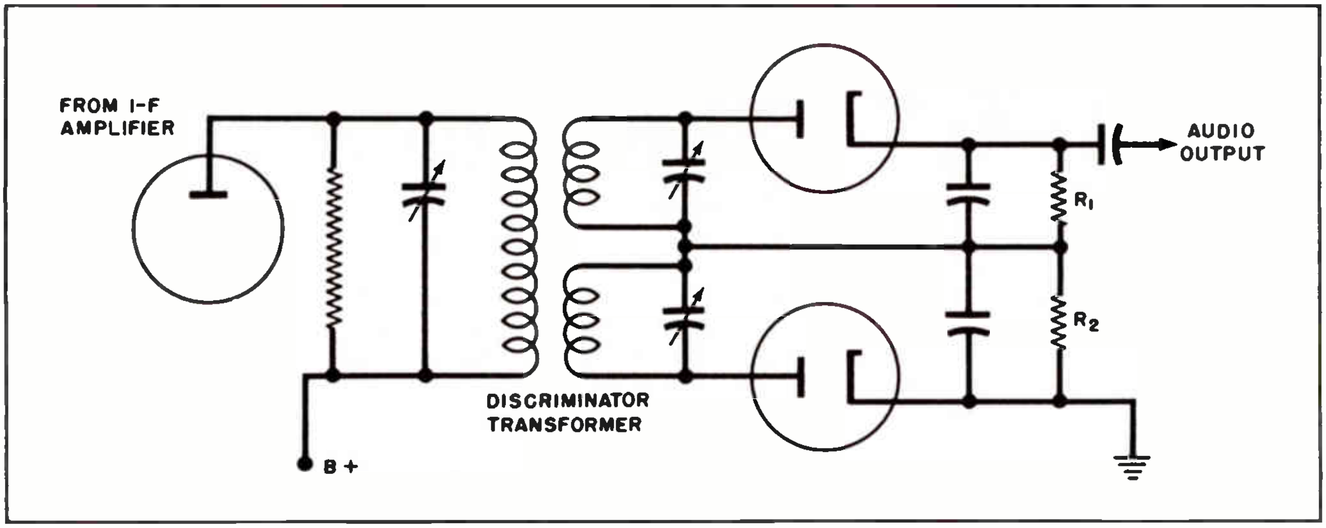

Fig.16. Circuit of Travis Discriminator Circuit.

frequency slightly below the I-F modulated frequency.

A small diode rectifier tube is connected to each of the secondary windings as indicated in the diagram. As the frequency of the I-F signal varies up and down, above and below the mid-frequency, first one and then the other of the two diodes are affected by the frequency changes. When the frequency is above the normal mid-frequency one diode will be conducting more than the other. When the frequency is below the normal mid-frequency the other diode will conduct more.

Variations in the conduction of the two diodes affects the voltage drops across the two resistors, R_1 and R_2. The voltage variations across the two resistors are equivalent to the original audio signal. All of which means that this circuit is capable of converting frequency variations in the I-F frequency into audio voltage variations across the two resistors, and can thus be applied to the AF amplifier stage which follows.

When properly adjusted the Travis discriminator works very well. It has not come into general use in FM radios because of the complicated windings on the discriminator transformer, and the difficulty of keeping all the tuned circuits properly adjusted.

A variation of the Travis discriminator circuit known as the Foster-Seeley discriminator has found much greater favor among FM manufacturers. The circuit of the latter type discriminator is shown in Fig. 17.

The Foster-Seeley is not so easily understood as the earlier type discriminators. This is because its action is dependent upon the shifting of the phases of the several voltages involved as the frequency of the signal shifts. Many electrical workers find it difficult to keep in mind the electrical action involved in the shifting of phase relationships.

A brief review of certain electrical fundamentals is useful at this time. It would be well for you to go back and review your lessons on fundamental electrical theory, including the action of capacitors and inductors in AC circuits.

It will be recalled that when AC current flows through an inductor the current tends to lag the impressed voltage. If the circuit is free of resistance, and the impedance is nearly pure inductance, the current will lag the voltage by approximately 90°. On the other hand, when a capacitor is in the circuit and the circuit is free of resistance, the voltage will lag the current by about 90°.

Note here that the current lags the voltage through an inductor, but the voltage lags the current through a capacitor.

There is another thing to remember. Increasing the frequency of the AC voltage increases the opposition, or reactance, of the inductor. Thus, increasing the frequency for any reason affects the capacitor and the inductor differently.

On the other hand, reducing the frequency

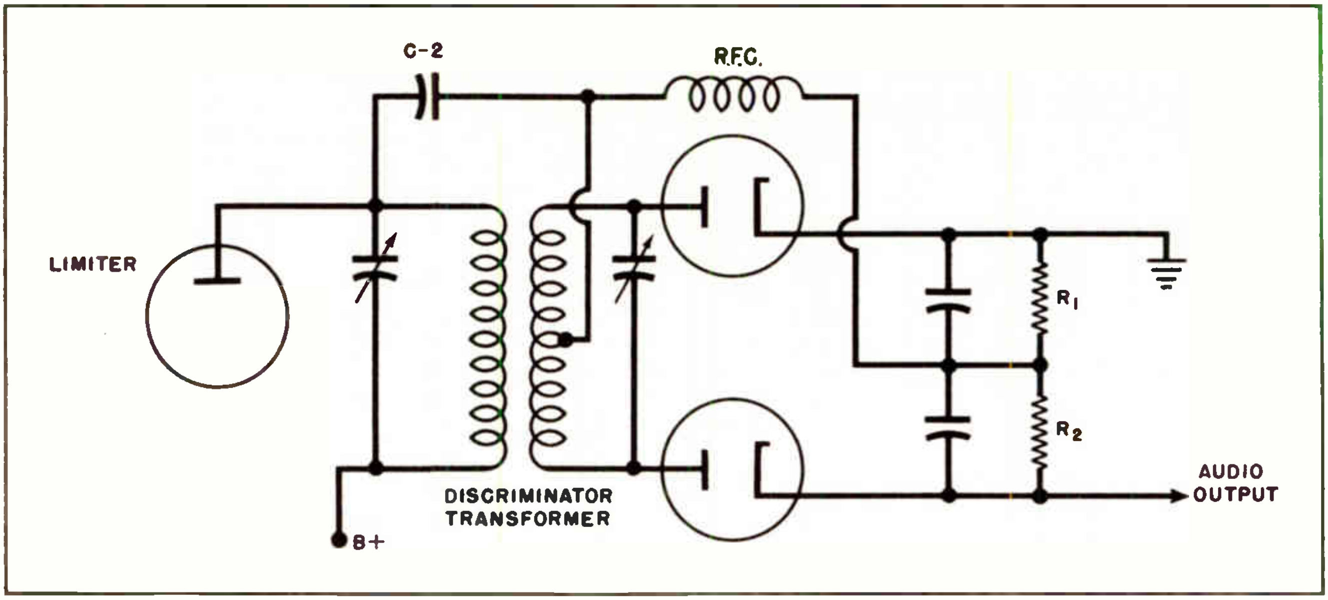

Fig.17. Conventional FM Discriminator Circuit.

of the AC voltage causes the reactance of the capacitor to increase, but the reactance of the inductor goes down. Here, again, the action of the AC voltage affects the capacitor and the inductor differently.

All of which means that a variation of the frequency applied to a circuit containing an inductor and a capacitor will affect them differently.

In Fig. 17 we have the signal from the plate of the limiter tube feeding into the primary of the discriminator transformer. The action of the AC signal in the primary winding is to induce a voltage in the secondary winding through capacitor C-2. The signal through C-2 arrives directly from the anode circuit of the limiter tube.

All of which means that the signal from the anode of the limiter reaches the center-tap of the transformer secondary by two different paths; one of the paths is inductive and the other is capacitive. One path is through the inductance of the transformer windings; the other is through the capacitance of C-2.

Because of the tuned circuits in the primary and secondary of the transformer, and because of the action of C-2, the net result is to make the current in the secondary out-of-phase with that in the primary by 90°, as shown in Fig. 18.

This means the voltage applied to the anodes of the two diodes is equal, but opposite. When the transformer coils are properly adjusted the voltage will be as shown in Fig. 19, the current through the two diodes will be equal, and the phase relationship of the voltage across the two resistors R_1 and R_2 will be equal; and the phase displacement will be balanced.

All this occurs at the mid-frequency, or "resting frequency", of the I-F signal.

When the frequency shifts above or below the mid-frequency there will be a shift in the phase relationship of the signals reaching the center-tap of the discriminator secondary winding. The signal arriving through the capacitor will be more nearly in phase with the voltage induced in one side of the secondary, but will be still further out-of-phase with that induced in the other side of the secondary winding. The net result is that the signal will tend to aid the voltage induced in one-half of the secondary winding, but will tend to oppose that through the other half of the secondary.

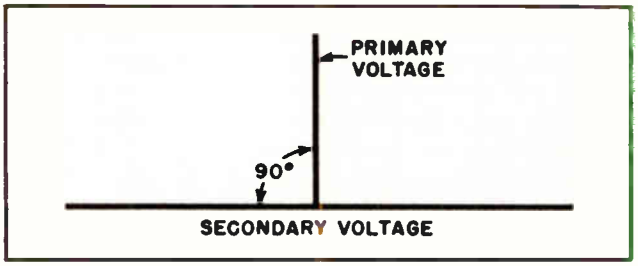

Fig.18. Voltage Displacement in Primary and Secondary of Tuned Transformer.

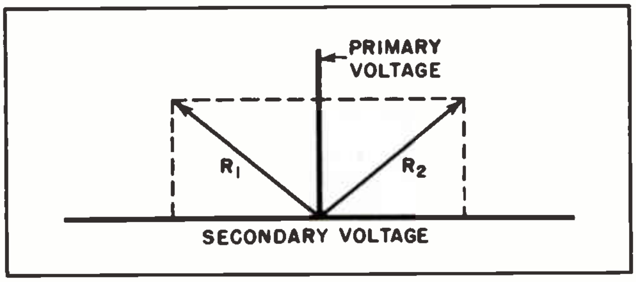

Fig.19. Voltage Displacement on Two Resistors and Transformer Windings When the Circuits of Transformer are Tuned.

Figure 20 indicates the result of this shift in the phase relationships of the voltages involved. With the signal through the capacitor aiding one-half of the secondary winding and opposing the other side it means that more voltage will be applied to one of the diodes than to the other. This further means that more current flows through one of the resistors than the other.

When the frequency shifts in the other direction the other diode will be favored, and there will be a corresponding change in the opposite direction of the currents through the two diodes. The diode which was favored by the original condition will now be discriminated against.

All of which means that as the frequency shifts above and below the mid-frequency point the two diodes will be alternately favored. The current through the two diodes varies as the diodes are alternately favored or discriminated against.

It should be noted that DC flowing through the diodes then flows through the secondary winding of the transformer, out through the center-tap and through the RF choke, then to the center-tap between the two load resistors R_1 and R_2. The presence of the RF choke prevents RF voltages and currents following that path.

A more complete diagram of a discriminator circuit is shown in Fig. 21. With all the parts of the circuit labeled a little more clearly than in figure 17 it is easier to follow the action of the circuit. The waveforms of the signal at the input to the circuit, and inside the circuit are compared with that of the audio component at the output which feeds into the audio driver tube.

Capacitors C-4 and C-5 serve to pass the RF component of the signal applied to the diodes around the resistors. Thus, the RF component flows through the capacitors while the audio component passes through the resistors. As the audio component flows through the resistors it creates varying voltage drops corresponding to the original audio signal.

Thus, the voltage at point "X" varies in accordance with the original audio signal. Capacitor C-6 couples the audio voltage to the high side of the manual volume control.

Section 8. AUTOMATIC VOLUME CONTROL

During the early developmental days of FM radio it was rather generally assumed among engineers and radiomen that the limiter would effectively eliminate the noise peaks from the signal. This belief was partially justified because most noise pulses are in the form of amplitude-modulated signals, and the limiter removes such pulses reasonably well.

It was also believed that the limiter would control strong signals, and tend to hold them to a normal level.

In practice these things did not work out exactly as they were originally visualized. Actually, modern FM receivers are equipped with AVC (automatic volume control) circuits in much the same manner as the more conventional AM receivers -- and for the same purpose. The AVC circuit helps in controlling excessive peaks ofnoise pulse voltages,

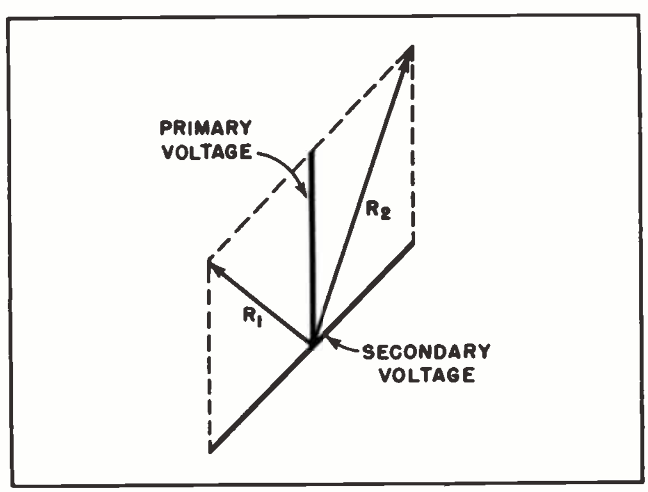

Fig.20. Phase Relationships of the Voltages in Primary and Secondary Windings, and Across Resistors, when the Frequency Shifts.

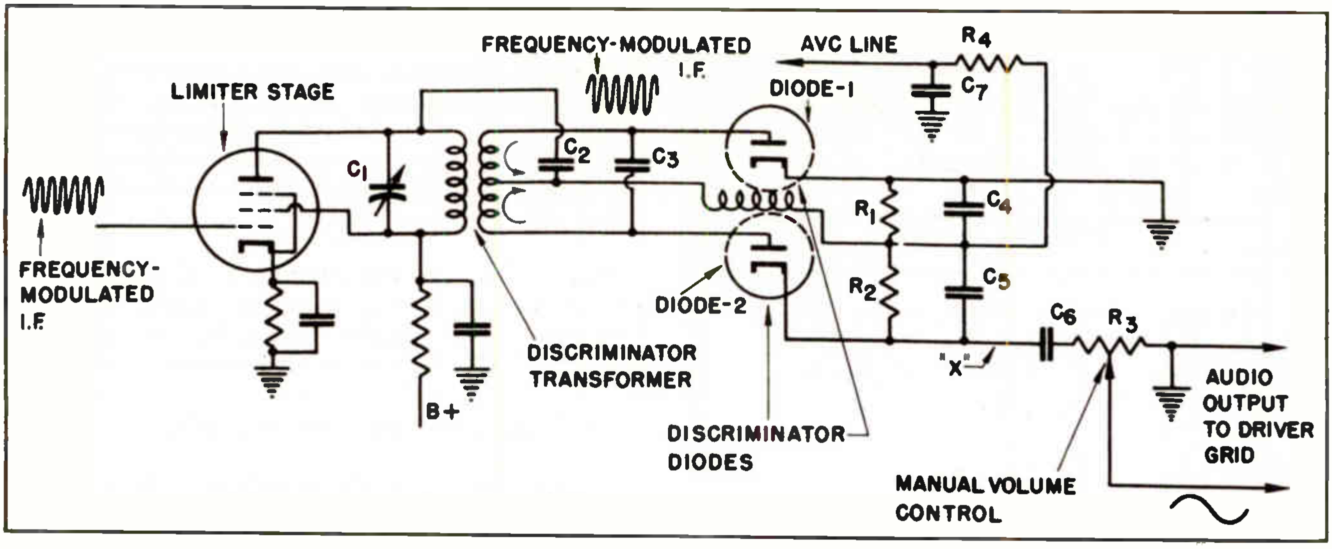

Fig.21. Frequency Discriminator Circuit.

and also helps reduce the level of strong signal voltages by holding the signal to a lower level than would be true if the AVC circuit were omitted.

The AVC voltage is developed in a slightly different manner in FM receivers. By referring to Fig. 21 it can be seen that the AVC voltage is developed at the center-tap of the two load resistors, which also corresponds to the center-tap of the transformer secondary insofar as DC voltage is concerned.

A connection at this point makes the AVC circuit always negative with respect to B-minus. Furthermore, the stronger the signal reaching the diodes the greater the bias voltage developed. Thus, the greater will be the tendency to reduce the amplification of the signal in the RF and I-F circuits of the receiver.

As a matter of fact, there is no radical difference in the way the AVC voltage is developed in the FM receiver from the practice most generally followed in AM receiver work.

The AVC voltage is filtered by the action of R_4 and C_7.

Section 9. THE RATIO DETECTOR

The intense competition which is always a powerful factor in all kinds of radio manufacturing was largely responsible for the design of a somewhat different FM demodulating circuit. It is called the ratio detector.

There are many points of similarity between the discriminator circuit and the ratio detector, but there are also important points of difference.

Figure 22 details the important features of a ratio detector circuit.

Probably the one feature which immediately attracts the attention of the observer is the fact that in a discriminator circuit, such as that in Figs. 17 and 21, both anodes of the diodes are connected to the transformer secondary, while in the ratio detector one anode and one cathode are so connected.

The chief advantage of the ratio detector is that it need not be preceded by a limiter tube since the ratio detector circuit is not sensitive to amplitude modulation. Doing away with the limiter tube and the circuits in that stage reduces the number of tubes needed in the receiver. This results in a definite reduction in the cost of manufacture.

Some engineers and technicians maintain that the ratio detector does not provide the same high degree of fidelity which can be achieved with the limiter-discriminator combination. In fact, some go so far as to say that the use of ratio detectors in FM receivers rather than the more costly limiter-discriminator circuits deprives the listener of the more important benefits which only FM can deliver.

It is not our purpose to become involved in arguments of this kind. The ratio detector is very popular, especially in the lower priced FM receivers.

The circuit of the ratio detector is similar in many respects to that of the discriminator. At first glance the most important difference appears to be the one noted earlier -- that one side of the transformer secondary is connected to one anode, and the other side connected to the other cathode. But there are other differences.

By studying the circuit diagram it can be seen that the secondary winding of the transformer is in series with the two halves of the duo-diode. Further than this, the secondary winding and the two halves of the tube are in series with the two .002 capacitors for RF voltages, and with the 33K resistor for DC voltages.

In addition to that circuit there is another in parallel with a portion of it. The second circuit consists of the circuit from the center-tap of the transformer secondary, through the RF choke, through the 1-megohm potentiometer, and from there to the cathode of one of the diode sections.

When an I-F signal is applied to the circuit the tuned constants of the circuit are adjusted for the mid-frequency of the incoming I-F signal. When that circuit is properly adjusted the voltage relationships at the center-tap of the secondary of the transformer will be virtually the same as with the discriminator in Fig. 19. When so adjusted there will be no voltage developed across the potentiometer.

This is because at the mid-frequency the voltages on each side of the center-tap are equal, and the current flows through both halves of the tube equally.

But when there is a shift in the frequency the voltage at the center-tap of the transformer secondary changes its phase relationship. One side or the other of the secondary winding will be favored, depending on whether the frequency shift is up or down. All this is very similar to the action in the discriminator.

In the ratio detector circuit, the shift in voltage phase relationships results in a higher or lower voltage being impressed across the circuit containing the RF choke and the potentiometer. The current which then flows through that circuit will be either greater, or less, than that which flows through the series combination of the two halves of the tube. This is where the term "ratio" originates.

The current which flows through the RF choke and potentiometer bears a ratio relationship to the current which flows through the other part of the circuit. It has a higher ratio, or a lower ratio, than the current through the main circuit, depending on the phase relationship of the voltages present at the center-tap of the transformer secondary. But the ratio of the one to the other is always a direct result of the phase relationship of the voltages in the secondary of the transformer.

From all this it can be seen that the current which flows through the two halves of the tube varies. The current which flows through the RF choke and potentiometer bypasses one half of the tube.

All of which means that a higher or lower ratio of the current flows through one or the other half of the tube. Here, again, the term "ratio" appears rather apt. The current and voltage across the potentiometer is a direct ratio of the ratio between the currents through each of the two halves of the tube.

While the ratio detector is not generally responsive to amplitude modulations on the incoming signal, it is responsive to variations in the amplitude of the signal itself. Put another way, if the incoming signal is strong the output of the ratio detector will be strong, will have a high level of amplitude. On the other hand, if the incoming signal strength is weak the output of the ratio detector will be weak; it will have a low level of amplitude.

This means it is imperative that the ratio detector develop an AVC signal for application to the preceding stages to maintain the signal level at a constant amplitude. The manner in which the AVC voltage is tapped off in Fig. 22 shows how the voltage is developed.

The audio output of the ratio detector is handled in the conventional manner. The signal is fed to the grid of an audio ampli-

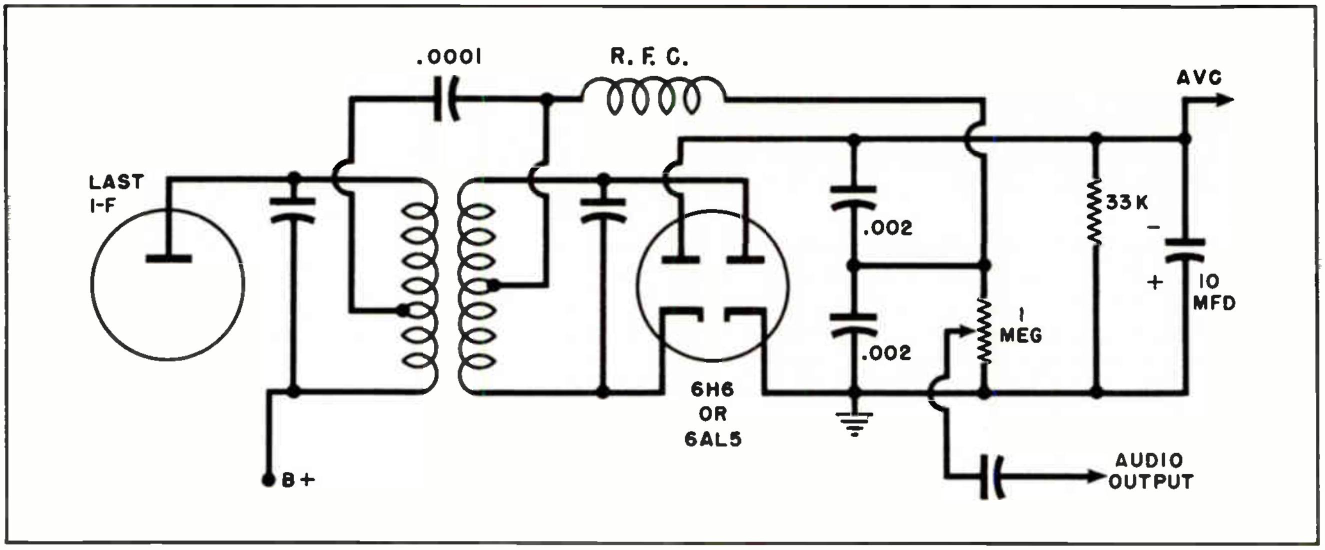

Fig.22. Ratio Detector Circuit.

fier tube, and from there to the output power amplifier tube, or tubes.

Section 10. ADVANTAGES OF FM RADIO

Arguments which are both long and loud can be started with almost any kind of a reference to FM broadcasting. There are some who listen to little else. There are others who seldom listen to FM radio at all.

FM radio has some very clear advantages over AM radio. Some of these advantages are more useful for the broadcasting of music, others are more useful in communications work.

Probably the greatest advantage of FM radio in ordinary broadcast work is its inherent ability to reproduce audio signals with great fidelity. For music lovers this is a priceless advantage. This is one of the reasons why FM broadcasting of high quality music is so popular in many quarters, and why that type of programming occupies so much of the time the station is on the air.

Ordinary AM radio broadcast stations are unable to transmit high fidelity music because the range of its audio modulation is limited. The AM broadcast frequencies are spaced 10 kilocycles apart, and the stations are prohibited from permitting their modulated sidebands penetrating into the adjacent channels. This means that the highest audio frequency which can be transmitted and reproduced by amplitude modulation is 5000 cycles.

Since high fidelity music requires the reproduction of frequencies as high as 12,000 to 15,000 cycles it is instantly obvious that true high-fidelity music simply cannot be transmitted over AM broadcast stations.

FM broadcasting is not limited in that manner. An FM transmitter can readily transmit audio frequencies far higher than the human ear can hear. This being so it follows that an FM transmitter can reproduce and handle any audible sound in exactly the same way it originates. This makes for true fidelity.

Many FM receivers are so cheaply constructed that they are unable to reproduce the full sweep of audio frequencies sent out by the transmitter. But this is no reflection on the transmitter.

Many FM receivers -- so-called -- are capable of picking up FM signals, and demodulating them. But the circuits which handle the audio frequencies after they have been demodulated are so poor that all the advantages of FM reception are lost before the audio signal reaches the loudspeaker. Furthermore, so many of these inexpensive, so-called FM receivers have such a poor speaker system they are unable to reproduce the higher audio frequencies.

Such receivers are called FM receivers because they are capable of picking up FM broadcasts. But since they are unable to reproduce the full range of audio signals sent out by the transmitter they can be called FM receivers only because there really isn't any other name for them. Such receivers are often a disappointment to their owners, and because they are unable to do the things which have been claimed for FM radio many music lovers become embittered with FM reception, and turn against it.

Unfortunately, the trouble is not in the system of FM transmission, nor in the quality of the signal sent out by the transmitter. The trouble all lies with the owner who has purchased a receiver which is inadequate for the job.

An FM receiver capable of reproducing all the tonal qualities of the music sent out by an FM transmitter is always expensive. The so-called FM receivers which sell for $75 to $150 can seldom do the job right. One that sells for less than that will do an even less satisfactory job.

If all the overtones transmitted by the transmitter are to be handled in the audio section of the receiver after the carrier has been demodulated that audio section must be of the very highest quality. The audio amplifier and electrical circuits must be constructed of the very finest components, and be fully ample for the job. Such audio section should consist of not less than one audio driver tube, and probably two. It will include an inverter tube, or some other method of inverting a portion of the signal. The output stage must be push-pull; there can be no deviation from this requirement. No single-ended output stage can possibly drive a speaker which is large enough to reproduce the full tonal range of the audible frequencies.

The audio circuits alone in a radio of that design will range from $75 to more than $100. All of which indicates quite clearly that a receiver which sells for that amount or less cannot faithfully reproduce FM quality.

There will naturally be differences of opinion as to the type of speaker needed to reproduce high quality music. Even so, no intelligent audio engineer or technician will argue that anything less than a 12-inch speaker can possibly do the job. Most will insist on a co-axial speaker, and probably one as large as 15 inches. Such a speaker cannot be purchased for less than $50, and even an average-to-good high-fidelity speaker will range up to three times that cost. Many high-fidelity speakers cost well over $500 each.

In addition to its use in ordinary broadcast work FM radio is widely used in communications work. Many police departments are now using FM radio in their communication work. The same is true of fire departments and public utilities.

Most taxicab radio dispatching is done through the medium of FM radio, although there are some minor exceptions to this general rule. It is used almost exclusively in point-to-point communication work such as walkie-talkies, handie-talkies and the new Citizens Band communication transceivers.

The usefulness of FM radio is limited somewhat by its limited range. Due to the general necessity of operating at the higher frequencies FM signals do not reach out the great distances which are commonly covered by AM radio. The powerful FM broadcast stations rarely have an operating range greater than 75 to 100 miles, although freak conditions often arise during which times the broadcasts can be picked up at greater distances.

The limitations of short range create no serious problems for most of the uses to which FM radio is put. Local fire, police, utility and taxicab service are readily handled within the limitations of FM transmission.

Probably the greatest advantage of FM radio in communication work is its noise-free feature when the transmitter is operating at low power. In AM radio work the only way to override the ever-present electrical noise is to pound out a powerful signal. The radio signal is then so much stronger than the normal electrical noise level that it overrides the noise by brute force.

In FM radio communications the signal can be transmitted at very low power. Often the output power is not more than 25 to 50 watts. Sometimes it is even less.

Since the receiver circuits are sensitive to frequency deviations and are not sensitive to amplitude changes the signal always gets through clear and loud -- provided, of course, the receiver is within range. It was largely because of this noise-free feature that FM radio was adopted for so many uses during the second World War. Armored tanks, tracked vehicles, and other kinds of mobile units always operate in the midst of electrical noise. An AM transmitter strong enough to override that electrical noise would have been very powerful, and would have carried over long distances.

By using FM radio the communications system could be operated at low power, and thus not be so likely to reach the enemy, and still would not be seriously affected by the electrical noises created by all the motors and other electrical equipment in the vicinity.

NOTES FOR REFERENCE

The purpose of the limiter stage in an FM receiver is to reduce all signals and noise peaks to an even level -- to a constant amplitude.

The frequency discriminator separates the audio component of the radio-borne signal from its carrier. It corresponds to the second detector in an AM radio.

The limiter and discriminator stages can be replaced by the ratio detector. The ratio detector is less expensive than the limiter-discriminator combination, but there is some dispute about its ability to reproduce as clear a signal as the latter.

In general, the audio circuits in an FM receiver are conventional. But an FM receiver intended to take full advantage of FM superiority in transmitting audio information must have a very high quality audio section. Otherwise much of FM radio's advantage is lost to the listener.

A big advantage of FM radio in communication work is its ability to operate at low-power, and its noise-free characteristics.

A disadvantage of FM radio for many purposes is its short range, although that is counted an advantage for some purposes.

NOTES

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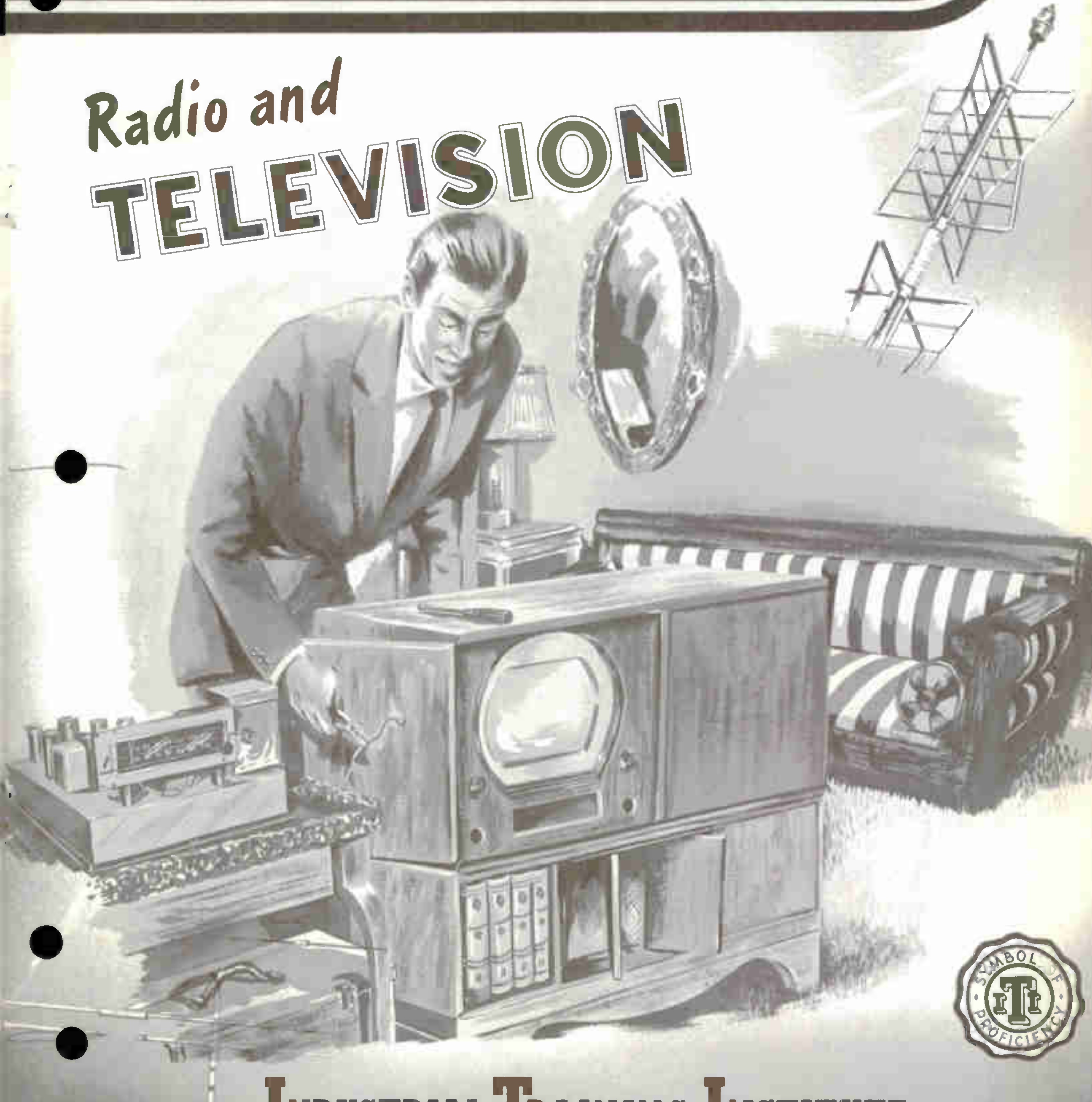

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RADIO TELEVISION

SERVICING FM RECEIVERS

Contents: Introduction - General Considerations - Trouble-Shooting Procedures - Trouble-Shooting FM Circuits - FM Signal Distortion - Absence of an FM Signal - Weak FM Signals - Noise and Hissing - Cross-Talk - Motor-Boating - Hum Interference - Tuning Defects - Aligning the FM Circuits - The Meter Method - Notes for Reference.

Section 1. INTRODUCTION

Servicing FM receivers and the sound channel of television receivers, is but an extension of the principles applied in trouble-shooting AM receivers. Fundamentally they are the same types of circuits -- they differ primarily in the nature of the signals being handled.

For the sake of emphasis, we present in Fig. 2 a series of block diagrams showing: (A), the AM receiver; (B), the FM receiver; and (C), the television sound channel.

It is significant that in all three cases the radio-borne signal goes through the same process of being captured from space, tuned, amplified, converted to an I-F frequency, demodulated, and audio-amplified, all in much the same manner. In all three cases the final product of the receiver circuits acting upon the received signal is to produce audible sound corresponding to that which actuated the microphone back at the broadcasting studio.

Trouble-shooting AM receivers has been covered in other lessons. It is the servicing, trouble-shooting, and alignment procedures of the FM receiver toward which we turn our attention in this lesson. It should not surprise you greatly to learn that the methods which apply to AM receivers will also, in general, apply to FM receivers and the sound channels of television receivers. The differences are mostly in the details of construction and spring from the differences in the nature and frequency of the signals it is desired to pass from the antenna down through the receiver into the loudspeaker.

Section 2. GENERAL CONSIDERATIONS

In approaching the analysis of trouble in an FM receiver several important considerations stand out. In the commercially-produced receivers we seldom find the FM by itself; in most cases it is combined with an AM receiving circuit. Less frequently we find the AM-FM combination radio receiver

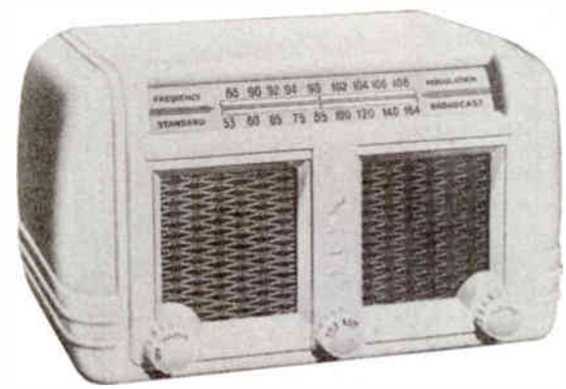


Fig.1. Table Model Combination AM-FM Receiver. (Courtesy FADA Radio)

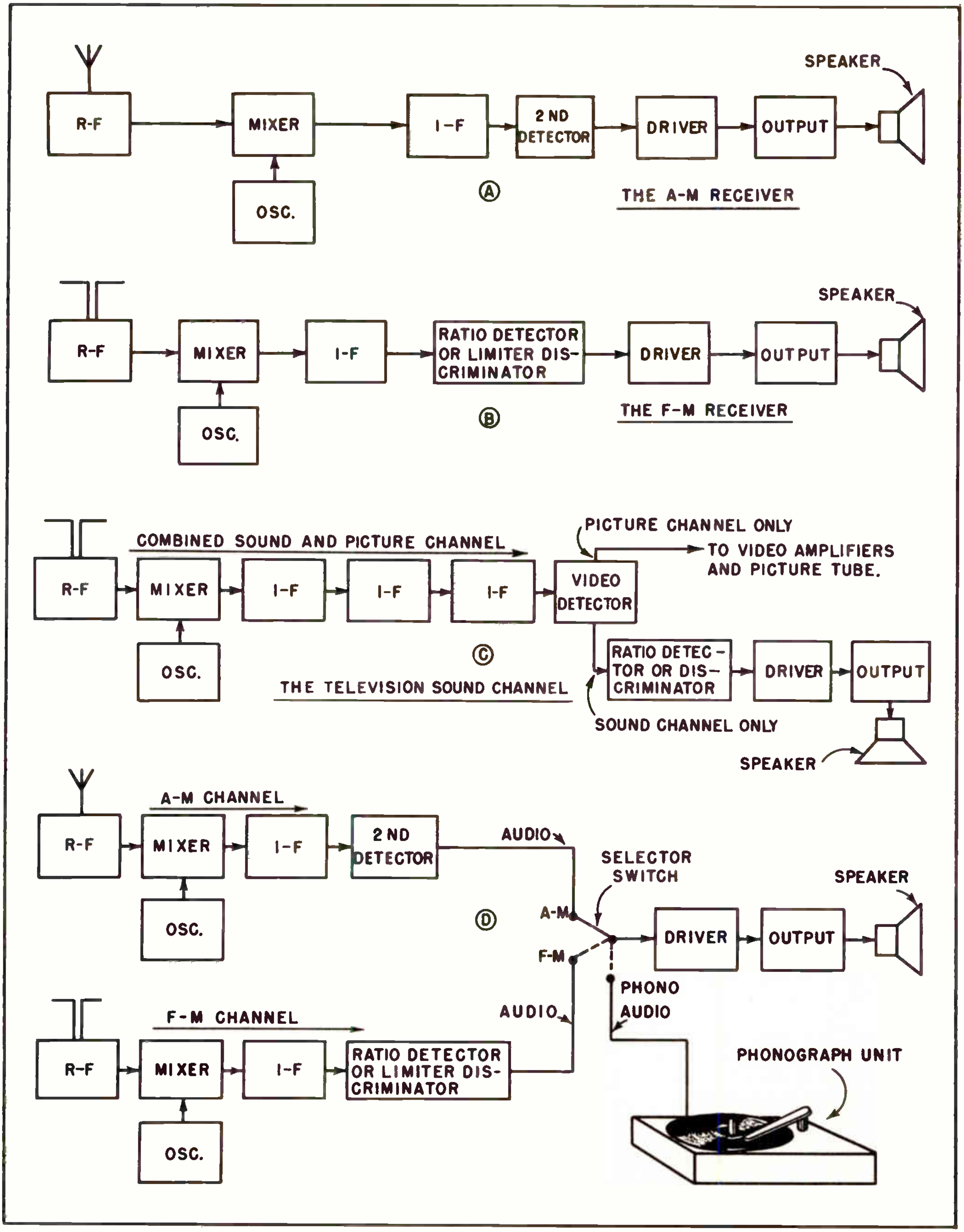


Fig.2. Note the Similarity in the Block Outlines of AM, FM and Television Sound. Also Note the Common Audio Amplifier System of the AM-FM-Phono Combination.

as part of a radio-phonograph combination as well. In some cases the AM-FM-phonograph-television system is a complete and self-contained unit which enables the user to select the exact type of entertainment which suits his fancy at the moment.

The fact that the FM receiver, except in special cases, is a part of a more complete unit is of the utmost importance from the trouble-shooting point of view. An early lesson of this series pointed out the interesting fact that the more complex the electronic equipment, the easier it is to trouble-shoot. There is no better proof of this statement than in the methods employed in trouble-shooting an FM circuit in a combination AM-FM-phonograph.

Fig. 2D will help us to visualize why this is true. We find there a block diagram of a typical AM-FM-phonograph unit, such as is often encountered by the technician.

The system described in the block diagram of Fig. 2D consists of three independent branches which are tied together by a common power supply and using the same audio amplifying system. The AM channel handles an amplitude-modulated signal and converts it into electrical impulses at an audio frequency. The FM channel, in its own way, does the same with the frequency-modulated signal, converting changes in frequency to changes of voltage at an audio frequency rate. The phonograph unit is an electromechanical generator which converts "bumps" in the record groove into voltages at an audio frequency rate. The audio amplifier accepts voltage changes at audio frequencies from any of these three sources of the signal which the selector switch selects. The result is that the desired signal is then amplified by the audio section and converted into sound energy at the speaker. These principles have been mentioned in connection with other subjects and are not new to us.

However, we are placing emphasis upon these principles here to illustrate a highly important trouble-shooting technique. Any trouble occurring in any part of this system will readily reveal its general location by the way in which the system acts.

For simplicity's sake, the power supply has been omitted in the block diagram of the system shown in Fig. 2. We may easily picture it, however, as the source of power for every one of the stages shown. Hence it must be common to the three signal branches as well as to the audio amplifier. A power supply trouble, therefore, will at once indicate its presence by the fact that none of the channels operate, or that none of them operate satisfactorily.

On the other hand, if both the FM signal and the phonograph records are brought through to the speaker satisfactorily, but the AM signal is not heard, it is only reasonable to assume the trouble lies in the AM circuit channel. Furthermore, we may safely conclude that the nature of the trouble in the AM channel is not such as would make either of the other signal channels inoperative.

Likewise, a trouble in the FM channel, providing it does not prohibit the passage of signals through the other two branches, will make the FM channel, and only the FM channel, inoperative.

Section 3. TROUBLE-SHOOTING PROCEDURES

Exact conditions may be adequately ascertained by an operational check of the entire system. We may now formulate a most valuable approach to trouble-shooting equipment of which an FM signal channel is a part: Before making any other tests, operate the set in all positions of the function switch, carefully noting the presence or absence of symptoms in each position.

The trouble-shooting procedure which follows this initial step will be determined by the results of this operational test. If we once recognize the exact response of the system as a whole, we may set forth a procedure which will lead us along a direct path to the exact trouble. The specific trouble-shooting pattern to be followed in a given case will be indicated when the overall operational check reveals one of the following conditions:

System completely inoperative. Trouble in the power supply or the audio channel. If B-plus is present, look for trouble in the audio amplifier. If B-plus is absent or suspiciously low, look for trouble in the power supply. Carefully check the power rectifier and the audio tubes.

System inoperative on phonograph only. Look for trouble in the crystal pick-up, the connecting leads to the phonograph input jack, and the selector switch.

System inoperative on AM only. If the system consists of separate AM and FM chassis, check the tubes on the AM chassis. If FM and AM use the same chassis, and the same tubes, check the AM antenna connections and the selector switch.

System inoperative on both AM and FM, but phonograph operates. This indicates that some component or circuit, *other than the power supply and the audio amplifier,* but in common to both the FM and AM functions of the receiver, is causing the trouble. Such components are: tubes (which should be checked), combination AM and FM intermediate frequency transformers, screen by-passing condensers, and RF by-passing and filtering circuits. It will be shown that components *other than* the power supply and the audio amplifier, which are used in common to both the AM and FM functions, are very few. For this reason, a receiver which is inoperative on both AM and FM, but in which the phonograph signal is satisfactory, may be rather easily analyzed.

System inoperative on FM only. If the system operates satisfactorily on AM and on phonograph, but is either completely or partially inoperative on FM, then trouble is indicated in the FM channel. By *partially inoperative,* we mean many things. Absence or attenuation (weakening) of the signal, distortion of any kind, inability to properly tune stations, stations running into each other, hums, whistling, motor-boating, and hissing -- these symptoms of abnormal operation are indicated by the term "partially inoperative".

Having established the fact that the system is satisfactory on both AM and phonograph, but failing on FM, we may now take a path that will lead us, directly or indirectly, to the trouble which we know must lie in the FM circuits. In other words, we are ready to trouble-shoot an FM system.

Section 4. TROUBLE-SHOOTING FM CIRCUITS

Trouble-shooting FM circuits will be discussed under the following headings:

(1) Signal distortion.

(2) Absence of signal.

(3) Attenuated (weak) signal.

(4) Noise and hissing.

(5) Cross-talk, whistling, and howling.

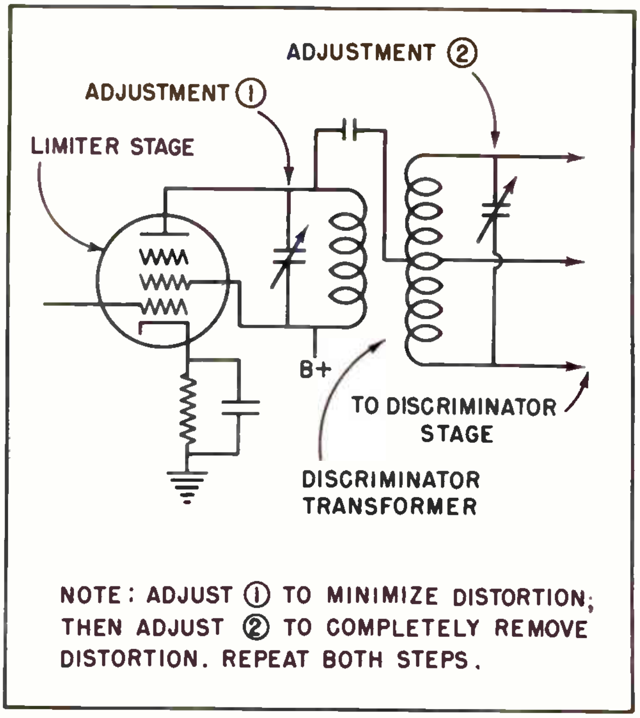


Fig.3. Making a Discriminator Adjustment and Checking Results by Ear.

(6) Motor-boating.

(7) Hum interference.

(8) Tuning defects.

Let us keep in mind the practical, and important, thought that almost all commercially-made FM receivers are built in association with an AM receiver. Trouble-shooting the FM circuits of this type of combination receiver must take this fact into consideration, since the two signal systems present in the same receiver have certain common components. Constant reference will be made to these components which the AM system and the FM system jointly include, for they will provide a reliable and simple method of checking the troubles which are *peculiar to the FM system only.*

Section 5. FM SIGNAL DISTORTION

The most common cause for signal distortion in FM circuits is the misalignment of the discriminator transformer resonant components. These include the primary and secondary windings, each of which is resonated by means of a trimmer condenser to the I-F frequency of the receiver. This is illustrated in Fig. 3.

If distortion *does not* take place on AM, and all tubes have been checked and found good, or replaced if bad, then we may suspect misalignment in the discriminator as a first probability. The reason for distortion taking place when such misalignment is present is that the discriminator tuned circuits, which should be tuned *exactly to* the unmodulated I-F carrier value, will cut off an appreciable portion of the sidebands when tuned to any other frequency.

Since in FM the intelligence is carried in the sidebands in the form of frequency deviations, it is essential that these sidebands be retained throughout the receiver's tuned circuits. The action of the discriminator is such as to produce changes of voltage at an audio rate which correspond with frequency changes *above and below* the resting I-F carrier frequency. If the modulated I-F signal is suppressed with respect to the excursions of frequency either above or below the resting carrier, then certain audio components will be likewise suppressed. This results in distortion of the audio signal which is heard in the speaker.

The remedy for misalignment of the discriminator tuned circuits is to re-align the trimming condensers of both the primary and secondary windings. This may be done either by ear or by the use of test instruments. The latter is a part of the general alignment procedure for FM circuits, and is presented in full in subsequent paragraphs of this lesson.

The former method, that of re-aligning the discriminator tuned circuits by ear, is extremely simple. Tune in a strong FM station and adjust the tuning dial so that the distortion is at a minimum. Then adjust the trimming condenser of the primary of the discriminator transformer to further reduce the distortion. (It may be necessary to try turning the trimming screw *both* ways, about a quarter of a turn, to determine which way is correct.)

Next repeat the operation on the trimmer for the discriminator transformer secondary, until the distortion disappears. Follow these steps with a re-adjustment of both the primary and secondary trimmers. Check the results by tuning in several different FM stations located at either end, and in the center, of the FM dial.

In some FM discriminator circuits, the tuning of the primary and secondary windings is accomplished by a pair of tuning slugs. These slugs are slotted at the top for the screwdriver, and the adjusting is done on the *inductance* of the circuits rather than on the capacity. The procedure, however, is identical.

Where the ratio detector is used instead of the limiter-discriminator stages, the same procedure also holds. The discriminating transformer, following the last I-F stage, is used in the ratio detector as well as in the discriminator stage, and adjustments to correct misalignment are the same in both cases.

Another fairly common form of distortion in FM signals is due to a phenomenon known as "shift-of-peak" of the I-F response characteristics. It is most noticeable when a fairly weak FM station comes in without distortion, but the strong stations are distorted. A typical method of checking this is to tune *slowly* to a strong station on the FM dial. If there is a shift of the peak it will be revealed by the fact that the signal will be distorted when it is tuned in at its loudest point, and will be fairly clear when slightly *detuned*. Weak stations, as mentioned before, will show no distortion. The electrical cause of this phenomenon is that the limiter grid, following the final I-F stage, is driven highly positive on the positive swing of the strong I-F signal, thereby drawing grid current and thus detuning the limiter grid tuned circuit. This detuning process, taking place on a strong signal only, seriously affects the overall I-F response characteristics by as much as 25,000 cycles per second, clipping off important sidebands and causing audio distortion.

The correction for this defect may be done by ear with satisfactory success, or as a part of the alignment procedure. By ear, the adjustment of the limiter grid tuned circuit may be accomplished with a screwdriver trim-up of the condenser associated with the limiter grid coil. This coil, as illustrated in Fig. 4, is the secondary of the final I-F transformer. To adjust this circuit, tune in a strong station on the FM band, and turn the secondary trimmer about a quarter of a turn. (It may be necessary to turn it both ways to find out which is correct.) If this is the cause of distortion, the trimming action, if done in the right direction, will clear up the distortion while the selector dial is set at the point of loudest response to the station. Since there is a considerable amount of reflected impedance between primary and

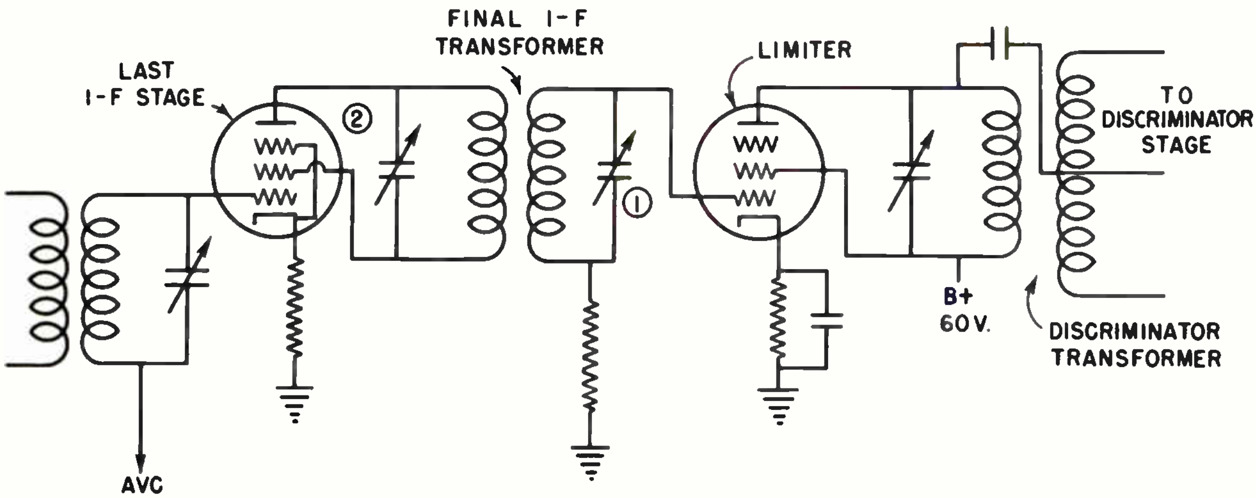


Fig.4. Removing the Effects of "Shift-of-Peak" in the Limiter Grid Circuit. This Can Often be Done by Ear.

secondary of the I-F transformer operating at the I-F frequency of an FM receiver, a trim-up should be made on the primary of this transformer, following the adjustment of the secondary. Then, to be sure of results, re-trim the secondary again, turning only a very small amount, and check the response of other strong stations on the band. A satisfactory alignment of the limiter grid will be indicated by the lack of any noticeable distortion on any of the strong stations while they are tuned in at maximum loudness.

The same point of view may be taken for any adjustment made by ear in an FM receiver; the technician is usually more critical of imperfections in signal reception than his customer is. Hence the ear of the technician is an excellent standard of comparison for the quality of an audible signal.

Alignment of the limiter grid by the application of the alignment procedure of the FM circuits may also be attained, probably with greater accuracy, by the use of test equipment. The details of the complete alignment procedure may be found at the end of this lesson.

In some cases, where an FM receiver is located close to the transmitter, no amount of correction of the limiter grid resonance will eliminate this distortion. This is simply due to the fact that in this case the station signal is so strong that neither the limiter grid circuit nor AVC control will compensate for the wide shift of the I-F peak. Correction here can most successfully be made by reducing the size of the antenna used on FM, or by orienting the FM antenna (if it is a half-wave type) in some other direction. As a final resort, of course, the offending distortion of any nearby station may be decreased by explaining the nature of the defect to the customer and instructing him to set *this particular station* at a slightly detuned point on the dial. Ordinarily this would cause a higher noise-to-signal ratio, but if the station signal is being distorted by too strong a signal, then there will be sufficient AVC action, even when slightly detuned, to override the noise.

In those receivers employing the ratio detector there is no limiter, since the ratio detector accomplishes both the limiting and discriminating action in the same stage. There can thus be no distortion due to a strong signal overdriving the limiter grid.

It is conceivable, but not common, that distortion of the FM signal can take place by the drifting of the I-F transformer components, before the signal is fed to the limiter or to the ratio detector. Such drifting may be due to the aging of the components, changes in dielectric characteristics of the condensers, and temperature conditions. Since the I-F band-width is extremely wide in FM, this is not a likely source of sudden trouble. However, while repairing the receiver, the technician may inadvertently change the I-F trimmers to such an extent as to require a complete re-alignment of the entire I-F strip. In order to avoid this situation, which requires time and equipment to correct, it is a wise policy to refrain from making I-F adjustments unless the symptoms clearly indicate they are necessary. Then, if the alignment is made by ear, turn each trimmer *only a small amount*.

Section 6. **ABSENCE OF AN FM SIGNAL**

If the tubes have been checked and found satisfactory, or have been replaced where necessary, and the AM signal is brought in satisfactorily, yet the FM signal is not heard, trouble is indicated in those circuits peculiar to FM only. These include several different channels. Some of these are the FM antenna and the FM RF components, the FM intermediate stages where they are separate from the AM intermediate components, and the limiter, discriminator, and the ratio detector. A clear inspection of the selector switch should be made visually, to eliminate any defects in the switch as being the cause of trouble.

If the receiver uses one antenna for AM and another for FM it is wise to check the connections to the FM antenna. These are usually a *pair* of binding posts to which a two-wire transmission line is attached. The disconnection of these leads may easily result in the complete loss of the FM signal, while the AM signal, because of its separate antenna, is brought through in a normal manner.

Where the receiver employs two separate chassis, one for FM tuning and one for AM tuning, and the signal is suppressed on FM only, the FM chassis will have to be analyzed as a unit. In many cases, when two separate chassis are used, each chassis has its own power supply. Therefore the technician is wise, when he encounters a receiver with two separate chassis and his inspection reveals two separate power supplies, to check the FM power supply for defects. This is a matter of measuring the value of B-plus at the rectifier cathode, and noting other indications. For instance, he may notice that the plates of the rectifier of the *FM power supply* become red-hot. This, as we recall from our analysis of AM power supplies, indicates a shorted filter condenser or some other short-circuit across the high-voltage power supply. Trouble-shooting power supplies in FM receivers is exactly the same as in AM receivers.

If in the case of two separate chasses the FM power supply is tested and found good, and still the FM signal does not come through, a stage-by-stage analysis, equivalent to the FM alignment procedure, is the best way of locating the trouble. Such procedure will be explained later in this lesson.

In some cases, one power supply provides "A" and "B" voltages for each of the separate chassis. If the AM signal is normal, but the FM signal is absent, power supply troubles may still be the cause. This at first seems difficult to understand, since if we know that the power supply is common to both AM and FM, trouble in the FM portion of the circuit, if caused by a defect in the power supply, should be accompanied by trouble in the AM portion of the receiver. Yet the reason becomes clear on consideration.

Due to the high frequencies involved in FM, many by-passing and de-coupling circuits are used. Among these are circuits using RC filters, a part of which is the by-pass condenser. There are many of these condensers used, and they are almost entirely in the high-voltage B-supply circuits. In some cases, a by-pass condenser may puncture through, or otherwise short out, which is in the FM portion of the circuit. This is technically a power supply trouble, although the defective condenser is *physically located* in the FM chassis. A good indicator of this condition is the action of the *tuning eye indicator* of the receiver, supplemented by a visual inspection of the rectifier tube plates.

The combined selector switch, between FM and AM, most often switches B-plus *out of* the chassis which is not in use at a given time, and switches it *into* the chassis which is in use. The selector switch, therefore, removes the short-circuit from the power supply system when turned to the AM position. The AM signal will be present in this case, and the tuning indicator will light up bright green. The plates of the rectifier will not be red-hot. However, when the selector switch is turned to the FM position, in addition to switching the *signal circuits*, it switches B-plus into the FM chassis. A short across a by-pass condenser in this chassis will thus be placed in the B-plus circuit. The tuning indicator will grow dark, the signal will be absent, and the plates of the rectifier tube will become red-hot.

Verification of this condition may be readily made with an ohmmeter (with receiver power turned *off*) across the B-plus-to-B-minus circuits in the FM chassis. Also, if such a short is taking place, the voltage dropping resistor associated with the shorted condenser will become very hot and will probably smoke. Check the condenser associated with this hot resistor, and the trouble will be found. (See Fig. 5.)

Another common trouble similar to the previous one is characteristic of AM-FM receivers which use a common power supply, two separate tuning chasses, but in which the selector switch does not remove B-plus from the chassis not in use. If a by-pass condenser in the FM chassis shorts out, B-plus throughout the entire receiver will drop to a low value and neither the AM nor the FM circuits will deliver a signal. The tuning eye indicator will be dark and the rectifier plates will become red-hot on both functions. This, too, is technically a power supply trouble, but the trouble is in the FM chassis. The method used above, measuring the value of B-plus in its various branches throughout the receiver, and looking for a hot voltage dropping or de-coupling resistor, will readily reveal the defective by-pass condenser. Findings can then be finally confirmed by the use of the ohmmeter with receiver power turned off. (See Fig. 6.)

Note that the signal, in this case, is absent in both the AM and FM positions of the selector switch. If a phonograph is also used in the system, it, too, will not be heard at the speaker. This is because B-plus, permanently connected to all branches of the system, will drop to a very low value, and this will include B-plus in the audio section.

Absence of the FM signal, when B-plus is normal throughout the entire receiver, may be most readily traced to the limiter, discriminator, or ratio detector stages. In the limiter circuit, as indicated in Fig. 7, the FM signal can be lost by an open primary

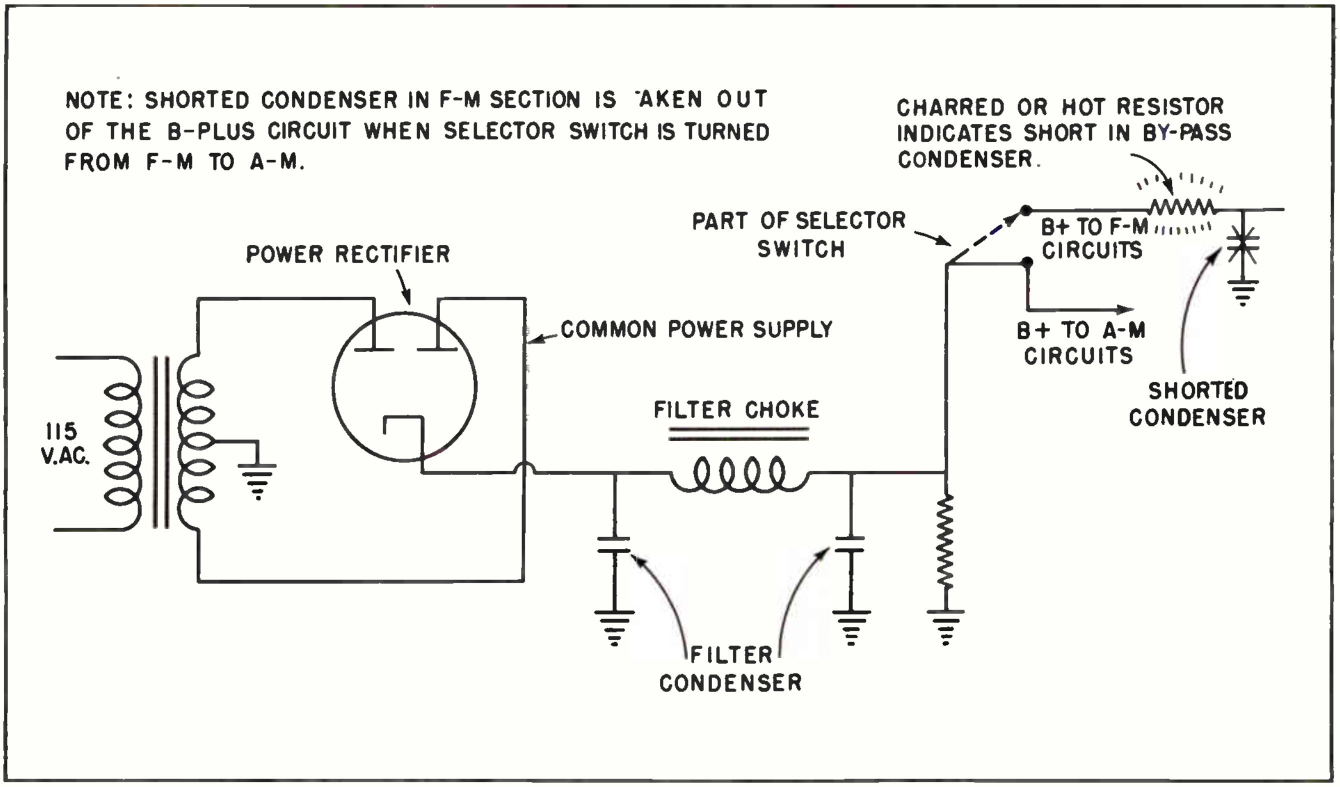


Fig.5. How a Power Supply Trouble Located in the FM Section of the AM-FM System Will Affect the Operation of FM Only.

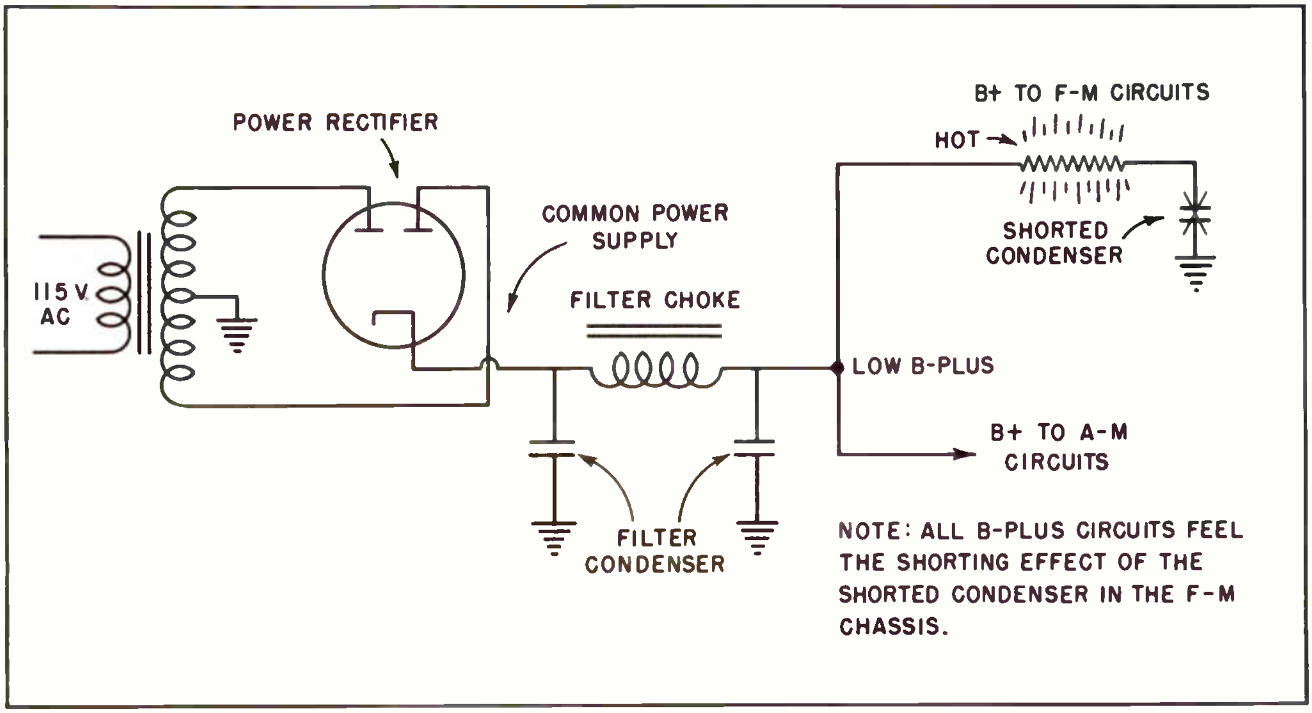


Fig.6. Where B-plus is Permanently Fed to Both the AM and FM Circuits, a Short in the FM Components Will Prevent the AM Signal From Coming Through.

or secondary transformer winding, or by short circuits in the trimming condensers. If these windings are inductance-tuned, shorts across the fixed condensers would result in the absence of the signal.

In all such cases, except a direct or partial short across the B-plus circuits to ground, the value of B-plus will be normal, or even slightly higher than normal. A voltage slightly higher than normal will be the consequence of a grid winding being open, or a plate winding being open. In the former instance, an open grid winding would result in the blocking of the stage; in the latter case, an open plate winding, no current would flow in the plate circuit. In either case the stage would draw no plate current and the drain from the power supply would be decreased sufficiently to cause a lower drop in the filtering networks. A lower drop in these components results in a slightly excessive value of B-plus.

A certain indication of an open limiter stage plate winding is indicated by the diagram of Fig. 8. If B-plus is absent at the limiter plate, but present at the limiter screen grid, an open plate winding should be suspected and can be readily confirmed by an ohmmeter check. If B-plus is normal throughout the remainder of the receiver, but absent at *both* the plate and screen, then the voltage-dropping resistor to these elements may be open. Note that limiter plate and screen voltages are set at a low value to effect the required limiting action.

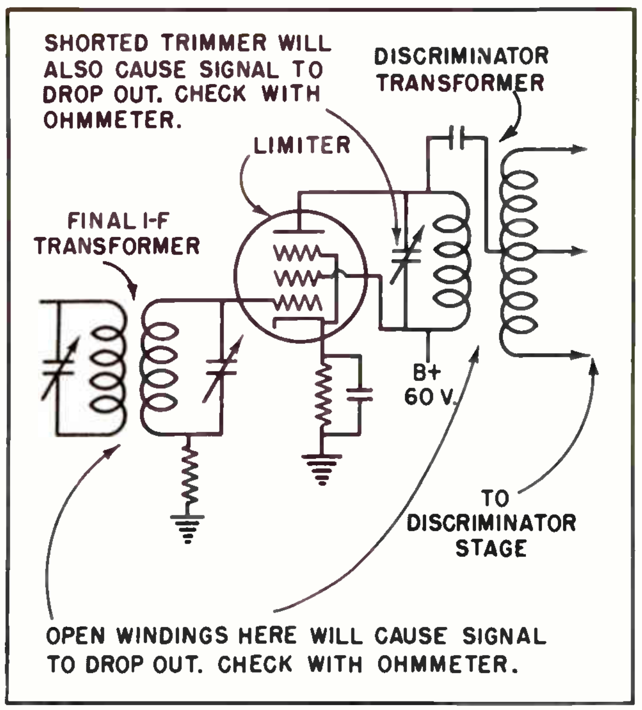


Fig.7. Distinguishing Between the Possible Causes of the Total Loss of the FM Signal, by the Use of the Ohmmeter.

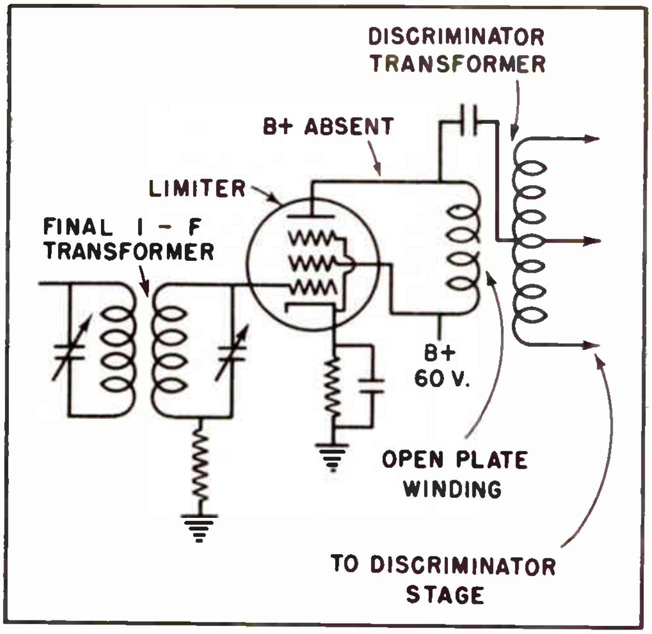


Fig.8. Checking With the Voltmeter for an Open Limiter Plate Winding.

Neither the plate nor the screen should read over 60 volts under *normal* conditions. The de-coupling capacitor shown in the diagram should also be checked for short circuit, since such a short could also account for the complete lack of both plate and screen voltage in the limiter stage.

Checking the condition of the limiter grid winding may most readily be done by the use of an ohmmeter, with power in the receiver turned off. Ohmic resistance should not exceed 10 ohms in a winding which is intact.

Discriminator troubles generally center around the discriminator tube itself. In AC-DC powered AM-FM receivers this tube is usually a 12AL5 or part of a multiple-purpose 19T8. In A-C powered AM-FM receivers, the discriminator is often a 6AL5 or part of a 6T8. In all cases of discriminator troubles -- to be suspected when the system is inoperate on FM only -- the discriminator tube should be very carefully checked for shorts, leakage, and emission on all of its sections.

If the tube is known to be in good condition the ohmmeter and voltmeter may then be brought into play to determine the exact nature of the circuit trouble. Fig. 9 indicates the findings of these test instruments

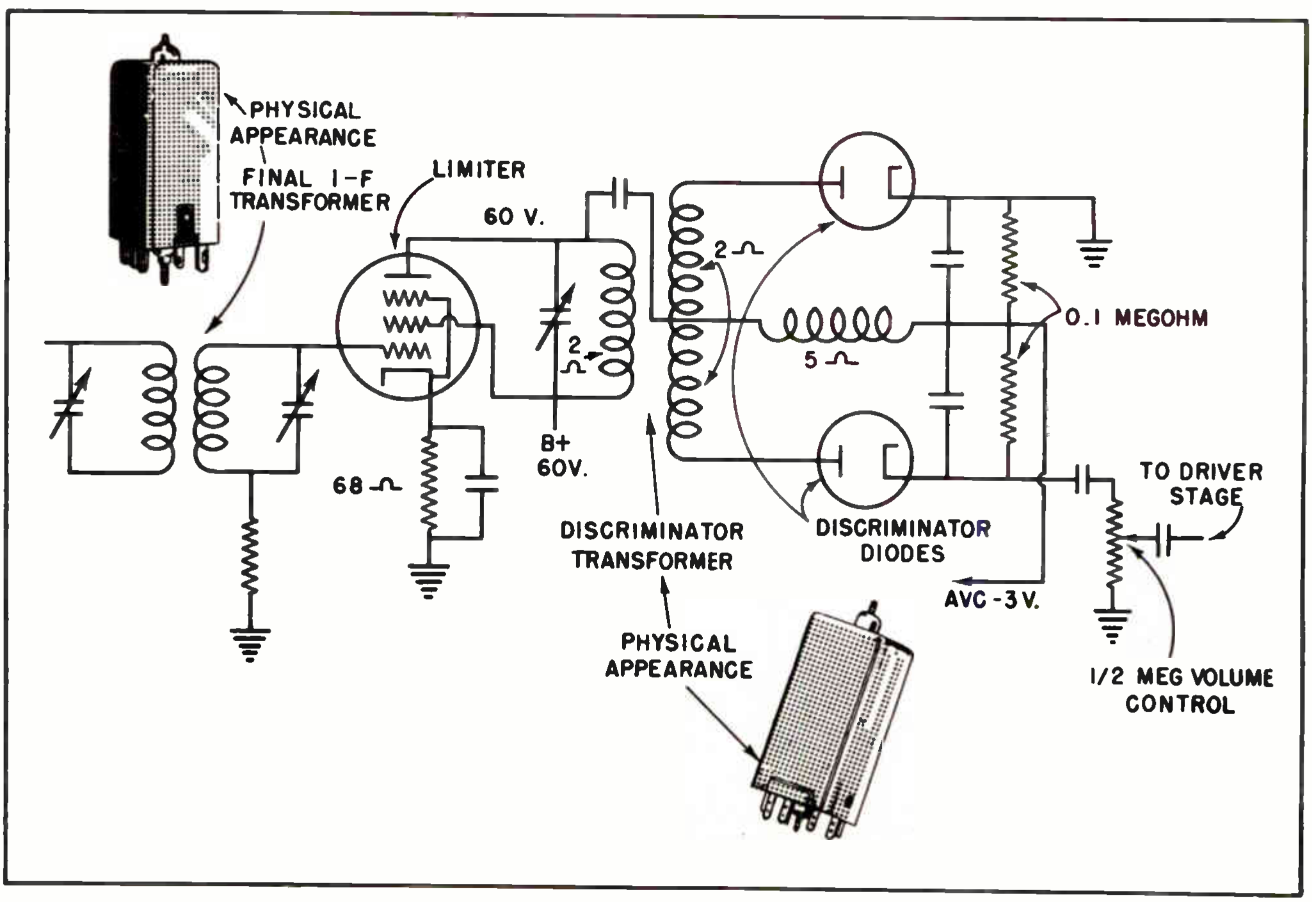


Fig.9. Check Data for the Discriminator and Associated Input Components.

in the normally-operating discriminator stage. The ohmmeter tests for continuity in the discriminator transformer windings are identical with those of the limiter stage, with the exception of the center-tapped secondary. The primary winding of this transformer is the plate load of the limiter.

Ratio detector troubles most often spring from defective tubes, which are identical with those of the discriminator for any given type of power supply. Careful checking of the ratio detector diodes is essential, and replacements should be made where necessary. After the tubes are known to be in good condition, test instrument analysis may proceed on the circuit components. The discriminating transformer (used in both the discriminator stage previously discussed and the ratio detector) is subject to the faults common to all such transformers: open primary and secondary windings, shorted condensers across the coils and shorted or open by-pass condensers.

Particular attention should be directed toward the screen and plate supply circuits in the primary of the transformer. As indicated in Fig. 10, B-plus at the plate and screen of the last I-F stage, in contrast to those found in the limiter, are normally high. In A-C receivers, plate and screens are rated at very close to 300 volts, while in the AC-DC receiver these values are reduced to approximately 100 D-C volts.

A fruitful policy for any type of electronic servicing is that complicated test set-ups should be used only where necessary. Where the job can be done *effectively* by a simpler method, the more direct and simpler method should be used. It must be remembered, however, that in some cases the use of test equipment is essential. The ability to use and improvise special test equipment for a given case builds confidence in the technician, making him feel the full confidence which comes only with knowledge and experience.

Section 7. **WEAK FM SIGNALS**

If signals are below normal volume, but otherwise tunable and clear, on both AM and FM, it is an indication of trouble in the audio section. This is because the audio section is common to both functions. Major causes under this heading are open audio coupling condensers and defective audio amplifier or power rectifier tubes.

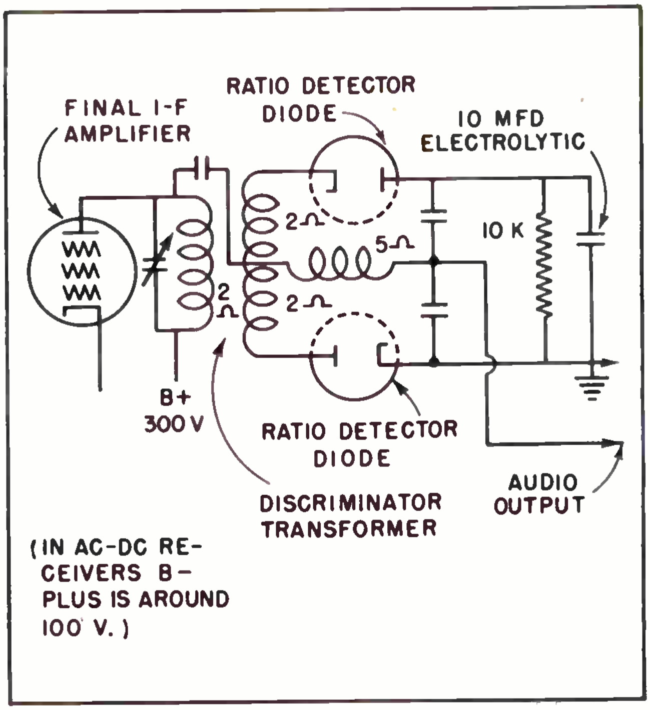


Fig.10. Check Data for the Ratio Detector Stage. Note the Absence of the Limiter Stage.

If, however, the FM signal *only* is below normal volume, a sharply different approach is necessary. After checking every tube used for FM reception, and replacing those found to be defective, if the signal is still below normal volume on FM *only*, the FM circuit components themselves must be checked.

Primarily responsible for low FM signal volume are antenna troubles. These include: omission of the FM antenna, loose connections to the FM antenna binding posts, too short an antenna, and improper orientation of the antenna.

In the console type of AM-FM receiver the AM circuits are usually fed by a loop antenna which is mounted within the cabinet so that it may be physically oriented for best reception from most of the local stations. The loop is connected to the RF input of the chassis by means of two wires connected to a pair of binding posts.

In FM, this practice is seldom followed. Instead, the usual procedure is to split a piece of two-wire transmission line along its length, fold over the split ends, and fasten the opposite ends to a pair of binding posts on the chassis connected to the FM RF input circuit. This arrangement is shown in Fig. 11. In most cases this is satis-

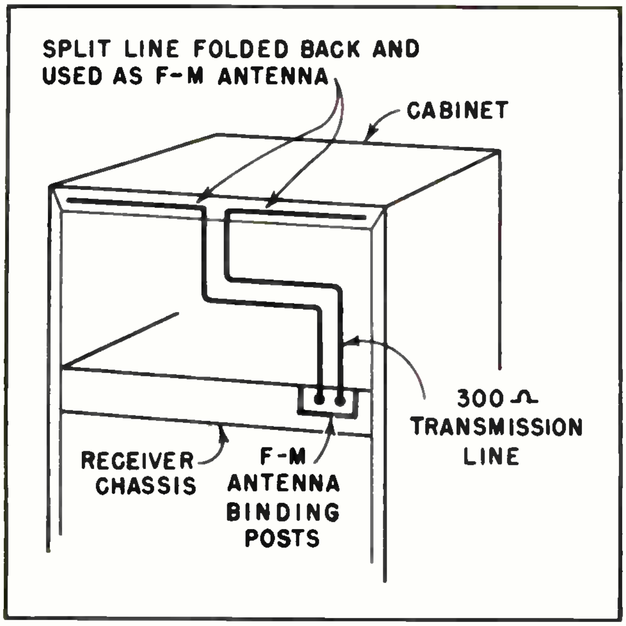


Fig.11. Improvising a Piece of 300-Ohm Transmission Line as a Suitable FM Antenna. This is a Common Practice in the Console Type AM-FM Receiver.

factory for practically all stations in a given locality. There are exceptions, of course. Among these are those installations where signal strength is low, including areas surrounded by steel and building structures, and the so-called "fringe areas". In cases of this type, the remedy for weak reception is to mount the antenna out-of-doors and as high as possible. Special FM antennas, very similar to those used for television receivers, are available for this specific purpose. A certain amount of experimenting with antenna positioning is often helpful in bringing in stations whose signals are attenuated.

The transmission line is usually of the 300-ohm type, which is now standard for both FM and television lead-in purposes. Care should be taken in connecting the FM lead-in line to the set, making certain that it is connected to the "FM" pair of binding posts, that the wires are firmly attached, and that no shorts occur across the binding posts. (See Fig. 12.)

Another reason for low volume FM signals is the lack of correct alignment in the I-F tuned stages. While these stages are necessarily wide in their band-pass response, a misalignment of their tuned circuits may result in a clear, but weak, signal.

The I-F band-pass characteristics are inherently wide, due to the high frequencies they carry. In addition, the band-pass is often made even wider by the use of damping resistors placed across the resonant intermediate components. Such an arrangement is shown in Fig. 13. Fig. 13 illustrates how the "Q" of an I-F tuned circuit is lowered, and its band-pass deliberately widened, by the addition of pure resistance. This technique serves to increase the tone response of the overall system and virtually eliminates distortion due to side-band suppression.

In order to compensate for the loss in gain due to the band-pass widening, it is essential that the I-F resonant circuits themselves be properly set. This is a matter of alignment technique and is best

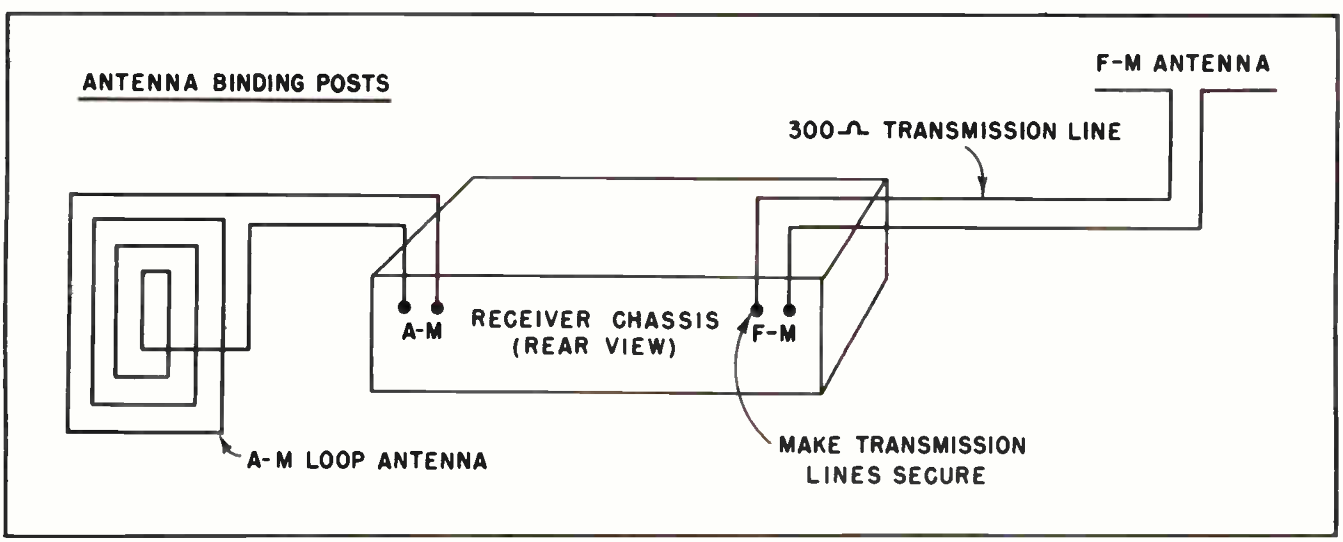


Fig.12. Care Should be Taken in Securing the FM Antenna Connections.

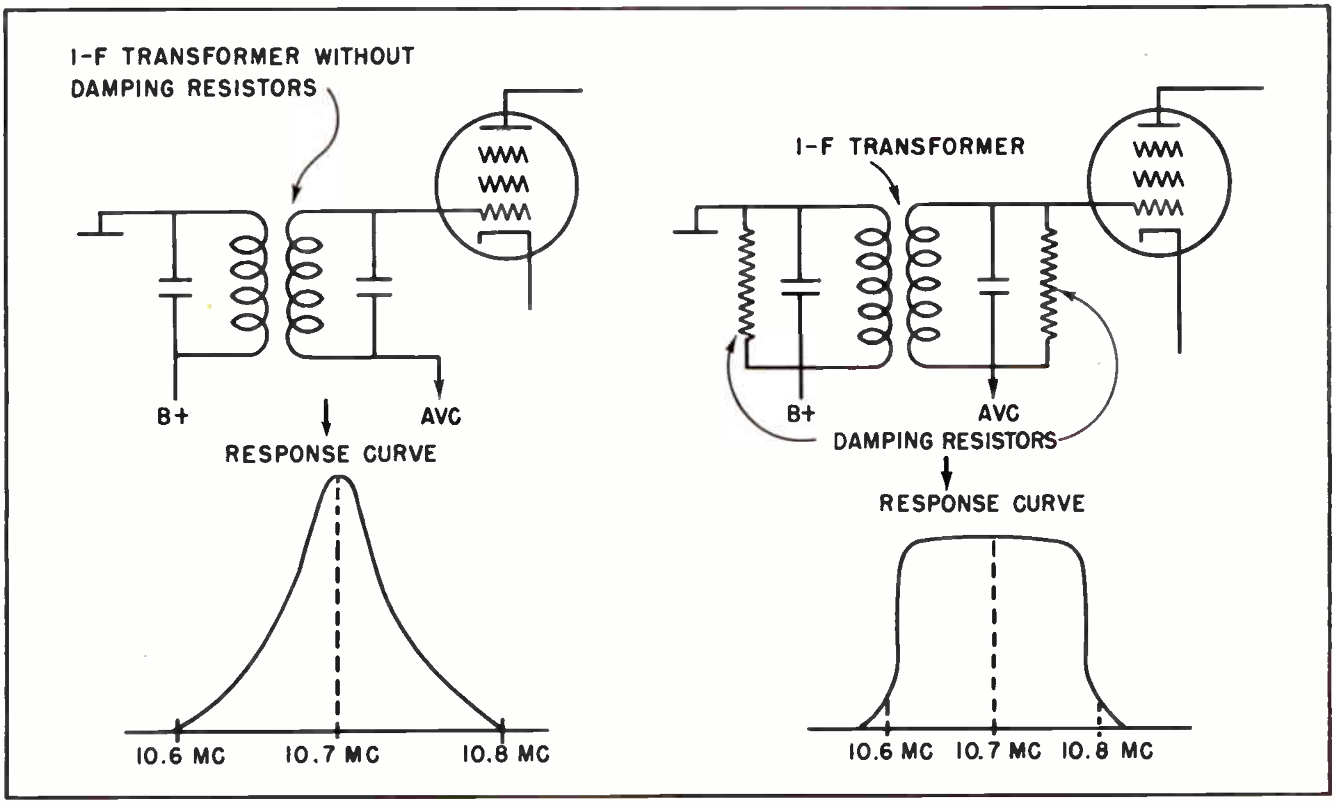


Fig. 13. How Damping or Loading Resistors Widen the I-F Band-width for Superior Overall Tone Response of the FM Circuits.

accomplished during the FM alignment procedure with adequate test equipment. While this procedure is applied to the I-F stages at the factory, and drifts are negligible over long periods of time, the alignment of these circuits often is the answer to weak signals in an FM receiver.

Section 8. NOISE AND HISSING

Noise interference in an FM receiver is generally accompanied by weak signals, since the presence of strong signals, in FM as well as in AM, is the best guarantee against such interference. This, as we know, is due to the assistance of the AVC circuit in suppressing noise during reception of a strong signal. If noise is present on FM *only* while the signal is weak or when the tuning dial is set at a point between stations, tuning in a strong station or correcting the cause of weak signals will reduce noise interference.

If the noise is present on FM only, even while a station is brought in with what appears to be normal volume, then trouble in the AVC circuit is indicated. In those FM circuits employing the limiter-discriminator combination, AVC originates in one of two places: the limiter grid resistor, or the center-tap of the discriminator transformer secondary. In either case, the AVC voltage may be measured at the grid of any I-F amplifier, and should read approximately 3 volts (negative with respect to common ground), in the presence of a strong signal. If this circuit is shorted to ground, as, for instance, when the AVC audio by-pass condenser shorts out, the reading will be zero with or without a signal, and the AVC line will show direct continuity to common ground when measured with an ohmmeter. (See Fig. 14.)

The signal-to-noise ratio may also be reduced, resulting in more noise per unit of signal strength, by defects in the RF section of the receiver. These may include defective RF pre-amplifiers, imperfect band-switching contacts and misalignment of the RF tuned circuits. In these cases, in addition to increased noise, which takes on a "hissing" or "rushing" character, the signal strength will be below normal. Strong stations, however, may be brought in with what *appears* to be normal volume, provided the receiver volume control is sufficiently advanced. The user of the receiver, however, will soon notice that the volume control

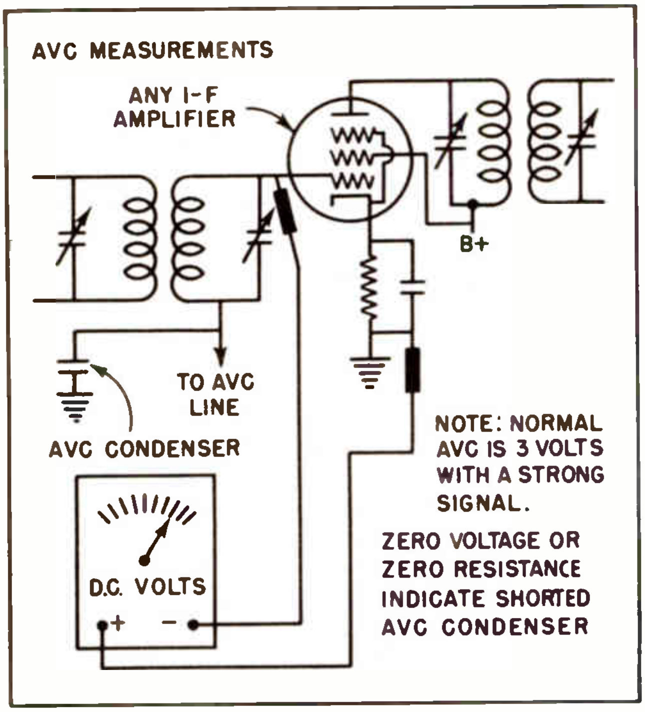


Fig.14. AVC Voltage May be Measured at Any of the I-F Amplifier Grids.

must be advanced abnormally far to bring in signals that formerly were loud enough with the volume control rather retarded for strong signals. This is obviously a defect, in spite of superficially satisfactory reception, and may be corrected under the heading of weak signals.

Section 9. **CROSS TALK**

Stations that interfere with normal FM reception are not as frequent as in AM. In AM one of the chief offenders in cross-talk (interference of the desired station by an undesired station) is often due to the phenomenon of "images". Due to the fact that there are *two* possible RF frequencies which can beat with an oscillator frequency to produce the I-F frequency, image interference in AM receivers may occur throughout the entire AM band, and depends mostly on the proximity of the receiver to the interfering station.

In FM there is an inherent difference, one that tends to practically eliminate images on the present FM band. Since this band begins at 88 megacycles and runs up through 108 megacycles, and since the FM intermediate frequencies are 10.7 megacycles, *no station on the band can come in as an interfering image*. Let us take as an example the lowest possible FM frequency, 88 mc. When the RF stages are tuned to 88 mc the local oscillator is automatically set at 88 plus 10.7, or at 98.7 mc. In order for a station to interfere as an image when the local oscillator of the receiver is tuned to 98.7 mc, the interfering station would have to be 10.7 mc above 98.7, or 109.4. But 109.4 mc is *above* the FM band, at least with respect to commercial FM stations. For any dial setting above 88 mc the interfering station would have to be correspondingly higher; that is, still further above the allotted commercial band. There may be FM stations of the non-broadcast type operating above the FM broadcast band. The Federal authorities in charge of allocating wavelengths are not rigorously bound to keep this portion of the FM spectrum free from interfering stations. However, in the public interest, the FM band is kept practically free from image interference.

Cross-talk in an FM receiver, then, is usually due to causes other than image interference. Among these are: misaligned I-F stages, interwiring interference, and lack of adequate shielding. Misaligned I-F stages, if caused by drifting of the capacity and inductance of the resonating components in the direction of identical I-F resonance in all of the intermediate stages, will almost always be accompanied by whistling or howling. The presence of a series of resonant stages, all tuned to exactly the same frequency, will produce a complex series of beat frequencies. Of these, or of the harmonics of these, there will be some which will beat with the incoming signal to produce a frequency close to the 10.7 mc I-F value.

Under these conditions, mixing may take place in any stage, and FM carriers may easily be picked up by the stray wiring between stages. The result is that in addition to cross-talk, audible beats in the form of whistling, howls, and general oscillations may readily take place. The correction for this condition, as may be expected, is the staggered tuning of the I-F stages, and can best be done with test equipment. If desired, a trial adjustment of the I-F trimmers may be made, with the precaution that they should not be turned too far; then the results should be checked.

Interwiring interference and lack of shielding are practically synonomous, and they produce the same undesirable results. The FM receiver circuit designer and manufacturer takes special pains to place the high frequency components, lead wires, and

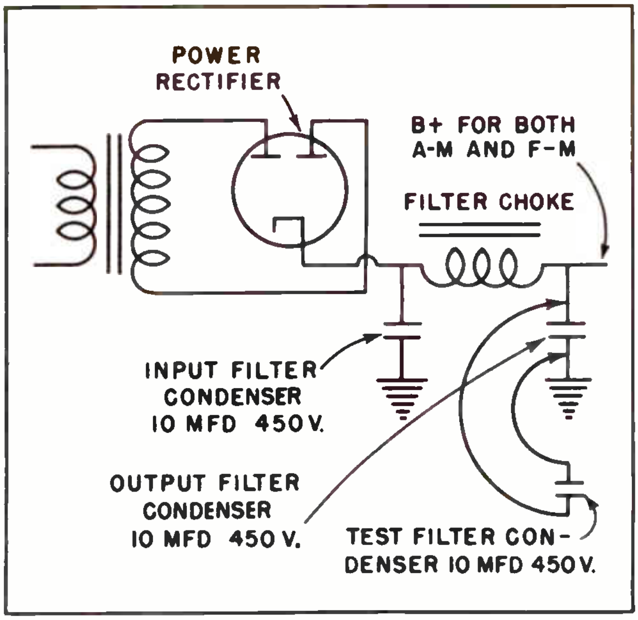


Fig. 15. Checking a Likely Probability for the Presence of Motor-boating in a Receiver.

shields in positions which minimize induced voltages from one circuit to another. In addition, by-passing and de-coupling are a required technique at the FM frequencies. However, certain defects in shielding, and feed-back, may occur. If, in servicing an FM receiver, a pair of wires are moved from their original position and cross-talk, whistling, or howling takes place after the job is completed, then the technician should return all wires to their former position, positioning them as accurately as possible. Shields over tubes, transformers, and between coils should all be replaced and firmly connected to ground. FM, as in television, employing the very high frequencies, contains critically tuned circuits in close association with each other. At the very high frequencies which are used, every precaution must be taken to avoid regeneration and feed-back in the RF, oscillator, and I-F circuits. This, of course, includes the limiter, discriminator, and ratio detector as well.

Section 10. **MOTOR-BOATING**

As in the AM receiver, motor-boating in FM is most commonly caused by an open or deteriorated output filter condenser. The first investigation in the case of motor-boating in an AM-FM receiver is to see if motor-boating takes place on both AM and FM, or whether it is peculiar to one or the other. If present on both, the chances are in favor of a defective output filter condenser in their common power supply. This may be readily verified by shunting the output filter with an equivalent and noting if the motor-boating disappears. This is shown in Fig. 15.

If the motor-boating is present on FM only, this does not *necessarily* rule out the possibility of an open or defective output filter condenser. This is shown by the circuit of Fig. 16. Note that the power supply contains *three filter* condensers. The first two, C-1 and C-2, are standard and are used for both the AM and FM portions of the set. However, C-3 is used for the FM circuits only, in spite of the fact that it is permanently connected to the power supply. If this condenser opens, or deteriorates below a critical value of capacity, it will cause motor-boating. This will be evident on FM only. This is because of the fact that while the selector switch is on AM the FM audio signal is not delivered to the driver grid.

Other causes of motor-boating in the FM circuits are open de-coupling condensers. Where motor-boating cannot be traced to open output filter condensers of the power supply, all plate and screen by-passing condensers should be tested for defects by shunting each with a test condenser which is equivalent in mfd and voltage rating. The

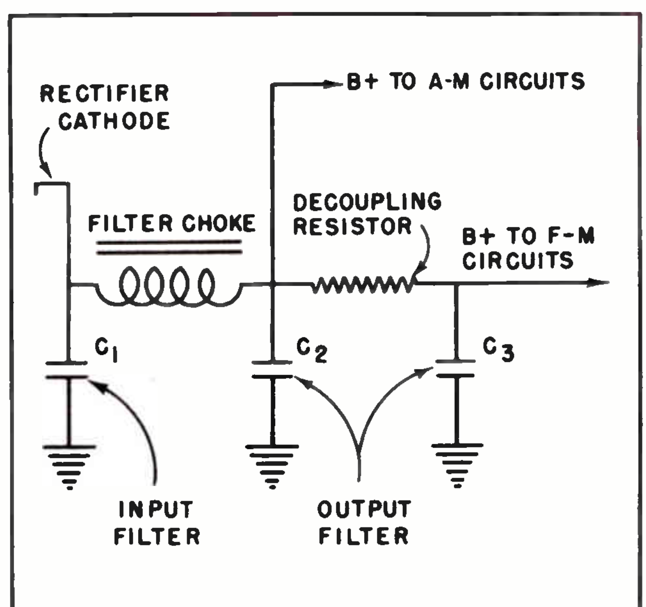


Fig. 16. If the Second Output Filter, Used Only on FM, is Open or Deteriorated, Hum Interference Would be Present on FM but not on AM.

open by-pass condenser will reveal its presence when the test condenser shunting it causes the symptom of motor-boating to disappear.

Section 11. HUM INTERFERENCE

If the signal is accompanied by 60- or 120-cycle hum interference on both AM and FM, notice if the hum drops out as the manual volume control is turned completely counter-clockwise, in *both* positions of the AM-FM function switch. If it does not drop out, trouble is indicated in the filter condensers of their common power supply. If the hum drops out when the volume control is retarded, two possibilities present themselves.

The first is an open line filter condenser, usually 0.1 mfd which is placed directly across the input power line beneath the chassis. If this component is open, a 60-cycle hum will be present with the signal, and will be most noticeable when certain, but not all, stations are tuned in. This is called a modulation-hum, or line-hum, and is removed by replacing the condenser mentioned. This is not an FM trouble.

The other possibility for hum interference on both the AM and FM positions of the function switch is an open I-F or RF winding (which under normal conditions is used to leak off excess electrons from grid to ground) will not completely block the stage, but will, instead, cause it to motor-boat at approximately a 60-cycle rate. To locate the offending open grid winding, measure the AVC voltage at all of the control grids in the RF and I-F stages, while a strong signal is tuned in.

If a standard 1000-ohm-per-volt meter is used for the above test, the hum will disappear when the meter is placed across the defective grid winding. This, as we know, is due to the fact that the resistance of the meter serves as a path for excess electrons and removes the symptom while providing such a path. Fig. 17 shows why the hum due to this cause will occur on both AM and FM. On the other hand, if the hum is present *only on FM* a different approach

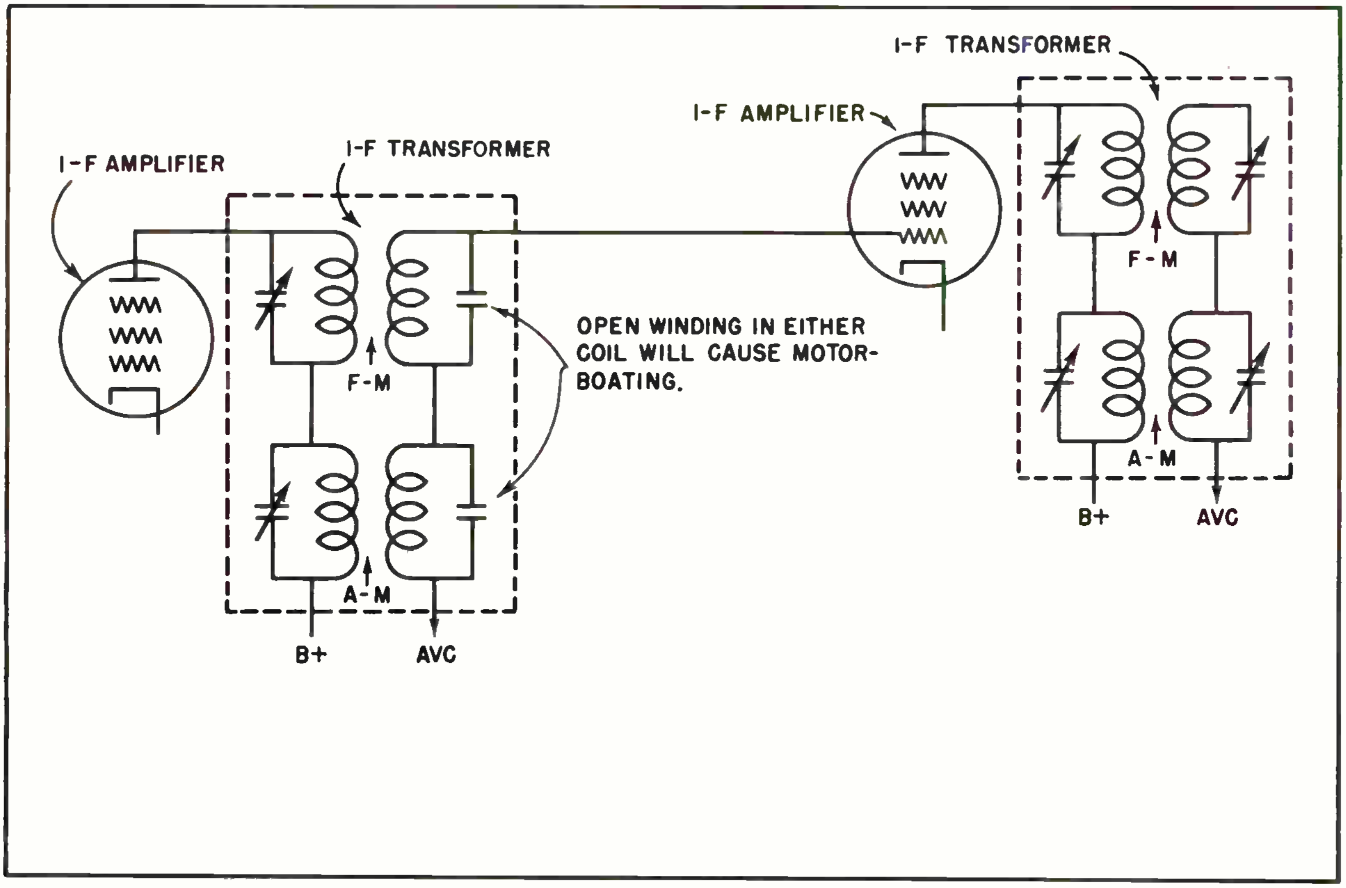


Fig.17. An Open AM or FM Winding in This Modern I-F Transformer Would Suppress the Signal on Both AM and FM.

to the trouble is taken, where again two possibilities suggest themselves.

The first is a defective FM output filter condenser, exactly as previously illustrated in Fig. 16. The only difference between a filter condenser which causes motor-boating and one which causes hum is in the *degree* of deterioration. If practically all of the capacity is lost, motor-boating will occur. If a substantial capacity remains, say 2 or 3 mfd, then the system will not motor-boat, but the capacity is still not sufficient to oppose successfully the voltage changes in the power supply, and a hum results. The correction is to replace the condenser.

A purely FM trouble may also cause an interfering hum when stations are tuned in. It will also be noticed that the amplitude of the hum at the speaker is adjustable by the volume control. The cause is a drifted or mis-aligned discriminator transformer, whether this transformer is present in a discriminator stage, or in a ratio detector stage. Here the remedy is easily accomplished by ear. Tune in a strong station which brings a strong hum along with it. First adjust the primary of the discriminator transformer, and then the secondary, in whichever direction necessary, until the hum disappears. Try several other strong stations. If these are hum-free, and the signal is not suffering from distortion or lack of volume, the job may be considered successful. Since the setting of the discriminator transformer tuned circuits is so critical, it only takes about an eighth of a turn on each winding to overcome a hum due to this cause.

Section 12. TUNING DEFECTS

The inability of an FM receiver to tune in stations properly is primarily a matter of alignment of all of its tuned circuits. A mis-aligned RF stage, for example, will cause the signal to be weak, and can also account for a certain amount of distortion. If the oscillator does not track correctly stations will come in at the wrong place on the dial. Mis-aligned I-F stages have a family of symptoms all their own. In view of this, we present the FM alignment procedure as a corrective measure to insure correct tuning of the FM receiver circuits.

Section 13. ALIGNING THE FM CIRCUITS

Alignment procedure for FM receiving circuits follows the general plan employed

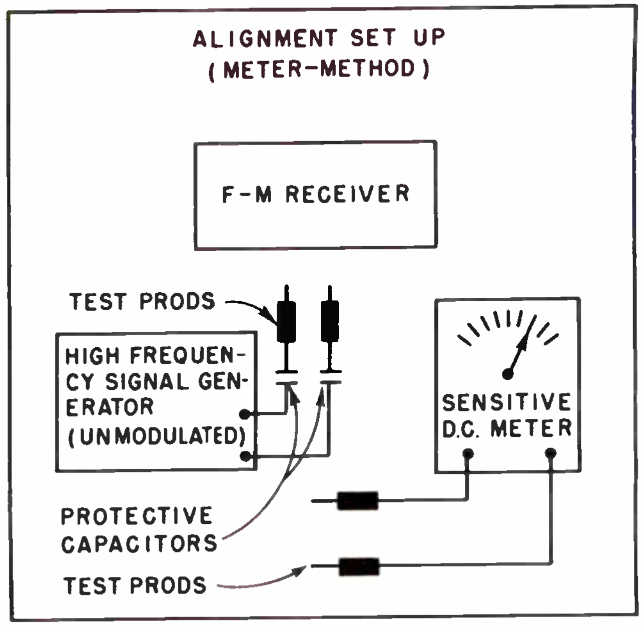


Fig.18. Test Equipment Set-Up for Alignment of FM Circuits by the Meter Method.

for AM circuits. An artificial signal is injected at various points in the circuits and is then monitored by suitable means after passing through certain sections of the receiver. This permits the technician to accomplish two separate, but related, processes: the receiver tuned circuits may be correctly aligned, and a defective stage may be isolated. A stage so isolated can then be examined in detail for the trouble and repaired before completing the alignment procedure. As in the case of AM, FM circuit alignment begins at the FM detector (a discriminator or a ratio detector) and progresses backward towards the antenna. This permits stage-by-stage adjustments and readily indicates a stage which is defective.

Section 14. THE METER METHOD

The most popular method of FM alignment is that using a good meter as an indicating monitor. This meter should be of the vacuum-tube type, or one with at least a 20,000-ohm-per-volt sensitivity.

Fig. 18 shows the equipment set up for the meter method of FM alignment. The signal generator shown in the Figure need not be an FM signal generator, contrary to first expectations, since it will be used without modulation. However, its range must be such as to include all of the frequencies in FM receiving circuits, namely the 80-108 mc band, and the FM intermediate band (about 10 mc.)

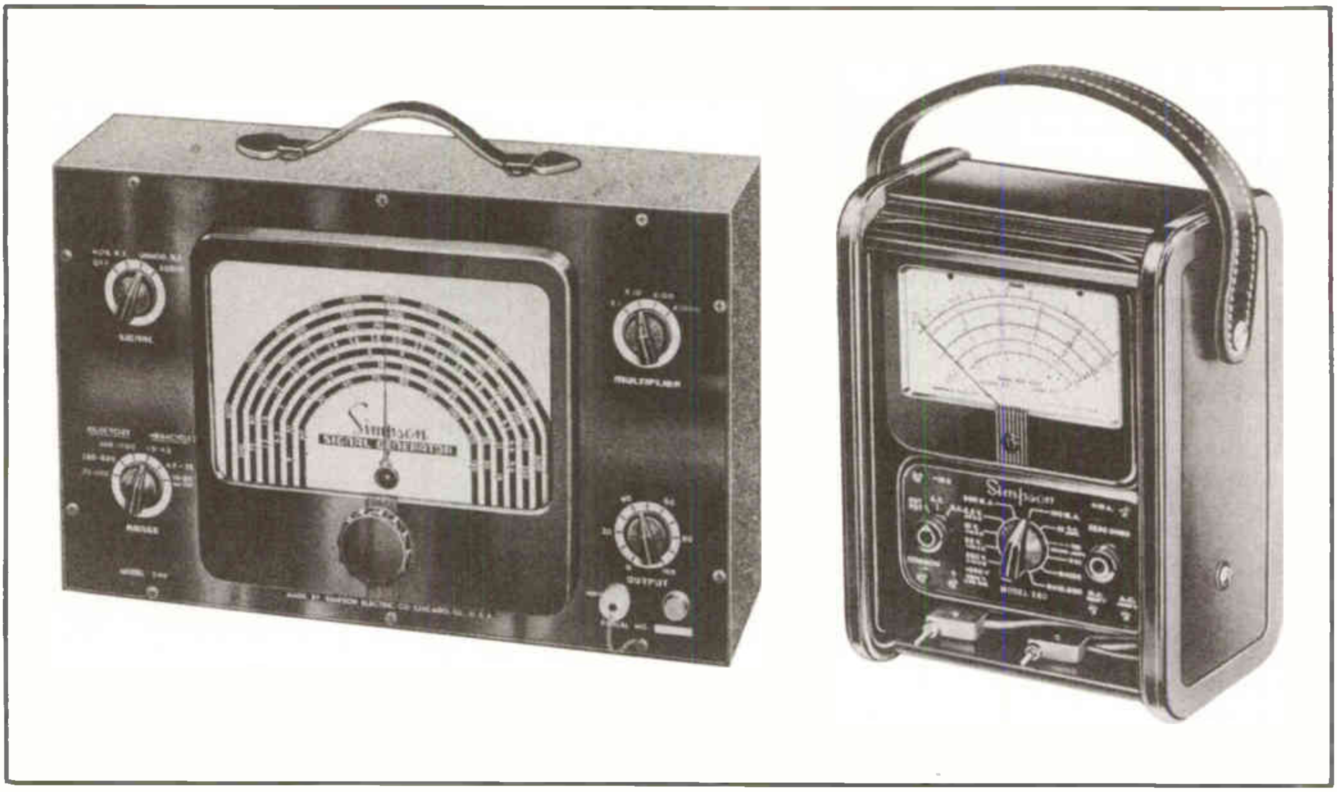


Fig.19. Modern Signal Generator and Sensitive Voltmeter Used for the Meter Method of FM Alignment.
(Courtesy Simpson Mfg. Co.)

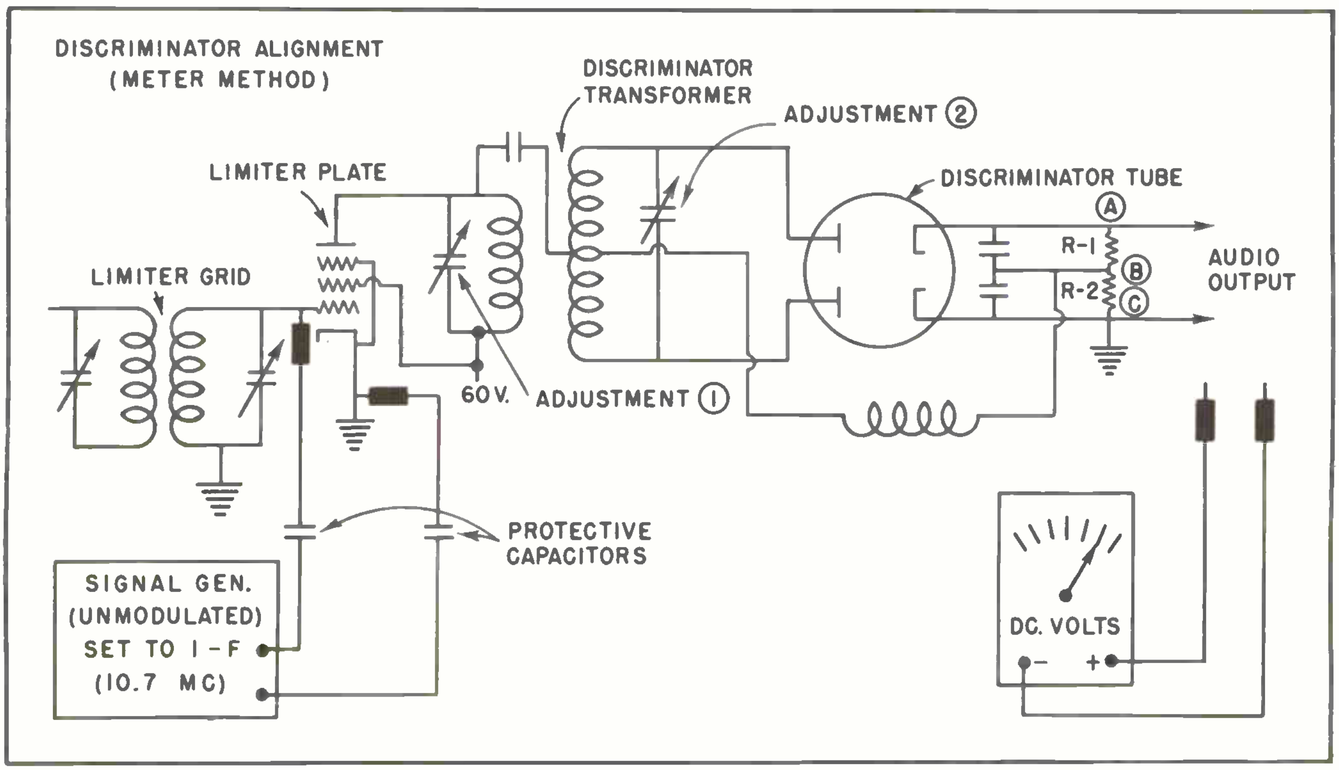


Fig.20. Aligning the Primary and Secondary of the Discriminator Transformer by the Meter Method.

The meter used is set to a medium scale of D-C voltage, and at any time may be altered for center-scale reading. Fig. 19 shows two modern Simpson alignment instruments that may be put to use in this procedure.

Preliminary steps of this procedure: check the audio stages by bringing in a signal on *AM*. Then set the selector switch for FM. Remove the FM antenna connections, and connect the test instruments as shown in Fig. 20. The signal generator frequency is set at the I-F value (usually 10.7 mc.) and is completely *unmodulated.*

either meter polarity, leaving the signal generator connected as previously.

Knowing that when the discriminator is correctly aligned at exactly the I-F frequency the net discriminator output is zero with a resting I-F carrier, we may now adjust the variable component in the secondary of the discriminator transformer for zero reading.

If the meter reads backwards before this adjustment, reverse the meter leads. Repeat both steps. The discriminator transformer is now properly adjusted.

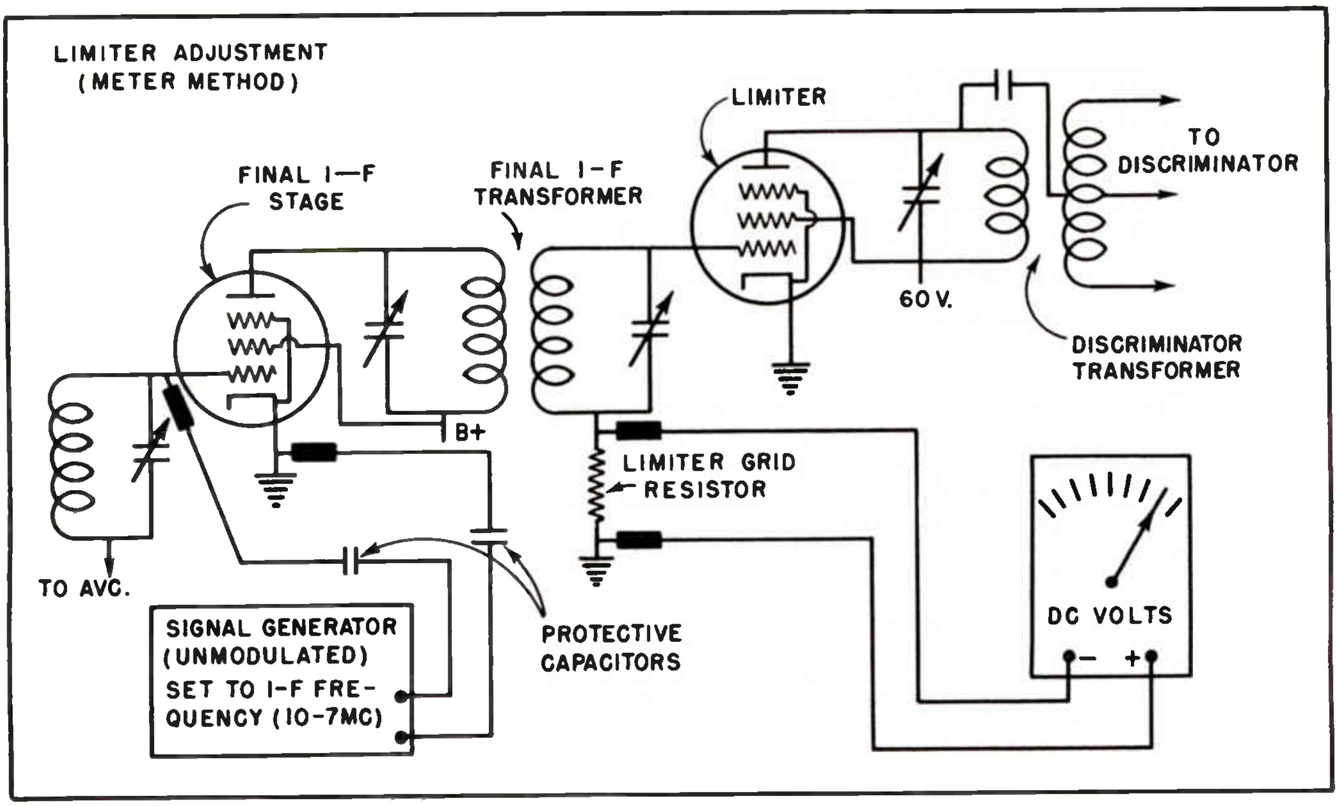


Fig.21. Location of Test Equipment Connection for Aligning the Limiter Circuits by the Meter Method.

Step 1. Place the negative lead of the voltmeter at point B of the discriminator load and the positive lead at either A or C. Adjust the discriminator *primary* resonance for maximum meter reading. (Either the capacity or the inductance in this transformer may be variable. Adjust whichever variable component is used.) During this test, the signal generator output may be set to give a convenient indication on the meter. This step aligns the discriminator primary at the I-F frequency.

Step 2. Place the meter leads across the entire discriminator load (across A to C) in

Step 3. This step aligns the limiter stage. Connect the test equipment as shown in Fig. 21. The signal generator is placed across the grid winding of the final I-F amplifier stage, and left with the I-F unmodulated output, 10.7 mc. The voltmeter is now placed across the limiter grid resistor, and will therefore read maximum voltage drop across this component when the strongest signal is applied to the grid. The meter polarity should be such that the end of the resistor toward the limiter grid is negative with respect to common ground, for this is the polarity of the voltage drop developed across this resistor. Now make the adjustment

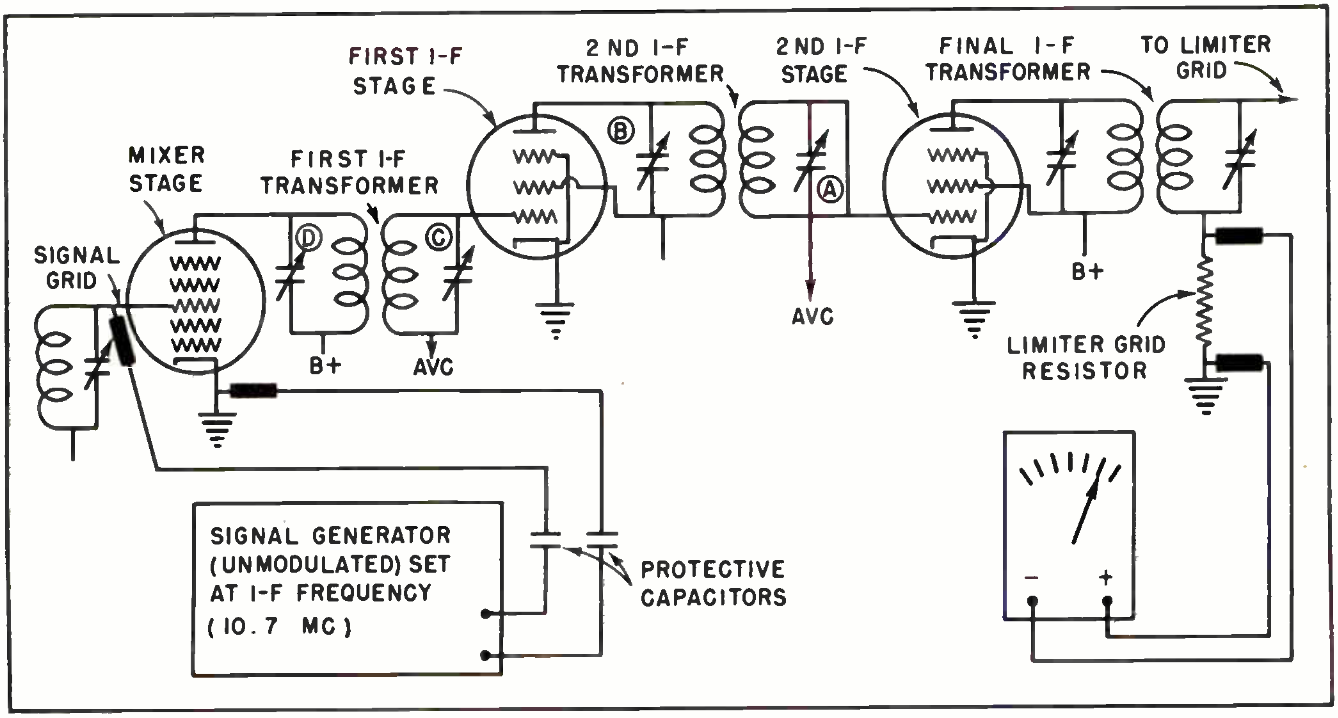


Fig.22. I-F Alignment by the Meter Method. Note the Indicating Voltmeter is Still Connected Across the Limiter Grid Resistor.

in the secondary of the final I-F transformer, seeking the maximum deflection of the meter. Next make the adjustment in the primary of the final I-F amplifier, also seeking the point of maximum meter reading. "Rock" the adjustments as they are made, to insure the exact setting. This aligns the final I-F transformer tuned circuits, including the limiter grid circuit. (The limiter plate circuit was adjusted previously.

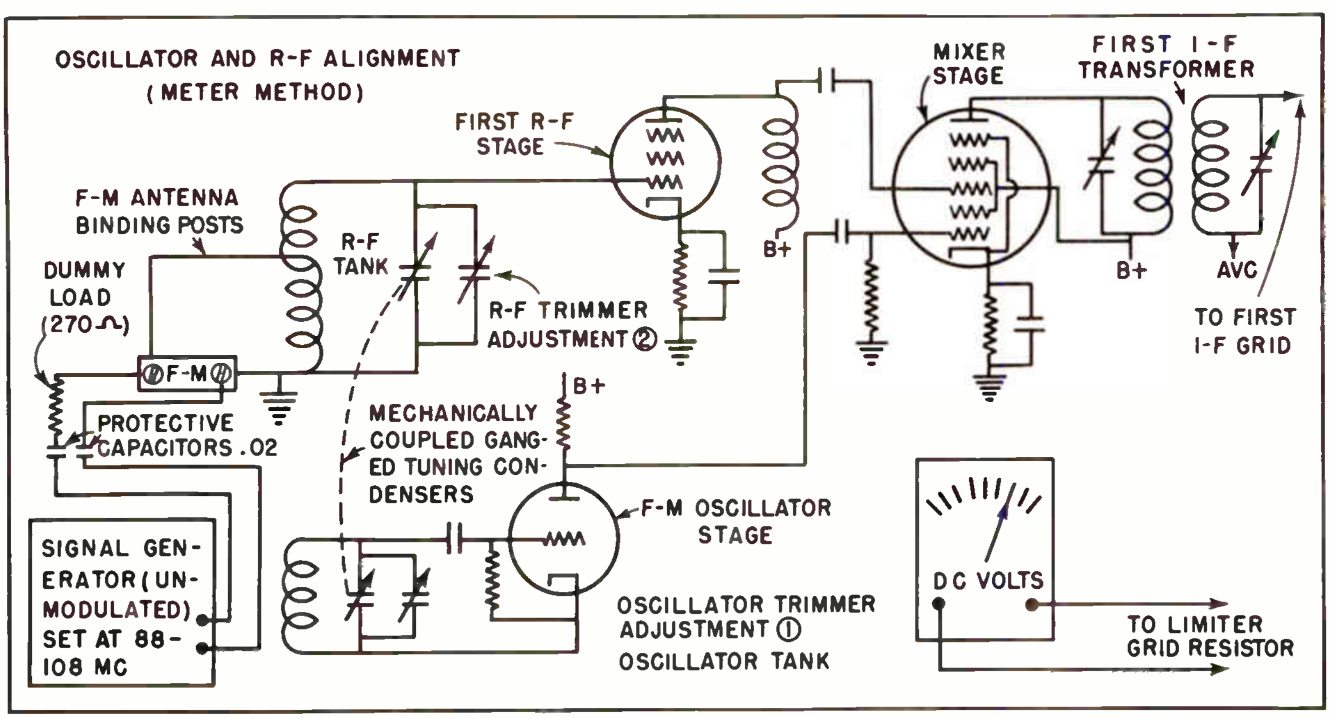


Fig.23. How the Dummy Load, Signal Generator, and Voltmeter are Connected for Oscillator and RF Alignment by the Meter Method.

Step 4. This step aligns the rest of the I-F tuned circuits, and is identical in technique to *Step 3*. The signal generator, as in Fig. 22, is now connected to the signal grid of the mixer stage, and is still without modulation. Its output is now being fed through the entire I-F system and its presence is indicated by the voltmeter placed, as before, across the limiter grid resistor. Make adjustments A, B, C, and D, in the order named, for maximum meter deflection, "rocking" each adjustment to insure the correct setting. Repeat this step again, in the same order. The entire I-F system is now aligned. (Previous steps have aligned the discriminator and limiter stages.)

in the diagram) for maximum deflection of the meter as the *FM tuning dial is set exactly at 107 mc*. "Rock" the trimmer adjustment to make sure that it is set at the correct point. Also, "rock" the tuning dial at 107 mc to assure correct alignment there, too, seeking maximum meter reading.

Now set the signal generator at a mid-point in the FM range, around 97 mc, and tune the FM dial of the receiver to the same value. If necessary, re-adjust the oscillator trimmer for maximum meter reading. If maximum reading occurs at 97 mc without re-adjustment, do not adjust. Next set the signal generator, and the FM tuning dial to

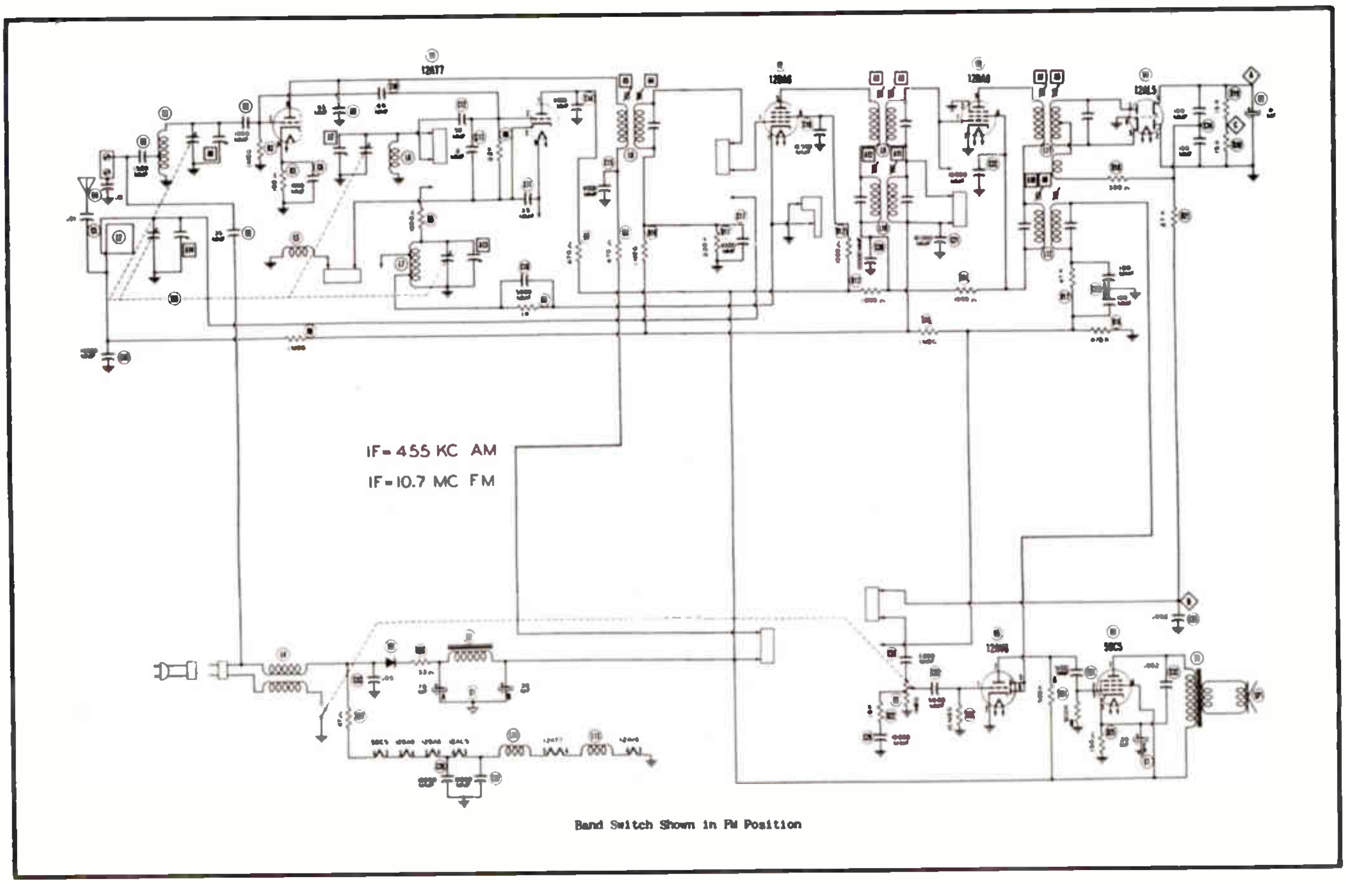


Fig.24. Full Schematic Diagram of a Table Model AM-FM Receiver. (Courtesy Admiral. Enlarged Figure Last Page.)

Step 5. We are now ready to align the oscillator tuned circuit. Leaving the D-C voltmeter connected across the limiter grid resistor, move the signal generator over to the antenna binding posts as shown in Fig.23. Set the signal generator (still unmodulated) at 107 mc, and use the "dummy-load" resistor of 270 ohms to match the signal generator to the FM antenna binding posts, as shown. Adjust the oscillator trimmer (adjustment 1 89 mc, checking for maximum reading when the signal generator setting coincides with the FM tuning dial. To double-check the alignment, repeat all three adjustments.

The oscillator is now aligned.

Step 6. This is the final step in the FM alignment procedure and consists of adjusting the RF tuned circuits. Both the signal

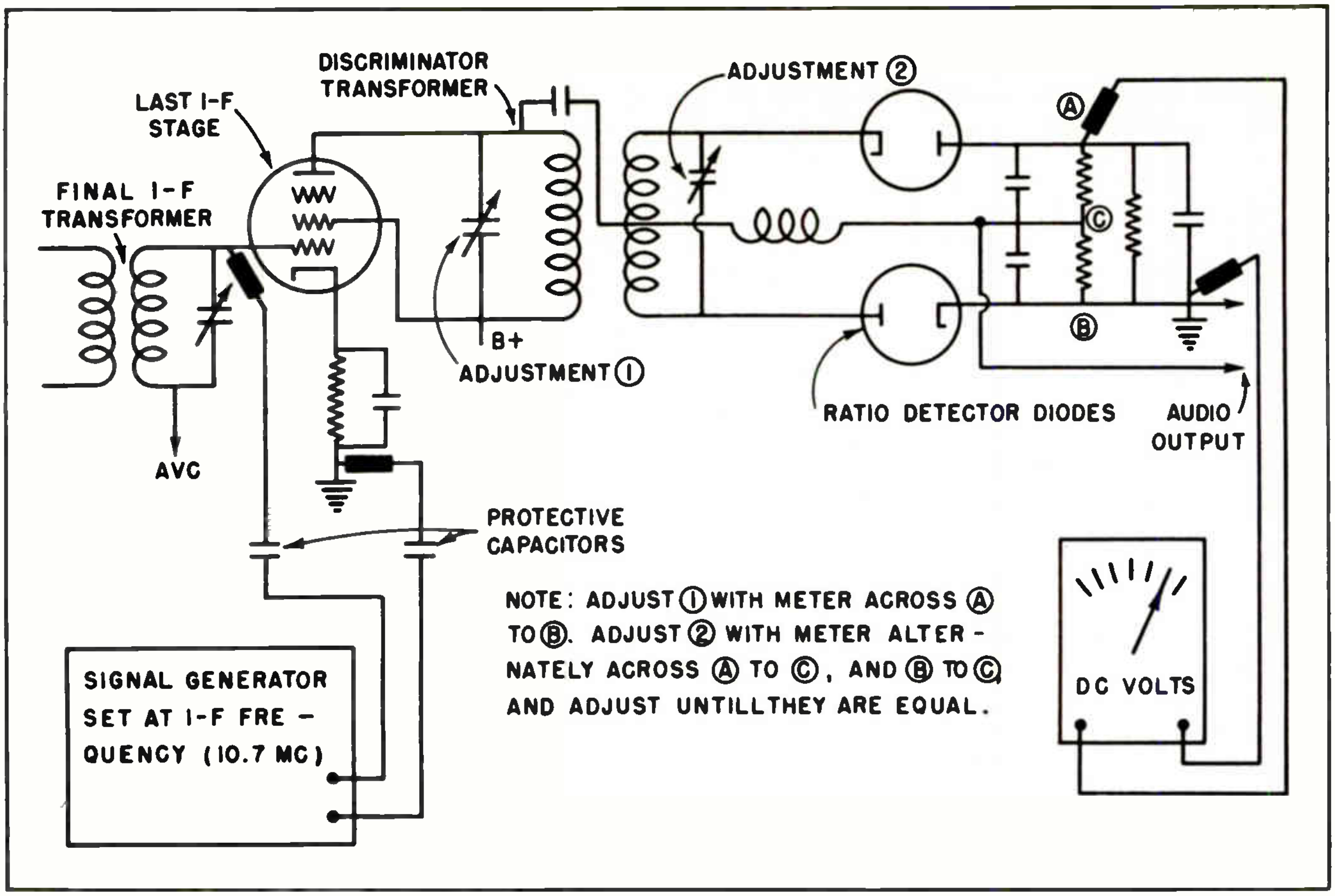


Fig.25. Alignment Procedure for the Ratio Detector by the Meter Method.

generator and meter are left with the same connections as in the previous step. Again setting the signal generator to 107 mc and the FM tuning dial to the same value, next adjust the RF trimmer (adjustment 2 in Fig. 23) for maximum meter reading. Repeat the procedure for settings of 97 and 89 mc on both the signal generator and the FM dial. Repeat all three adjustments. This completes the alignment procedure by the meter method.

Remove the signal generator and meter connections, re-connect the FM antenna (which was removed at the start of the procedure), and check results across the entire FM band by tuning in commercial FM stations.

General remarks on FM alignment. The meter method of aligning the FM circuits of a receiver is simple and easy to perform. Note that the only requirements are a sensitive voltmeter and a signal generator capable of producing FM frequencies. No modulation is employed at any part of the procedure, hence a special frequency-modulated signal generator, such as is shown in Fig. 19, is not needed for the method. The I-F stages are single-peaked, with the assurance that with the wide band-pass characteristics of their tuned circuits, it is only necessary to tune them to the resting I-F value.

In the diagram of Fig. 23 we have purposely simplified the circuit structure. In a complete circuit diagram, such as is shown in Fig. 24, the tuning components may vary. In I-F tuned circuits, for instance, the adjustments may be of the inductance rather than of the capacity. The various manufacturers use various methods with their various models. Also, in most FM receivers the inductance of the oscillator and RF coils are adjustable by squeezing the turns closer together by hand. This is in addition to the trimmer condenser adjustment.

Manufacturers' wiring diagrams of their FM products are replete with information on alignment and adjustment techniques for a given make and model number. The wiring diagram is, of course, the final authority on such procedures. In those FM circuits employing the ratio detector instead of the limiter-discriminator combination the alignment procedure differs only in the manner of reading the voltmeter during the discriminator transformer adjustments. Fig. 25 shows the connections for this step. The primary of the discriminator transformer is first adjusted for maximum deflection of the meter when placed across points A and B. The meter is then alternately placed across A to C, and B to C and the symmetry of the readings is ascertained while adjusting the discriminator transformer secondary.

From this point on, the alignment of the remainder of the tuned circuits follows that in the limiter-discriminator system, with the reasonable exception that the limiter, being absent in a receiver with a ratio detector, need not be adjusted, and the meter indicating correct maximum reading being connected across A to B of Fig. 25, rather than across the limiter grid resistor.

It is to be noted that modern FM receiver manufacturers, in addition to supplying information regarding the alignment of FM receivers by the meter method described above, also include data to perform the same alignment with the oscilloscope and an FM signal generator. Where this test equipment is available, the alignment procedure could be done equally well by both methods. Specific technique, however, differs with various manufacturers, but each supplies information to apply the "visual" method, and the types of 'scope patterns obtained throughout the procedure.

NOTES FOR REFERENCE

Servicing FM receivers is similar to servicing AM receivers, the alignment methods proceed in the same general manner for both.

FM receivers are seldom built as a separate unit. They are most frequently found in association with an AM receiver, a phonograph, or with both.

The FM portion of a combination AM-FM receiver is almost identical in nature with the sound channel of a television receiver.

The alignment procedure for FM tuned circuits may be applied to television sound channels with these specific differences:

A. In the television sound channel employing intercarrier sound modulation, the I-F frequency is 4.5 megacycles. The intercarrier system is explained in a later lesson.

B. In the separate television sound channel the I-F frequency is usually 22.1 megacycles.

C. In both cases a frequency discriminator circuit is used, which may also take the form of the ratio detector.

D. The RF frequencies for television are different from FM.

Except for the frequency values mentioned above, the alignment procedures are the same.

The overall performance of an AM-FM combination receiver is an excellent key to the source of the trouble.

In modern AM-FM radio receivers the RF and I-F stages employ the same tubes, as a rule, and often contain I-F transformers in which both the FM and AM windings are connected in series with each other.

Most FM troubles due to drifting of the tuned circuit components can usually be corrected by ear. In some cases, signal generating and indicating devices are required.

The simplest procedure for FM alignment uses a signal generator capable of generating FM frequencies, and a sensitive voltmeter. This is called the meter method of FM alignment.

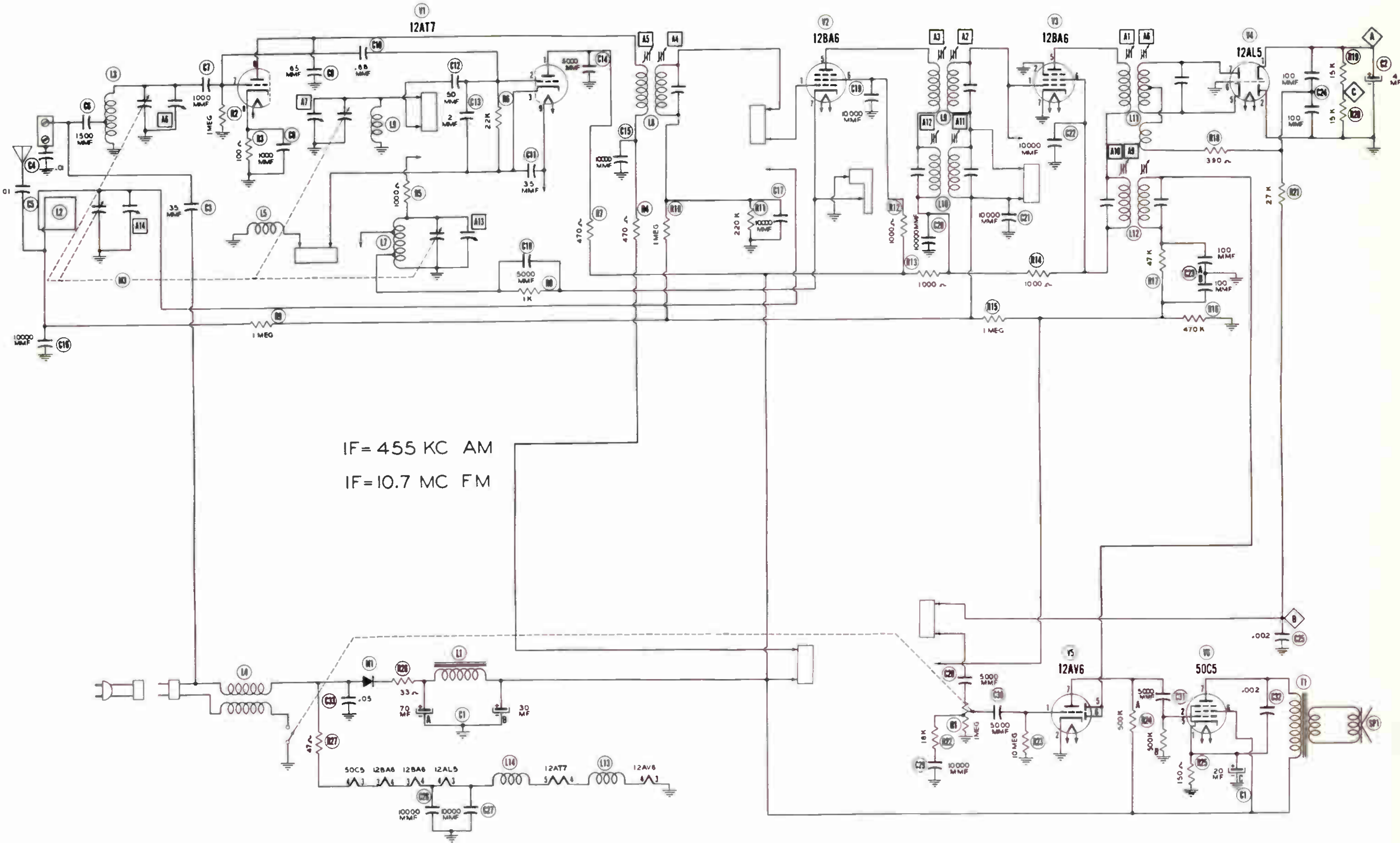
FM receivers may be also aligned by other test equipment, and manufacturers provide information in their wiring diagrams for the "visual method" as well as the meter method.

For specific alignment instructions on any given make and model of an FM receiver, consult the manufacturer's wiring diagram for that set.

Power supply troubles in the FM receiver may be approached in the same manner as in AM receivers. Voltage measurements at key points in the circuit, combined with observation and tests, are the best indicators of power supply troubles.

A common power supply trouble, in FM circuits, is a shorted screen by-pass or de-coupling capacitor. The abundance of these components in the FM receiver partially accounts for the frequency of short circuits across them. They generally reveal themselves in the form of charred or hot resistors, red-hot rectifier tube plates, and the partial or complete absence of B-plus in the receiver.

NOTES



Band Switch Shown in FM Position

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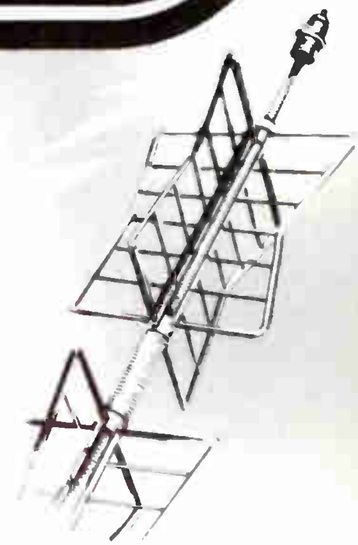

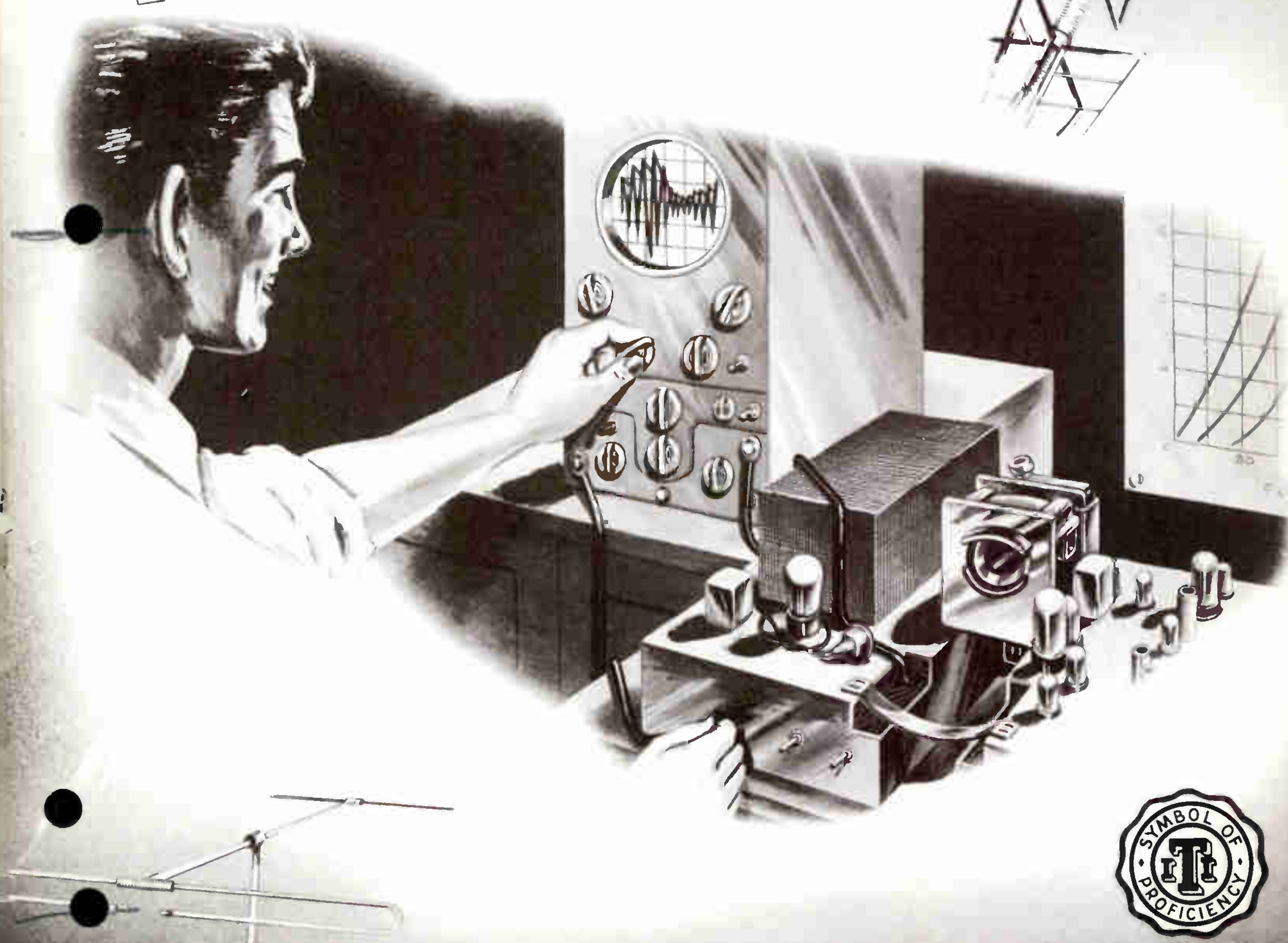

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RADIO TELEVISION

PRINCIPLES OF VIDEO TRANSMISSION

Contents: Introduction - Transmission of Video Signals - The TV Channel - Frequency Bands - Frequency Arrangement Within a TV Channel - How Television Differs from Radio - Why Such a Wide Channel is Needed for Television - Methods of Scanning - Persistence of Vision - Sidebands - Notes for Reference.

Section 1. INTRODUCTION

In our lessons up to this time we have learned many things about the transmission and reception of radio and television signals. Our attention has been directed toward those things which are common to the radiation and reception of both sound and video signals. There has been a good reason for this procedure. First, it is absolutely essential to understand the basic principles of radio before one can hope to understand the more complicated circuits which are peculiar to the transmission of video signals. Second, it is much easier to learn the principles of radio and television when our attention is directed to the relatively low frequencies employed in sound radio than it would be to attempt to learn the same principles when complicated by the more complex circuits and higher frequencies involved in video work.

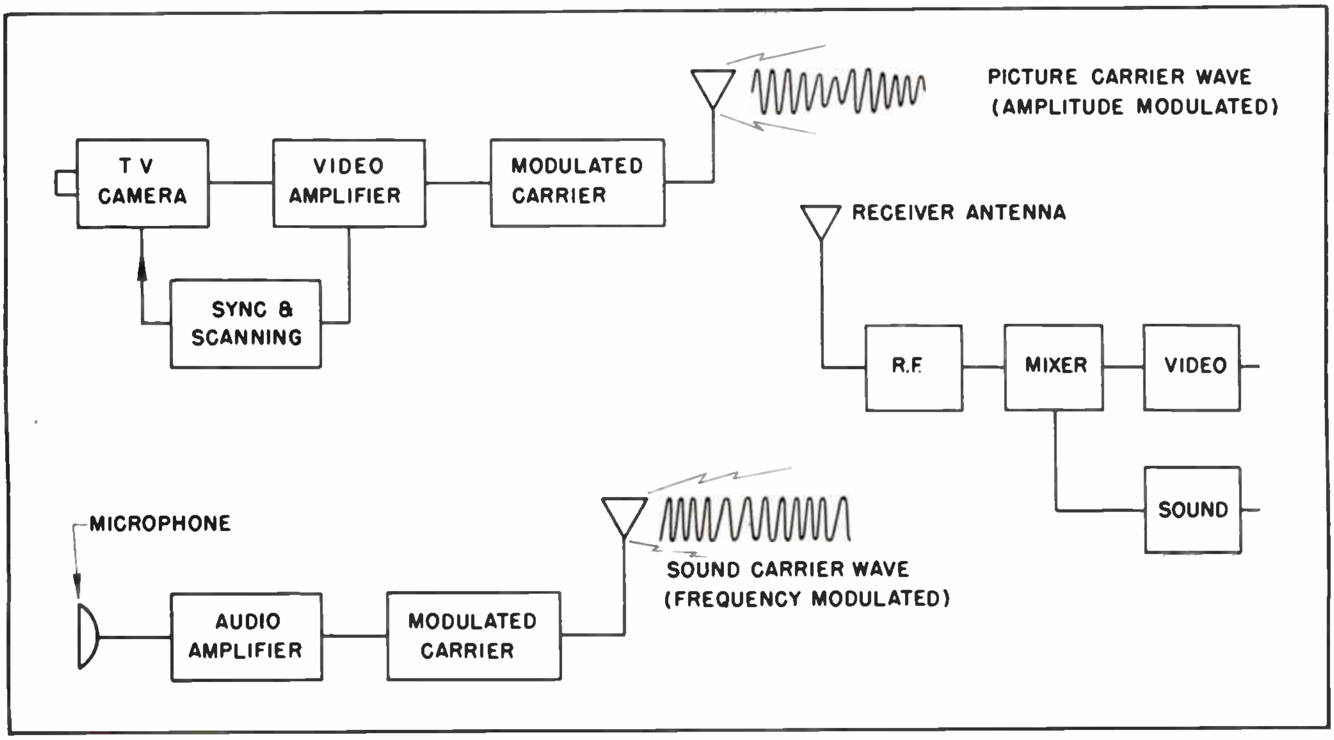

Fig. 1. Block Outline of a Television Station's Broadcast Transmitters.

But the time has now come when we must direct more of our attention to the higher frequencies used in video transmission, and to study the complex circuits which are a part of every television receiver. It is only fair to warn you that some of the lessons from this point onward will probably be a little more difficult than those lessons you have studied in the past. This is not to intimate that the future lessons are too hard for you. We know they are not. But because of the very nature of the subject, and because of the highly technical complexities involved, we know some of the material from here to the end of the course will have to be studied with care.

It is not out of place to mention another thing which is well worth your consideration. We have been very careful to keep our course as free as possible from unnecessary use of mathematics to describe the action of radio and television circuits and principles. We have succeeded in doing what many highly skilled radio and television engineers and technicians have said was impossible -- teach elementary radio and television without the use of mathematics.

In some of the lessons which are to follow, the technical nature of the circuits are such that a complete avoidance of mathematics is all but impossible. Some of the lessons will make use of somewhat more mathematical formulas than were used in the past. This does not mean that you should become uneasy about your ability to finish the course if your school day arithmetic has become a little rusty. But it would be a wise precaution for you to rub the dust off some of your grade school arithmetic books and brush up your knowledge of those branches of mathematics. We do not go so far as to say it is absolutely essential for you to be a good mathematician to finish this course, but if you take the time to brush up on your math you will find the balance of the course will be much easier for you.

If you have not been fortunate enough to have had a reasonably good foundation in ordinary high school mathematics it might be a good idea for you to arrange for some special review in elementary technical mathematics. Let us hasten to repeat what we said before: Such study probably is not absolutely necessary, but you will find that it will make the study of television much easier for you. Further than this, it will make your work in the field of television much easier. The reason is that so many of the radio and television technical magazines and publications are written in such a manner that a knowledge of mathematics is necessary to understand them.

Section 2. TRANSMISSION OF VIDEO SIGNALS

In our previous studies we have discussed very briefly the general outline of how a television signal is received and handled in a television receiver. In the previous lessons our discussions along this particular line have been very sketchy. This was done purposely to avoid the possibility of confusing you before you were prepared to fully understand what we were trying to teach you.

Before going into the more technical details of the operation of a television receiver, it is better that we explain briefly the essentials of how a television signal is put on the air for transmission to the receiver. If the basic principles of television transmission are understood, it is much easier to understand the operation of a receiver, and just why the various circuits in a receiver are so necessary if the receiver is to perform its functions properly.

Fig. 1 presents in block form a very sketchy outline of the more important elements of a television transmitter. Probably the first thing which will attract your attention is the fact that instead of only one transmitter, as in the case of ordinary radio broadcasting, there are actually *two* transmitters at a television broadcast station. This will probably cause you a little surprise at first, but a little reflection will tell you that such an arrangement is only natural, and should have been expected.

It is necessary to have one complete transmitter to prepare the video signal for radiation out through space. This transmitter is complete in every respect. It is also necessary to have a second transmitter to radiate the sound which accompanies nearly every television broadcast. This second transmitter is also complete in every respect, and could operate absolutely independently of the video transmitter if such a thing were desired.

The two transmitters operate on slightly different frequencies, but both frequencies are within one "channel". This matter of

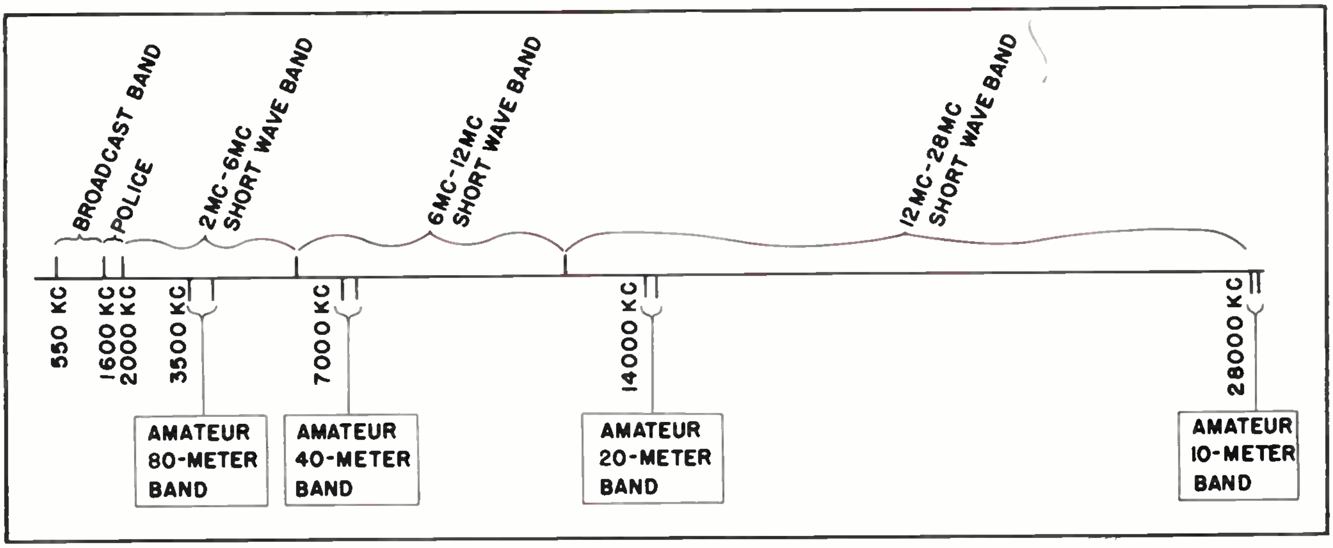

Fig.2. The Radio Frequency Spectrum Below 28 Megacycles.

television channels is worth a little discussion, and should be explained before we go any further in our studies.

Section 3. THE TV CHANNEL

You will recall from your previous studies that all radio broadcast stations are assigned a certain frequency, and are required to stay on that particular frequency. You probably also remember that the entire radio broadcast band is accommodated in that portion of the radio frequency spectrum which lies between 550 kilocycles and 1600 kilocycles. To put it in other words, the entire radio broadcast band covers a portion of the frequency spectrum which is only 1,050 kilocycles wide.

Fig. 2 gives some idea of the distribution of the radio frequencies below 28 megacycles. It should be remembered that 28 megacycles is the same as 28,000 kilocycles or 28,000,000 cycles per second. When the radio frequencies exceed one or two million cycles per second, it is customary to speak of them as megacycles.

No effort has been made to show the arrangement and distribution of all the frequencies in the frequency spectrum up to the 28-megacycle band. The broadcast band is shown, also the lower police band which lies immediately above the broadcast band. In addition to these, some of the amateur bands are also shown. But there are many frequency bands which are not shown at all. These would include additional bands assigned to police work, aircraft frequencies, and those assigned for use by ships at sea. No attempt has been made to show those frequencies used for SOS calling by ships at sea or by telephone companies for long distance overseas telephone communications.

One thing we would like for you to notice is that all the radio broadcast stations in the United States which are used to broadcast ordinary AM broadcasts are confined to a relatively small portion of the frequency spectrum, that between 550 k.c. and 1600 k.c. Notice what a small portion of the spectrum is used by this branch of the radio business.

You will now notice that the frequency spectrum covered by the diagram in Fig. 2 goes up to only 28 megacycles. Although this seems rather high compared to the amount of the spectrum used by the broadcast band, actually it does not go very high. It goes nowhere near the band used by those broadcast stations which use frequency modulation. The FM stations use the band of frequencies just above and just below 100 megacycles.

Neither does the diagram in Fig. 2 show the radio spectrum at frequencies high enough to include any of those used for the broadcast of television programs. All the television channels are located far higher in the radio spectrum than is shown in Fig. 2. But a careful study of the diagram there can bring one thing home to you far more forcefully than could any number of words. And that is the tremendous width of a single television channel.

You will recall that radio broadcast stations using amplitude modulation are assigned frequencies 10 kilocycles apart.

This enables them to radiate side bands which are 5 k.c. each side of the assigned frequency. Furthermore, by assigning the frequencies 10 k.c. apart, it is possible to divide the 1050 kilocycles of the broadcast band into 105 separate broadcast channels.

Now consider the fact that a *single* television channel occupies a space in the radio spectrum which is *six megacycles* wide. This means that a single television channel is 6,000 kilocycles wide, or nearly six times as wide as the entire broadcast band which contains 105 individual broadcast channels. To put it in other words, 600 radio broadcast stations could operate from the same vicinity, each on its own frequency and not interfering with any of the others, in the channel required for the operation of a single television broadcast station.

Because the bandwidth required for the operation of a single television broadcast station is so great, it is necessary for television to operate at high frequencies. There are several reasons for this. One is that much of the radio frequency spectrum below 28 megacycles has been used by various kinds of stations for many years. Much of the equipment working on these frequencies has been designed to operate on these particular frequencies, and much money has been invested in them. If any attempt were made to operate television stations on these lower channels it would force the abandonment of much of the existing radio equipment.

But there are other reasons why it is necessary for television stations to operate on the higher frequencies. You are already well enough versed in radio work to know that tuned circuits are a very necessary part cf any radio circuit used to capture electromagnet radiations which might be traveling through space. You are also aware that a circuit tuned to receive a signal at 1000 k.c. is not going to be affected by a signal of 2000 k.c. or 3000 k.c. or 5000 k.c.

You have learned from your studies of tuned, or resonant, circuits that the resonant curve of a resonant circuit can be broadened to a certain extent. But by no stretch of the imagination could a resonant circuit be broadened to the extent of picking up a signal whose frequency varied from possibly 10 or 15 k.c. to some 6000 k.c. Such a circuit would simply have long since ceased to be a tuned circuit.

But it is possible to broaden a circuit to such an extent that it can pick up signals which vary from 54 megacycles to 60 megacycles, or from 210 megacycles to 216 megacycles. It is not hard to understand, even without going immediately into the technical details of such a circuit, how such a circuit could be created.

The main point is that all television broadcast stations operate on the higher frequencies. And operation on these higher frequencies bring up phenomena which might be present at the lower frequencies, but are not noticeable there.

Section 4. FREQUENCY BANDS

As of this writing, the Federal Communications Commission has allocated 12 channels for use in the broadcasting of television. These are numbered from 2 to 13. The Frequency channel numbers and their allocated frequencies are:

CHANNEL NUMBER	FREQUENCY IN MEGACYCLES
2	54-60
3	60-66
4	66-72
5	76-82
6	82-88
7	174-180
8	180-186
9	186-192
10	192-198
11	198-204
12	204-210
13	210-216

In addition to the above frequency channels which have been definitely allocated for actual transmission of television programs, many other frequencies have been set aside by the FCC for experimental, color, high-definition and educational telecasting. Some of these frequencies run up to the thousands of megacycles. With the television industry growing at a tremendous pace, a lot of pressure is being constantly put on the FCC to allocate additional channels for the use of commercial television. The FCC is constantly revising and changing its schedule of frequency allocations. It is entirely possible that by the time you read this lesson, some changes may have been made in the TV allocations by the FCC. The FCC has been holding a constant series of

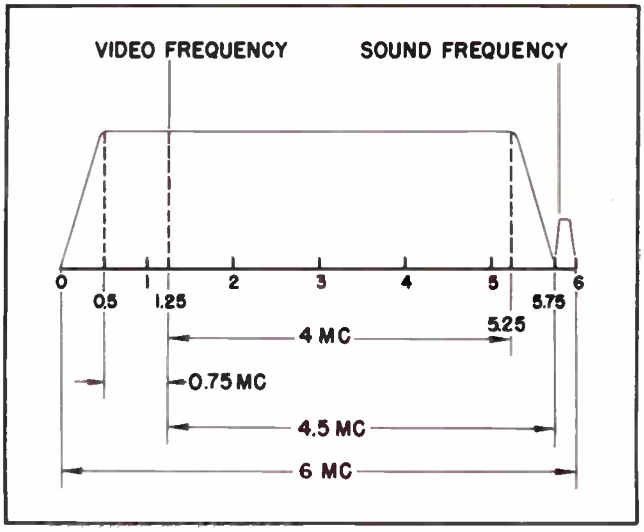

Fig.3. How the Video and Sound Frequencies are Located Within a Television Channel.

hearings for many months listening to arguments for and against assigning additional frequencies to television. In fact, the FCC began holding a series of hearings on these proposals almost before the guns had ceased firing at the end of the recent war. Many changes have been made during the years since the war ended, and many more will probably take place during the next several years. But these frequency changes will have little effect on the basic problems concerning the technical side of television.

Section 5. FREQUENCY ARRANGEMENT WITHIN A TV CHANNEL

The FCC has prepared standards governing the transmission of television signals. Among the standards imposed upon the industry are those governing the arrangement of the frequencies within a channel. All the video frequencies and all the sound frequencies for a given broadcast must be confined within the limits of the assigned channel. Considering the tremendous width of the channel, this seems at first a relatively easy thing tc do. But considering the enormous amount of intelligence which must be broadcast from a television station, the width of the channel is none too great. We will discuss some of the reasons why the channel must be so wide a little later.

The video carrier and the video sidebands occupy the major portion of the TV channel. This is indicated in Fig. 3. The sound portion of the broadcast occupies a relatively insignificant portion of the channel.

It will be noticed from a study of Fig. 3 that the video carrier and its sidebands occupy 5-3/4 megacycles of the 6 m.c. channel. Notice how the signal is quite broad, having an equal amplitude over the greater portion of the band. The video signal drops off sharply at each end of the band. The sound occupies a narrow portion of the band located at the highest frequency portion of the band.

Before going too deeply into a discussion of the arrangement of the frequencies in Fig. 3, we will study another situation to see just how it is possible to inject the entire television broadcast into a channel only 6 megacycles wide when an even wider channel would be more useful.

Reverting back to the ordinary broadcast channel of ten kilocycles we know the station frequency is held right in the middle of the channel by means of a crystal oscillator. This allows the sidebands 5 k.c. on each side of the carrier, 5 k.c. above the carrier and 5 k.c. below the carrier. This arrangement is adequate because it is seldom or never necessary to broadcast sounds which have a frequency greater than 5 k.c., which of course is the same as 5000 cycles per second.

Now in television work it is highly desirable to have a broadcast channel wide enough to carry sidebands which are themselves 4 m.c. wide. Such a channel would be more than 8 megacycles wide. (See Fig. 4.) In fact, the total width of the video channel

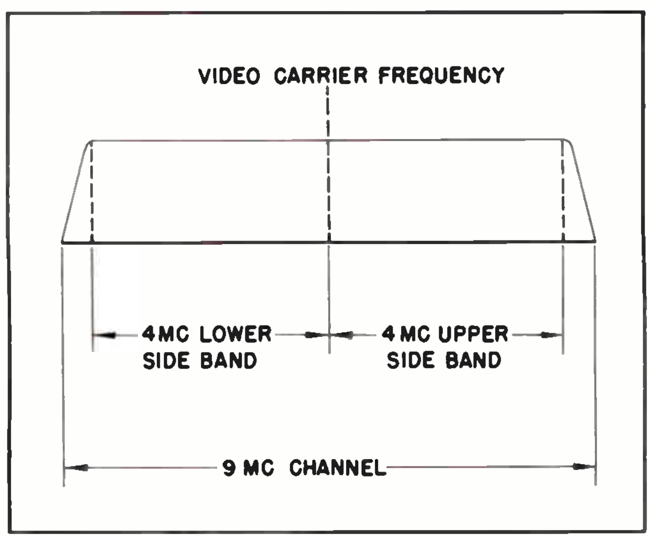

Fig.4. The Band Width which would Normally be Needed to Pass Both Sidebands of a Video Carrier.

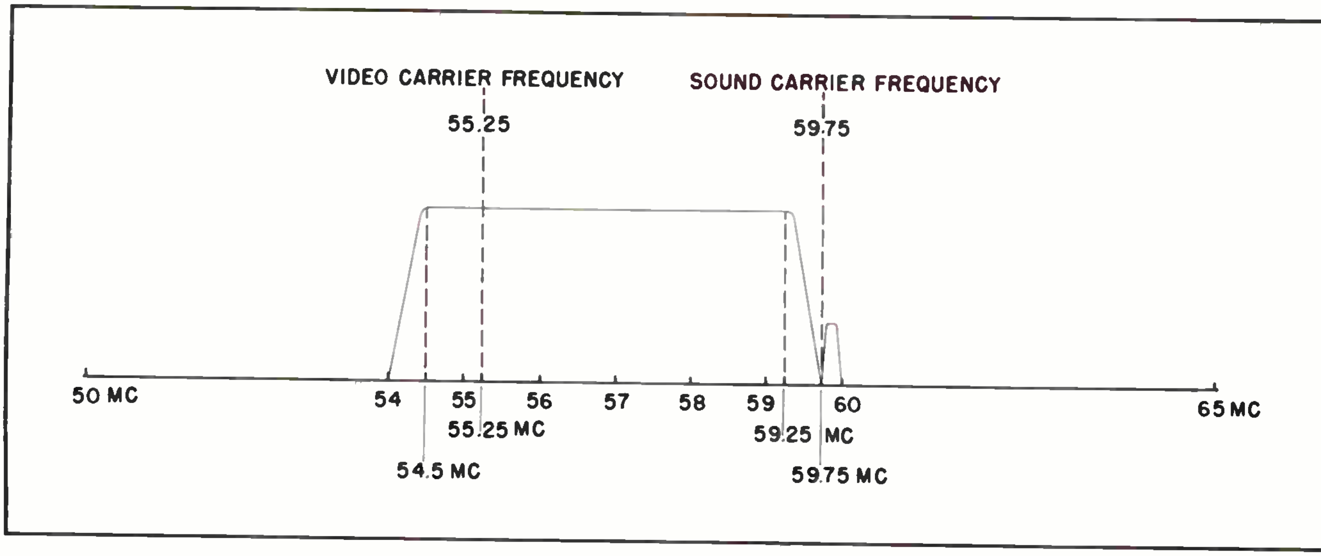

Fig.5. Arrangement of the Video and Sound Frequencies in the TV Channel No. 2.

alone, including the upper and the lower sidebands, would be about 9 megacycles wide. This would not include the sound portion of the channel.

To avoid the need for such a wide channel for the transmission of a single broadcast, the video transmitter is so arranged that a part of the lower sideband is suppressed. A little thought is sufficient to show that the suppression of the sidebands on one side of the carrier will have no effect on the picture which is being transmitted. You will recall in our study of detectors, we deliberately erased the sidebands on one side of the carrier so the audio portion of the receiver could respond to the *average* changes in the amplitude of the carrier voltage. Since we deliberately erase and discard one side of the sidebands at the receiver so we can make use of the other set of sidebands, it is readily apparent that the lower sideband is worthless for all practical purposes. Since it is discarded at the receiver, it is reasonably apparent that it could be suppressed at the transmitter just as well, and would in no way affect the transmission of the intelligence carried by the carrier frequency.

In television work this is done: The lower sideband is suppressed at the transmitter to such an extent that instead of the lower sideband being 4 m.c. wide, it is only about 3/4 m.c. wide. As a result of the suppression of the major portion of the lower sideband, it is no longer necessary to use such a wide channel in order to transmit the signal. Instead of the carrier itself being in the center of the channel as in Fig. 4, and as is common in radio work, the carrier is far to one side of the channel. In Fig. 3 the video carrier is shown to be located 1.25 m.c. from the lower limits of the channel.

To show what this means in an actual TV channel, suppose we see just how the frequencies would be arranged. Suppose we take the lowest television channel, that of Number 2 which is located between 54 and 60 megacycles in the radio frequency spectrum.

Fig. 5 indicates the exact arrangement of the various frequencies within the channel. Note that the carrier frequency of the video carrier is 55.25 m.c., while the carrier frequency of the sound transmitter is 59.75 m.c. The location of the band is shown with relation to the other frequencies between 50 m.c. and 65 m.c. Note how the frequencies correspond with those shown in Fig. 3. The upper sideband of the video carrier is still 4 m.c. wide. Including the "guard band", which includes the sloping portion of the amplitude curve, the sideband is 4.5 m.c. wide.

The partial suppression of the sidebands on one side of the video carrier is called *vestigial sideband transmission.*

Section 6. HOW TELEVISION DIFFERS FROM RADIO

In the reception of ordinary radio broadcasts we resort to the use of tuned circuits which have a "Q" as high as possible. It is possible to use high "Q" circuits in radio because the width of the band at any particular frequency is relatively narrow, never exceeding 10 k.c. in AM work, and being even narrower in many cases.

The first thing we run into in television work is that we must use tuned circuits which respond to a very wide band of frequencies. The immediate effect of tuning to a wide band is to reduce the "Q" of the circuit, and thus reduce its effectiveness in picking up a signal and aiding in its amplification. One serious problem which this immediately introduces is that so many of the stages in a television receiver have very low gain. Where gains of 25 to several hundred are commonplace in radio receiver stages, it frequently happens that we struggle to attain a gain of 4 to 8 in a TV receiver stage. A natural result of this is many additional stages of amplification.

Another difference between a radio receiver and a television receiver is the amount of "noise" which is picked up. Much "noise" in the form of static is always present in the atmosphere. Some of it is natural static created by lightning and other things, but much of it is man-made.

A sharply tuned radio using tuned circuits with a high "Q" will eliminate much of the static. Most static has random frequencies -- that is, it is not all the same frequency. All static which does not happen to fall within the frequency band acceptable to the tuned circuit will be rejected, or at least greatly attenuated. Thus the narrowly tuned circuits of an ordinary radio receiver tends to accept the desired signal but it discriminates against the random frequencies of the static "noise".

But an entirely different situation is present in a television receiver. The tuned circuits in the RF portion of the receiver are deliberately designed to accept a wide range of frequencies. Thus the TV receiver will admit the undesirable noise as well as the desirable TV signal. This creates a problem which must always be solved.

Most radio signals, at least those transmitted on frequencies below about 28 megacycles, can often be heard at great distances. By their very nature they bounce back and forth between the earth and the Kennelley-Heaviside layer of the Ionosphere, making it possible for them to travel great distances, even around the world. (See Fig. 7.) But radio frequencies operating at frequencies much above 28 m.c. are not regularly reflected by the Kennelley-Heaviside layer. They penetrate the layer and are lost in outer space. (See Fig. 6.)

At the present time we do not know as much about the action of the Ionosphere as we would like to know. The theory is that the Sun's rays act on the outer atmosphere in such a manner as to ionize some of the atoms in space. These ionized atoms affect the passage of electromagnetic waves. The long waves are affected most, and are generally reflected back to the earth. As you already know, the longer the wave-length, the lower will be the frequency. But as the wave-lengths of the electromagnetic waves become shorter, they are affected less and less. After the wave-length has become quite short -- that is, the frequency has become quite high -- the waves are virtually unaffected by the Ionosphere, and they pass on into outer space.

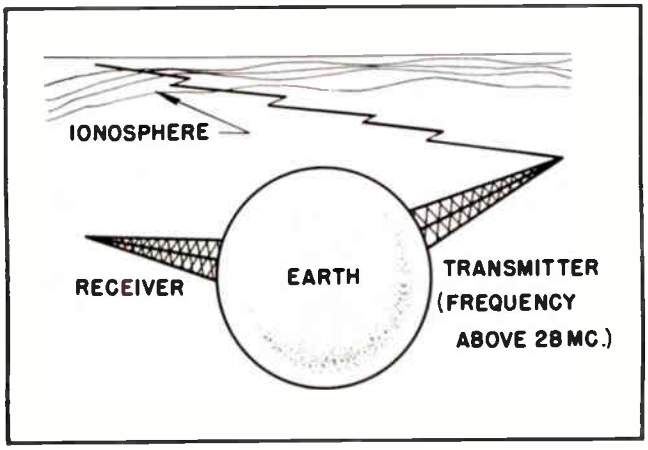

Fig. 6. How the Higher Frequencies Move from the Transmitter in a Straight Line and are Lost through the Ionosphere.

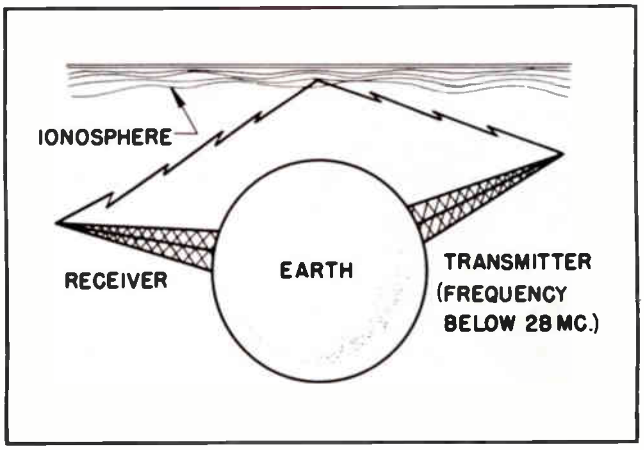

Fig. 7. How the Lower Frequencies are Reflected from the Ionosphere Back Toward the Earth.

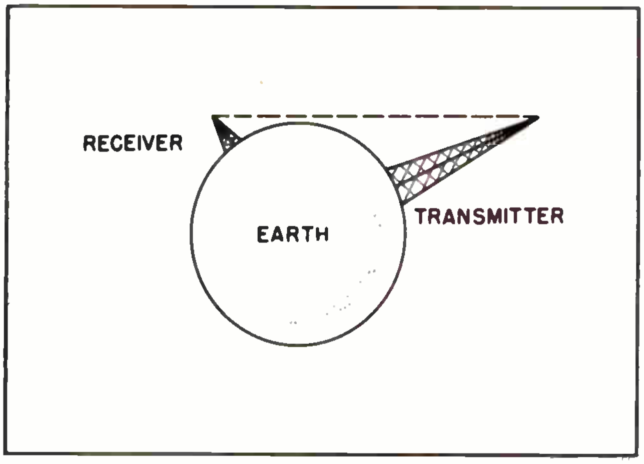

Fig.8. Television Signals Travel in a Straight Line from the Transmitting Antenna to the Receiving Antenna.

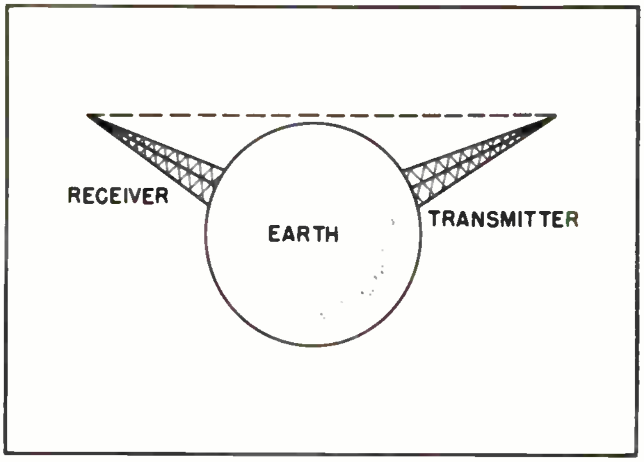

Fig.9. TV Signals can be Picked Up at a Greater Distance by Increasing the Height of the Receiving Antenna.

What this means to us in radio and television work is that ordinary radio waves will travel for long distances around the earth. But the television waves, being much shorter, tend to travel in a straight line toward outer space. This means the theoretical range of a television station is not much beyond the horizon. (See Fig. 8.)

It is possible to greatly extend the distance at which a television signal can be received by increasing the height of the antenna at both the transmitter and the receiver. It is the general practice to place the transmitting antenna as high as is possible or practical. If the receiver is at a distance from the transmitter, the antenna there should also be raised as high as possible. (See Fig. 9.)

Section 7. WHY SUCH A WIDE CHANNEL IS NEEDED FOR TELEVISION

To properly understand just why such a wide group of sideband frequencies are needed in TV work, it is first necessary to understand the nature of the transmitted video signal. By this we mean the electrical nature of the signal.

Perhaps you have not given much thought to the nature of the television video signal. But in your studies of the previous lessons you learned that a picture is "painted" on the screen of a receiving picture tube by means of a beam which was swept back and forth across the face of the screen. You already know from those studies that a picture is not painted on the screen in one simultaneous action such as that of taking a snapshot with an ordinary still camera. Rather it is a progressive action, one little bit of the picture being painted after another. Bit follows bit in such rapid succession that the picture appears to the human eye to be all placed there in a single simultaneous action. But the appearance is merely an optical illusion.

Since the picture is "painted" bit by bit, it follows as a natural result that the picture at the TV camera must also be taken bit by bit, and transmitted bit by bit. A study of Figs. 10, 11, and 12 will suggest the method used to accomplish this object. The picture is transmitted bit by bit through the medium of dividing the picture into lines, then sending the lines one after another. Theoretically, the picture of Fig. 10 could be prepared for transmission by dividing it into eight strips as in Fig. 11. Then by sending line *1* first, then line *2*, then line *3*, etc., the entire picture could be sent in the same manner

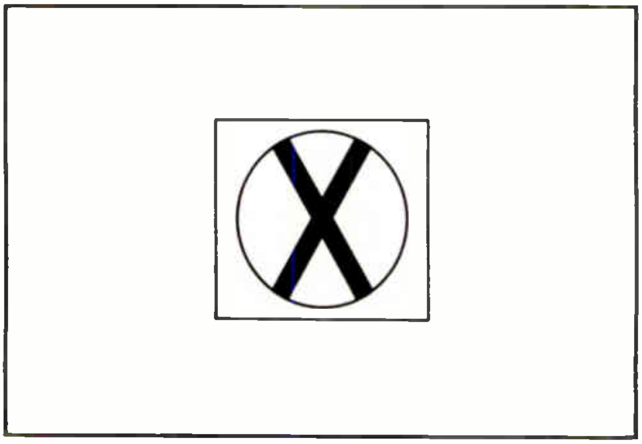

Fig. 10.

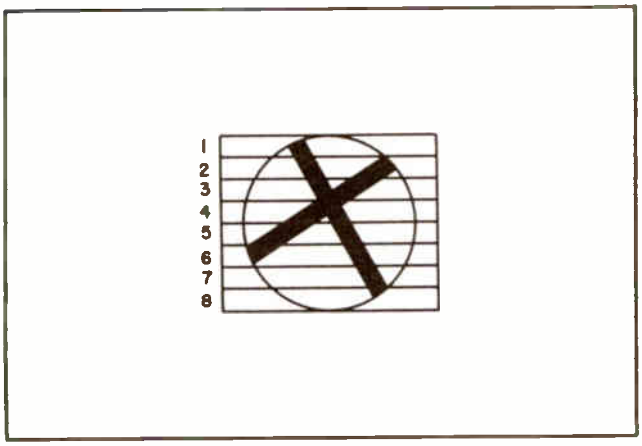

Fig. 11. How a Picture can be Divided Into Strips or "Lines".

as though it were laid out in a long strip like that of Fig. 12. This may seem at first glance to be an odd way to transmit a

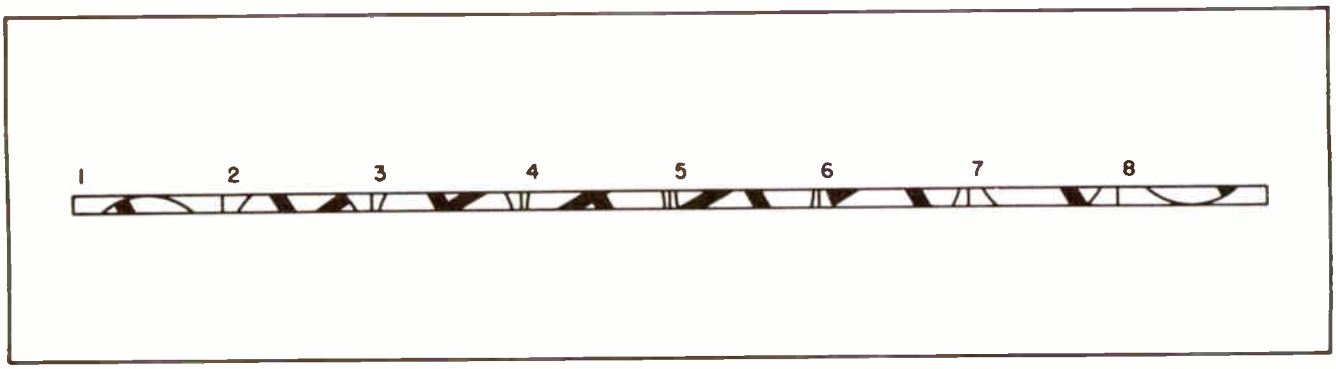

Fig. 12. Each Succeeding Line is Transmitted just as though it were Strung out in a Long Strip.

picture. But if you will stop and think for a moment you will see that it is not so strange. You are already familiar with the pictures used in newspapers and magazines. Each of the pictures look like a solid mass of black and white, or of color as the case may be. Yet if the picture is examined under a microscope you will see that the picture is actually made up of many tiny dots; literally thousands of the dots. Some of the dots are heavier than others. Where the dots are heavy, the picture appears to be dark, where they are not so heavy, the picture appears to be lighter. By properly regulating the weight of the dots, it becomes possible to govern the shading of the picture itself. (See Figs. 13 and 14.)

The finer the dots -- that is, the more of them there are -- the better the appearance of the picture. From a practical standpoint this means that by increasing the number of dots, the "grain" of the picture can be greatly improved. The reason is that the more dots are used, the less any of them stand out as an individual, the more they tend to merge into the creation of a complete picture.

In Fig. 11 we divide the illustration into eight lines. That would enable us to transmit the picture in such form that it would be recognizable at the receiver. But the picture would be quite coarse, and there would be little detail in the final reproduction. In actual television work the picture is divided into 525 lines, thus making possible a very fine division of the picture. This makes it possible to transmit by means of television, a picture which is adequately rich in detail.

In Fig. 11 the picture is divided into eight lines. Now if each line is broken

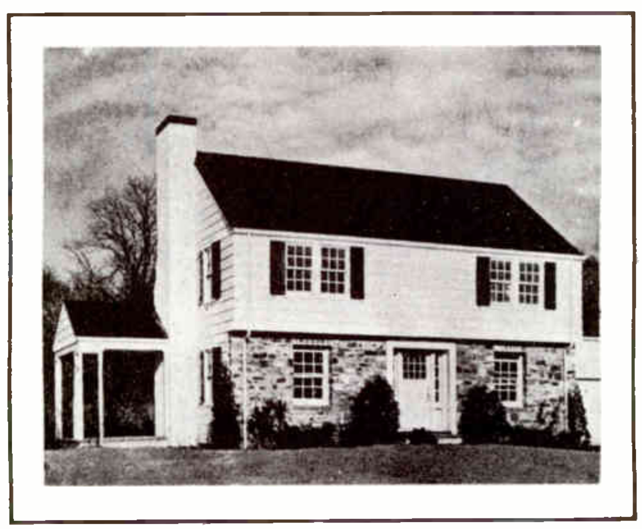

Fig. 13. Pictures are Composed of Many Tiny Dots.

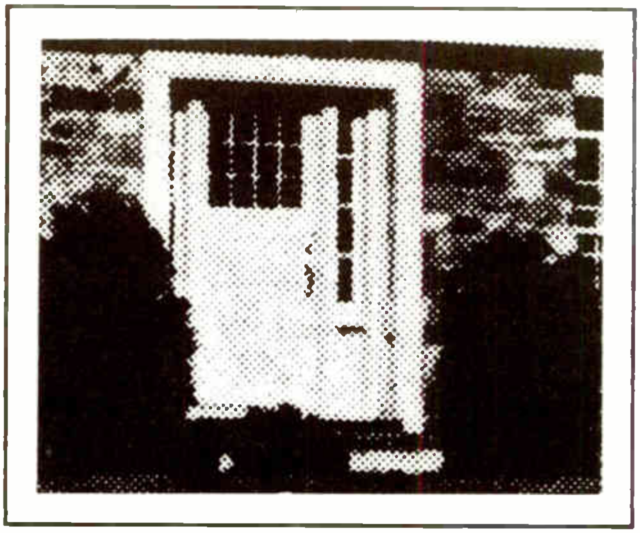

Fig. 14. Fewer Dots, or Magnified Dots, Makes them Readily Apparent.

down into eight parts and one part follows the other in rapid succession, as shown in Fig. 15, the entire picture could be transmitted in 64 parts. (Eight parts to a line and eight lines to the picture makes a total of 64 parts.)

As mentioned before, in television work the picture is broken down into 525 lines. For certain technical reasons it is not possible to use quite all the lines. The average number actually used under normal conditions is about 500 lines. The other lines remain dark.

The camera and circuits are designed so that the shading of the lines can be changed about 400 times for each line. What this does, in effect, is to divide the picture into approximately 200,000 parts. (500 lines, each divided into 400 parts, is equivalent to a total of 200,000 parts.) This requires that the electrical circuits be so designed that 200,000 changes in the electrical voltage can take place for each transmission of a single picture. 200,000 changes in the voltage during the transmission of a single frame of a picture seems to be quite a requirement. This is especially significant in view of the fact that not more than 5000 voltage changes *per second* are required to transmit voices and music.

But you might note that the 200,000 changes are required for the transmission of each *frame*. There are 30 frames transmitted each second. This means the electrical circuits in the television transmitter and receiver must be designed to pass not merely 200,000 voltage changes per second, but 30 times 200,000. 30 times 200,000 is 6,000,000. Thus the tuned circuits in television work must be designed to pass a band of frequencies 6,000,000 cycles, or 6 m.c. wide. It is now possible for you to begin understanding the need for the extremely high frequencies involved in television work. Fewer lines could be used, but that would not permit the transmission of fine detail as is demanded by the American public.

Section 8. METHODS OF SCANNING

In Figs. 11, 12, and 15, we divided the picture into eight lines. Then we started at the top left corner of the picture and moved our scanning "eye" from left to right

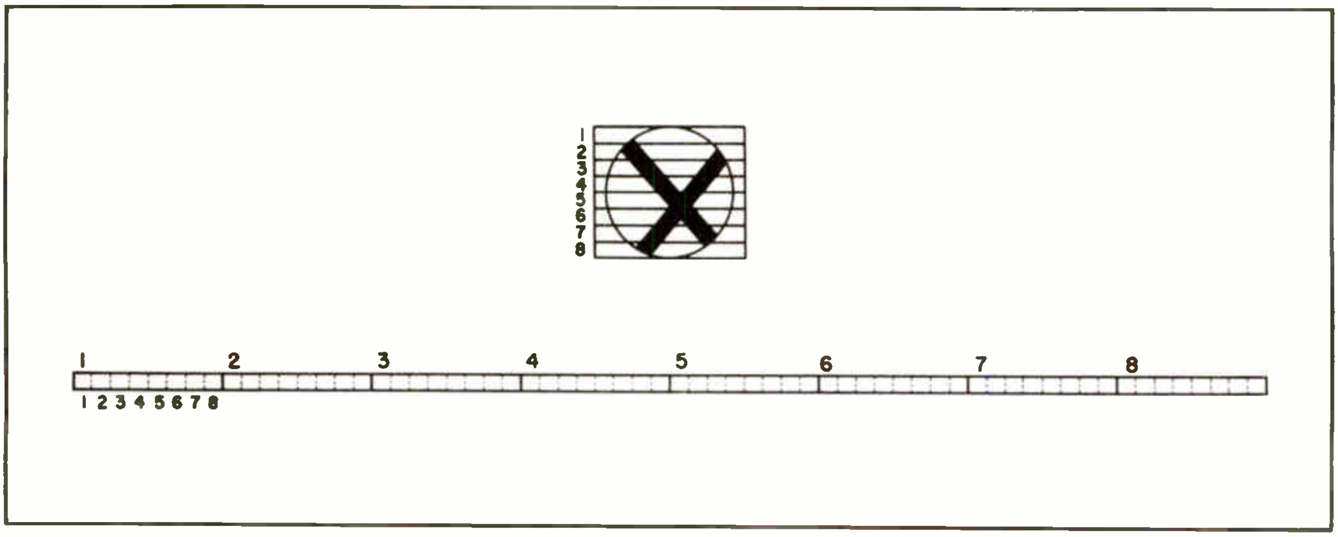

Fig. 15. How the Lines of a Picture are Broken Down into Many Separate Parts.

along line No. *1*. When we were finished with line No. *1* we went to line No. *2* and scanned it. We continued from there with the other lines in numerical order. This method of scanning is called the *successive method of transmission*. When the picture was divided into fewer lines during the early days of television, the successive method of transmission was quite commonly used.

But as the state of the art improved, and the use of a larger number of lines became the standard practice, it was found that the successive method of transmission was not adequate. It had several definite drawbacks from the standpoint of efficiency. Further than this, such a method of transmission frequently caused an unpleasant sensation of "flicker". To improve the quality of television transmission, a change in the method of scanning was adopted. The newer method was called "interlaced scanning".

"Interlaced scanning" was mentioned in a previous lesson, but it is well for us to mention it again at this time. Basically, interlaced scanning consists of transmitting alternate lines to complete one "field", then going back and scanning those lines which were missed, thus completing a second field. Both fields, when combined on the fluorescent screen of a picture tube, produce one complete "frame".

In interlaced scanning, the first sweep of the electron beam across the face of the screen will scan line No. *1*. The second sweep will scan line No. *3*. The third sweep will scan line No. *5*, then proceed to sweep each alternate line to the bottom of the screen.

After making the full trip to the bottom of the screen, the beam returns to the top of the screen and starts out again. This second trip it scans the alternate lines which were missed during the first trip down. By the time the beam reaches the bottom of the screen on its second trip, it will have completely covered the entire surface of the screen.

It should not be thought that the screen itself is physically divided into a certain number of lines. Such a conclusion would be wrong. The screen itself is a smooth layer of fluorescent material coated on the inside of the glass of the cathode ray tube. The "lines" represent the portion of the screen which is touched by the beam as it sweeps across.

Fig.16. Objects can be seen After the Flash of Lightning Due to a Persistence of Vision.

Section 9. PERSISTENCE OF VISION

The ability to transmit and receive pictures by means of television depends in large part upon the peculiar property of the human eye which is called "persistence of vision". Persistence of vision is the ability of the human eye to continue "seeing" something which has already ceased to exist. Or, has ceased to exist at the exact location still "seen" by the eye.

One example of the persistence of vision familiar to everyone, is the ability to continue seeing a flash of lightning long after it has ceased to exist. A brilliant flash of lightning can often be "seen" for several seconds after the flash itself has completely disappeared. Often the details of surrounding objects can continue to be seen for a relatively long period of time after the flash of lightning has gone. In some individuals this persistence of vision is so strong that it is possible to continue "seeing" objects for as much as a minute after the flash has gone.

Another familiar example of persistence of vision is the swinging of a lantern in a circle. Common sense tells us that the light from the lantern can be originating at only one location at any single instant. Yet, if the lantern is swung quite rapidly in a circle, the persistence of vision in the viewer's eye will give the illusion of a solid circle of light. (See Fig. 17.)

Fig.17. Persistence of Vision Makes the Lantern Appear to be a Circle of Light.

This peculiarity of the human eye was first taken advantage of in the production of motion pictures. The projection of motion pictures, as most everyone knows, consists of the projection of a series of still pictures on a screen. One picture after another is flashed on the screen in rapid succession. When each succeeding picture is slightly displaced with respect to the one preceding it, an illusion of motion will be imparted to the viewer. The viewer will see one picture. Even after it has actually disappeared, the eye will continue to "see" it due to the persistence of vision.

While the eye is still "seeing" the first picture, a second will be flashed on the screen. The "vision" of the first will be diminishing somewhat by the time the second is flashed on the screen. This makes the second picture register more importantly on the eye. The nerves of the eye will then concentrate on the second picture. If the second is slightly displaced from the first, the eye will effect the transfer from the first picture to the second as a smooth transition, just as though the motion were actually real rather than an illusion of the eye.

If the pictures follow each other fairly rapidly, the eye will see them as a continual movement, rather than as a series of still pictures. By fairly rapidly, we mean there should be 16 or more pictures each second.

In amateur motion picture photography, 16 "frames" per second is the standard. In commercial motion picture photography where better quality is desirable, the standard is about 24 frames per second. The eye does not ordinarily detect changes when they amount to 16 or more each second. However, in some individuals, changes having an even higher frequency can be detected. This is the reason the higher frequency in the change of frames is used in motion picture work.

In the earlier days of television broadcasting, various frequencies of frame changes were tried. But it was finally decided to standardize on 30 complete frames because that was a sub-multiple of the standard A-C power frequency used in most parts of this country. By linking the number of frames with the power frequency, it was possible to eliminate any interference from unfiltered, or poorly filtered hum, generated in the power lines.

You will recall from an earlier lesson we mentioned that the signal is blanked out during the retrace period. It is blanked out during both retrace periods; that from the right to the left, and that from the bottom to the top. Since the signal is blanked out during each retrace from the bottom to the top, and there are 60 retraces each second, this means the signal is blanked out for relatively long periods (approximately 1000 microseconds) 60 times each second. By making these blanked periods correspond with the power frequency, it becomes possible to reduce any interference from the power lines to a negligible amount. For all practical purposes, it is completely eliminated.

Section 10. SIDEBANDS

The matter of sidebands has been discussed rather freely in this lesson. It has also been mentioned quite a number of times in previous lessons. Up to this time we have avoided going into the technical nature of sidebands. But from this time on, we will be confronted with technical problems relating to sidebands so frequently, that it seems proper we should devote a little time right now to the discussion of their technical nature.

Many definitions of sidebands are in general use. Some are extremely complicated, others relatively simple. Stripped to its main essentials a sideband in radio work is that part of a radiated carrier

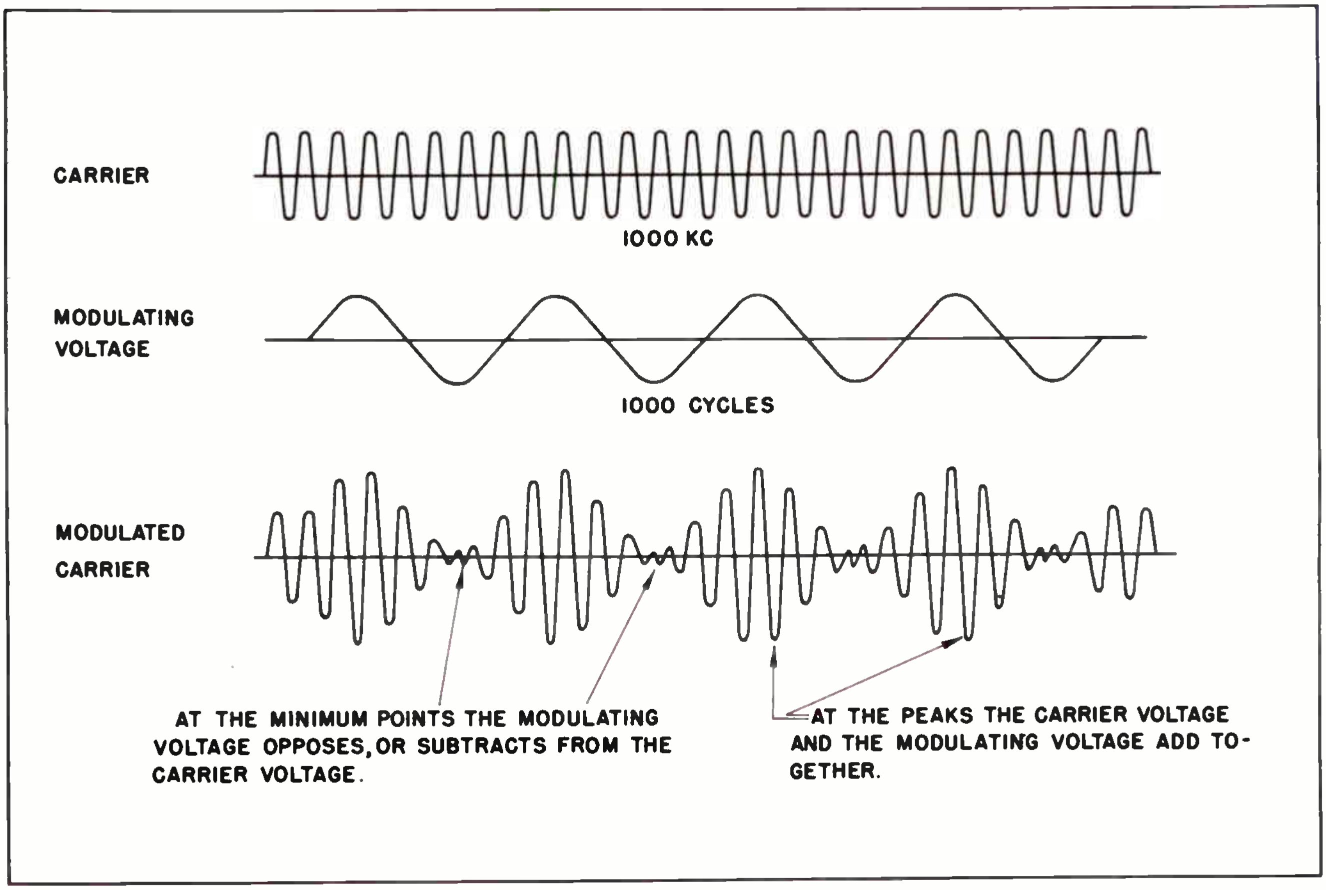

Fig. 18.

which carries the intelligence of the message being transmitted. This simple explanation we recognize, is rather inadequate from a strictly technical standpoint. Yet that is exactly what it is.

From a strictly technical standpoint, the matter of sidebands becomes an extremely complicated series of constantly changing frequencies. This situation arises from the fact that we have a constant-frequency-constant-amplitude carrier wave which is normally mixed with, or modulated by, a much lower group of frequencies. The carrier wave provides the means of transmitting a message through space.

Considered alone, it can be generally said that the carrier wave by itself does not transmit any intelligence. The intelligence of the message is provided by the lower frequencies. The voice of a speaking person consists of a considerable number of sound frequencies. The spoken words carry an intelligence from one person to another.

In like manner the sound created by musical instruments also consists of vibrations in the air. The sound caused by the spoken word, or created by the musical instruments, can be changed into rapidly changing electrical voltages by utilizing the proper kind of electrical instruments. These changing voltages -- changing in accordance with the sound of the human voice or music -- are of the type to which the human senses respond; to which they are sensitive. Technically speaking, we say they are the type of frequencies which carry intelligence.

When we modulate a high frequency such as an R-F carrier, by a low frequency such as an audio voltage, what we are doing is mixing two frequencies together. We have previously seen that when we mix two radio frequencies together, we can extract *four* frequencies -- the two original frequencies, the sum frequency, and the difference frequency.

Although the action is somewhat different in the modulation process, the ultimate result is not greatly different. To better understand just what we mean, suppose we consider the situation of modulating a 1000 k.c. carrier with a 1000 cycle audio note.

CARRIER = 1000 KC = 1,000,000 CYCLES.

MODULATING FREQUENCY = 1,000 CYCLES.

SUM FREQUENCY = 1,000,000 + 1,000 = 1,001,000 CYCLES.

DIFFERENCE FREQUENCY = 1,000,000 − 1,000 = 999,000 CYCLES.

FREQUENCY OF UPPER SIDE BAND IS 1,001,000 CYCLES OR 1,000 CYCLES ABOVE THE CARRIER.

FREQUENCY OF LOWER SIDE BAND IS 999,000 CYCLES OR 1,000 CYCLES BELOW THE CARRIER.

Fig. 19.

Fig. 18 reviews one of the actions with which we are already familiar. That is, that the carrier voltage will undergo considerable changes in its amplitude, or strength, as the result of combining it with the modulating voltage. The full amount of the changes which will take place in the carrier wave as the result of the modulation, will depend upon the voltage of the modulating frequency. If the modulating voltage is quite high, the carrier voltage will undergo some radical changes. If the modulating voltage is relatively weak, the changes will be much less pronounced.

If the value of the modulating voltage is the same as the carrier voltage, the end result is that the carrier voltage will be alternately twice as strong as the unmodulated carrier, then completely lose all voltage altogether. This action is indicated in Fig. 18. This is what is known as 100% modulation.

Now it should be clearly understood that the *frequency* of the modulating voltage has nothing to do with the percentage of modulation. Percentage of modulation is entirely dependent on the *voltage* of the modulating frequency. The example shown in Fig. 18 is that of a 1000 k.c. carrier being modulated by a 1000-cycle frequency. In that particular case, both frequencies have the same voltage amplitude. Had the frequencies both been the same, but the modulating

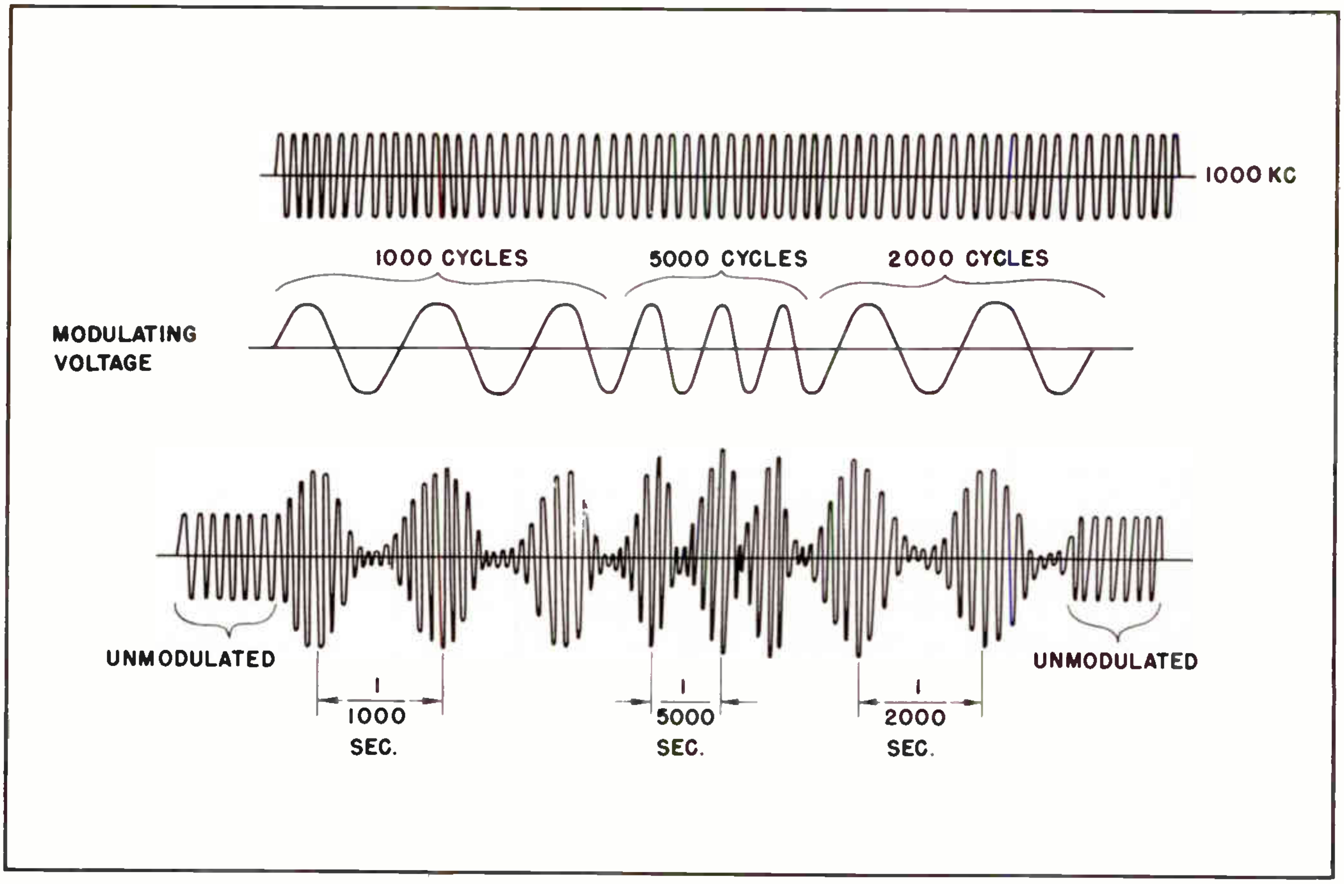

Fig. 20.

CARRIER = 1,000,000 CYCLES.

MODULATING FREQUENCY = 5,000 CYCLES.

SUM FREQUENCY = 1,000,000 + 5,000 =
1,005,000 CYCLES.

DIFFERENCE FREQUENCY = 1,000,000 − 5,000 =
995,000 CYCLES.

FREQUENCY OF UPPER SIDE BAND = 1,005,000 CYCLES.

FREQUENCY OF LOWER SIDE BAND = 995,000 CYCLES.

Fig. 21.

voltage been only half as great as that of the carrier, we would have had only 50% modulation. On the other hand, had the modulating voltage been greater than that of the carrier, we would have had over-modulation -- that is, greater than 100%. The main point to remember is that the percentage of modulation depends upon the *voltages* of the two signals involved, not upon their frequencies.

But another action is taking place during the modulation process entirely aside from the percentage of modulation. This is the creation of sideband frequencies. When the 1,000,000-cycle carrier frequency was mixed with the 1000-cycle modulating frequency, it became possible to tap off four frequencies at the output of the modulation stage. We would have the 1,000,000-cycle original carrier frequency, the 1000-cycle modulating frequency, the sum of these two frequencies which would be 1,001,000 cycles, and finally, the difference between them which would be 999,000 cycles. (See Fig. 19.)

The 1000-cycle frequency is so low that it can have no effect in the matter of radiating out into space, so from now on we can ignore it as though it did not exist. But the 1,000,000 cycle carrier frequency can be readily radiated, and so can the 1,001,000 cycle frequency and the 999,000 cycle frequency. Moreover, these three frequencies are so close together that any transmitter which radiates 1,000,000 cycles will also radiate the other two frequencies.

Before modulation, we had one frequency to be radiated out into space -- the 1,000,000-cycle carrier frequency. After modulation, we have three frequencies to be radiated. And all of them are radiated.

The above described action is what takes place when a 1,000,000-cycle carrier is modulated by a single 1000-cycle note. But we all know that such a situation would seldom or never exist under actual operating conditions. The modulation of the carrier is normally accomplished with a widely varying number of frequencies.

In Fig. 20 we have gone another step in showing what happens when several frequencies are used in succession to modulate a carrier wave. We first show the carrier being modulated with a 1000-cycle note, similar to that of Fig. 18. Then the modulating frequency is changed to 5000 cycles. Farther along the modulating frequency is changed to 2000 cycles.

When the modulating frequency is 5000 cycles, the upper sideband of the modulated carrier will be 1,005,000 cycles. This is derived in Fig. 21. The lower sideband will be 995,000 cycles. The calculation to show how this figure is arrived at is also shown in Fig. 21.

When the modulating frequency is 2000 cycles, the upper sideband will be 1,002,000 cycles, and the lower sideband will be 998,000 cycles. You can see by studying Fig. 22 how these values are determined.

From the above examples you can readily understand that the sidebands of a modulated carrier are constantly changing as the

CARRIER = 1,000,000 CYCLES.

MODULATING FREQUENCY = 2000 CYCLES.

SUM FREQUENCY = 1,000,000 + 2000 =
1,002,000 CYCLES.

DIFFERENCE FREQUENCY = 1,000,000 − 2,000 =
998,000 CYCLES.

FREQUENCY OF UPPER SIDE BAND = 1,002,000 CYCLES.

FREQUENCY OF LOWER SIDE BAND = 998,000 CYCLES.

Fig. 22.

frequency of the modulating voltage changes. One of the important things to remember in radio and television work is to prepare circuits in such a manner that a desirable band of sideband frequencies can be passed without undue attenuation. As an example of this we can take the situation of a carrier wave being modulated by a voltage responding to the voice of some man who is speaking. The frequency of the man's voice probably would never exceed 1000 cycles per second, possibly not go even that high. This means that the sidebands on either side of the carrier wave would never exceed 1,001,000 cycles nor drop lower than 999,000 cycles if the carrier was operating on a frequency of 1,000,000 cycles. From this it might be thought that circuits designed to pass all frequencies between 999,000 and 1,001,000 cycles would be adequate to take care of the situation. And of course, such would be true if the circuits were never to pass anything but men's voices.

But most AM radio transmitters and receivers are intended to pass both speech and music. In order to preserve reasonable fidelity, it is necessary to create circuits which will pass frequencies up to about 5000 cycles. This means that the sidebands will be 5000 cycles each side of the carrier, making it necessary to create circuits which will pass a band of frequencies 10,000 cycles wide.

In the case of FM, the sidebands are considerably wider. As mentioned in a previous lesson, the sidebands of an FM transmitter cause the carrier to deviate as much as 75 kilocycles each side of the unmodulated frequency.

It can be seen from the foregoing discussion that there are always two things to consider and remember when sidebands are the subject. One is the effect of the modulating voltage on the voltage of the carrier. The other is the resulting effect of mixing the modulating frequencies with that of the carrier.

It should be remembered that the frequency of the modulating voltage has no effect on the *amplitude* of the carrier voltage. Neither does the strength, or amplitude, of the modulating voltage have any important effect on the width of the sideband frequencies. But at the same time it should be remembered that the application of a modulating voltage to a carrier voltage will affect *both* the amplitude of the carrier voltage and the carrier frequency. By this we mean: That whenever a carrier is being modulated, the amplitude of its voltage will be constantly changing from instant to instant, and the width of its sidebands will also be constantly changing.

The foregoing explanation of sidebands will be sufficient for all our present purposes. There are some who might complain that we have overly simplified our explanation. They could complain -- and with good cause -- that we have given the diligent student who wants exact, rather than general information, little to go on. It is our belief that few students will require more than a general knowledge of sidebands at this time. But for those who prefer to have a sideband broken down into all its individual components where it can be better studied, we are including below an explanation of the exact make-up of the sidebands of a carrier.

In analyzing a modulated carrier wave, it is usually most convenient to break it down into its various sinusoidal components. In determining the magnitude of the carrier voltage at any one instant, several things must be taken into consideration: The value of the instantaneous voltage, the value of the unmodulated carrier voltage, the maximum voltage, the minimum voltage and the phasing of the several voltages involved.

The instantaneous voltage is usually represented by the little letter e.

The average amplitude of the wave (the unmodulated voltage) is represented by E_o.

The degree of modulation is represented by the little letter m.

The frequency of the modulating voltage is called f_s.

The carrier frequency is represented by f.

The degree of modulation is largely analogous to percentage of modulation. Fig. 23 shows what we mean by this. Here we can see that E_o represents the average amplitude of the unmodulated carrier. E_{max} represents the peak of the voltage during modulation. E_{min} is the minimum voltage during the moments of modulation.

The degree of modulation can be calculated by the formula:

$$m = \frac{E_{max} - E_o}{E_o}$$

This represents the maximum magnitude of the voltage at the instant of peak modulation, or to be more exact, at the instant of peak voltage.

For negative modulation peaks (which are actually troughs rather than peaks and represents the downward modulation) the formula is:

$$m = \frac{E_o - E_{min}}{E_o}$$

By carefully examining these formulas we can observe certain interesting things, yet they are not particularly new to us since we have been discussing them from a somewhat different approach. It can be seen that the degree of modulation on the negative peaks (troughs) can never exceed unity (100%). Any attempt to exceed this value results in losing the carrier completely -- it is at that time completely extinguished.

The modulation can exceed unity (100%) on the positive peaks. But when that happens we become involved in what is called overmodulation.

The first step in analyzing a modulated carrier wave is to examine the formula for the modulated wave. Such a formula would include the degrees of modulation, the value of the carrier wave voltage when unmodulated, and the magnitude of the modulating voltage. The basic formula for a modulated carrier wave is commonly written:

$$e = E_o(1+m \sin 2\pi f_s t) \sin 2\pi ft.$$

The little *t* in the formula stands for time in seconds.

Since there are three frequencies involved in any modulated carrier wave, the carrier itself and the upper and lower sidebands, it is usually necessary to modify the basic formula to include all three frequencies, or all three waves. This is done by rewriting the formula in this manner:

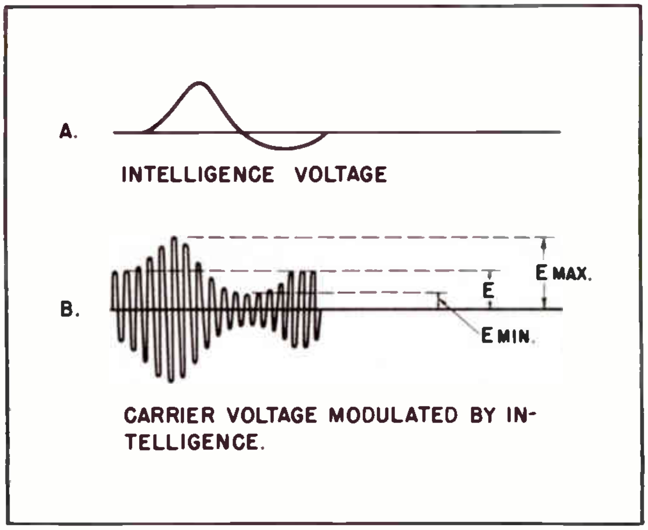

Fig. 23.

$$e = E_o \sin 2\pi ft + \frac{mE_o}{2} \cos 2\pi(f - f_s)t - \frac{mE_o}{2} \cos 2\pi(f + f_s)t.$$

The first part of the formula, that part preceding the plus sign, represents the carrier wave itself. This part is in simplified form, and is the same irrespective of the degree of modulation, or of the modulation frequency. The second part of the formula, that part between the plus sign and the minus sign, represents the upper sideband frequency. That part of the formula following the minus sign represents the lower sideband frequency.

Now it should be understood that this formula will express the magnitude of the carrier voltage at any given instant when the carrier is being modulated by a single frequency. In the event the carrier is being modulated by a more complicated modulating voltage, the formula will of necessity become considerably longer.. This will be because of the fact that each of the various frequencies of the modulating voltage must be taken into consideration. But once you know the basic formula, it is not too difficult to derive the exact form of the formula components for the other frequencies.

It is not our purpose to frighten you by including these formulas for calculating the instantaneous voltages on the carrier frequency. For many students it will have relatively little application. But for those who feel they need the exactitude which only a formula of this kind can give, we think it fair to include it for their benefit.

(over)

NOTES FOR REFERENCE

The circuits devoted to the transmission of video signals are much more complex than those used exclusively for the transmission of sound.

Television channels are 6 megacycles wide.

The video signal occupies about 5-3/4 megacycles of the television channel, leaving about 1/4 megacycle for the sound modulated carrier.

Frequencies below approximately 28 to 30 megacycles have a tendency to follow the curvature of the earth. This makes them useful for long distance communication.

Frequencies above 28 to 30 megacycles do not normally follow the curvature of the earth. They penetrate through the ionosphere and are lost in outer space.

Variations in the atmospheric conditions affect the transmission of radio signals. Sometimes some of the lower frequencies penetrate the ionosphere and are lost. At other times the higher frequencies are reflected back to the earth and can be picked up at great distances. Such cases are not normal occurrences.

A single television channel is approximately six times as wide as the entire radio broadcast band.

A radio broadcast carrier may have sidebands which do not exceed 5 k.c. each side of the carrier. A television video carrier will have a sideband which is 4000 k.c. wide.

To avoid a need for channels even wider than those now used, it is the practice to suppress the lower sideband of the video carrier.

The video carrier of a television broadcast station is amplitude modulated. The sound carrier is frequency modulated.

Each television station has two complete transmitters; one for the video and the other for the sound.

Television video tuned circuits have a low "Q".

Persistence of vision is that property of the human eye which causes it to continue seeing something which has actually ceased to exist, or has ceased to be visible.

NOTES

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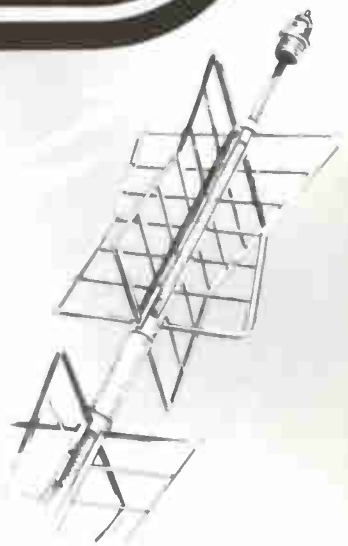

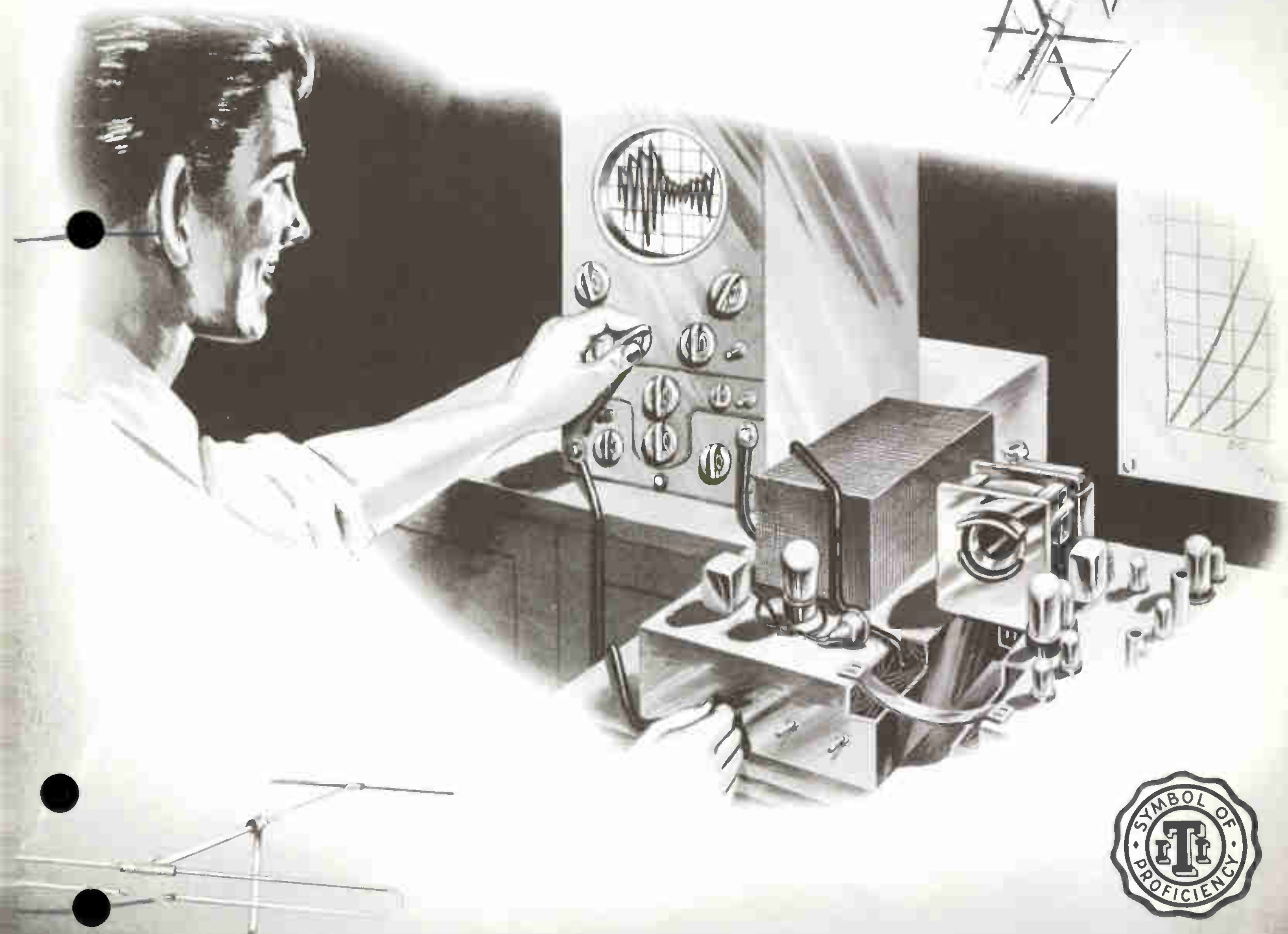

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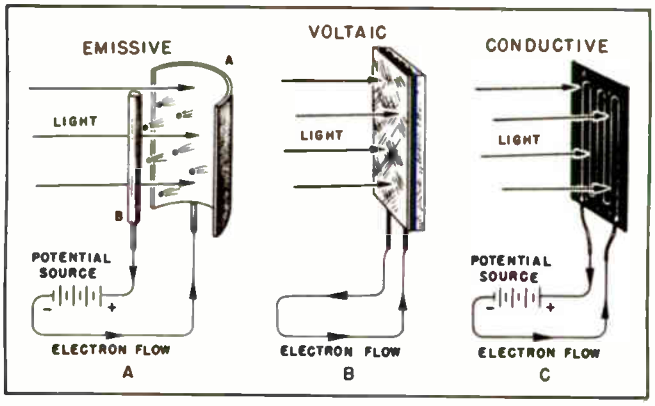

Fig. 2. Basic Types of Photoelectric Cells.

The use of photoelectricity is not confined to the field of television alone. In fact it is a big branch of electricity and electronics in its own right. The "electric eye" used to open garage doors, store doors, turn water fountains on and off, and to maintain rigid inspection on production lines are all practical uses of the photoelectric tube. The operation of the photoelectric tube closely parallels the method by which the television camera changes light variations into electrical voltage variations.

Section 2. PHOTOELECTRIC PHENOMENA

Before going into a discussion of a television camera tube it is necessary to first study briefly the phenomenon known as *photo-electric emission*. You will recall that previously in our studies we have discussed thermionic emission and secondary emission. There are at least two other types of electronic emission: Photoelectric emission and a peculiar type of emission which takes place under the stress of high voltages. We need not be concerned with this last type at this time, but we should understand a little more about photoelectric emission.

In the field of photoelectricity there are three basic types of photoelectric cells; the photo-emissive cell, the photo-voltaic cell, and the photo-conductive cell. The name of each type is fairly descriptive of its operation. (See Fig. 2.)

The photo-emissive type of cell emits electrons from a light sensitive cathode whenever light is allowed to strike the cathode. The photo-voltaic type of cell is one which actually generates an electrical voltage whenever light is allowed to fall upon the cell. The photo-conductive type of cell is one in which the resistance of the cell changes whenever light falls upon it.

The photo-conductive cell was probably the type which first became of any value commercially. It was usually composed of selenium in a special arrangement so that as light fell upon the cell, the resistance of the selenium would change in value and allow more or less electricity to flow through it. At one time the photo-conductive cell was used rather widely in burglar alarm systems. But the photo-conductive type of cell has fallen into disfavor in recent years.

The photo-voltaic cell is widely used in light-meters. When light falls upon the cell, the energy of the light is changed into a small voltage. The voltage generated is quite small, but it is strong enough to send a current through a sensitive D'Arsonval type of meter. The stronger the light, the more voltage will be generated, and the more current will flow through the meter. Such a meter is usually calibrated in light-units of some kind and the user can read the intensity of the light by glancing at the calibrated scale.

It is the third type of photo-electric cell which is now considered the most useful, and is the one which interests us in our work at the present time. That is the photo-emissive cell. The photo-emissive cell employs a cathode of comparatively large area. The cathode is coated with a light-sensitive material which has a tendency to emit electrons whenever light strikes it.

Section 3. SIMPLE PHYSICS OF LIGHT

You may wonder how light could do such a thing. A few words of explanation should be enough to make the matter sufficiently understandable for our purpose. We are generally so accustomed to light -- we take it so much for granted -- that we seldom pause to consider just what it is. Although we seldom think of it as such, light is actually a form of energy. Reduced to its basic form, light is a form of wave motion — wave motion energy. Light has a frequency just like radio or television waves, but its frequency is far higher than even the highest television wave. The frequency of light is so high that for the sake of convenience a special unit has been created to measure it.

At one time everyone -- even the best learned scientists -- thought light flowed

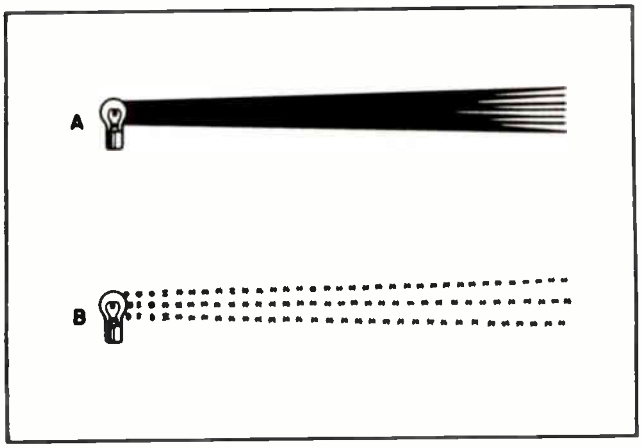

Fig. 3. Light Energy Flows in Pulses Rather than in a Continuous Stream.

in a continuous stream much as that shown in Fig. 3-a. But such a line of thinking led the scientists into many difficulties. They would develop a rule or a formula showing the relationship between the energy, the temperature, and the color of light. But they found that rules which held good for red would not work with blue or violet. Neither would those that held good for blue or green be good for use with red.

Finally after many years of effort and experimentation, a scientist named Max Planck proved that light did not flow in a continuous stream as shown in Fig. 3-a, but rather that it traveled in the form of wave motion in a series of separate and distinct pulses, as shown in Fig. 3-b. Countless experiments since that time have all tended to confirm Planck's theory, and formulas based on this idea have worked out successfully, regardless of the color of the light.

Radiated energy, such as light, can be broken down into basic units for the purpose of measurement. Each such unit of radiated energy is called a *quantum* of energy. This comes from one of the basic rules of physics. In the case of light, one *quantum* of radiated energy is called a *photon*. Thus we can see that so far as light is concerned, the units *quantum* and *photon* can be used interchangeably. In other words, a quantum of light is called a photon, but a quantum of some other kind of energy would probably have some other name. In the case of light, a photon is not a fixed quantity; instead, it depends largely upon the color of the light.

Light travels through space in the form of wave motion. However, it should not be thought that such wave motion is similar to that of waves upon water where there is a series of rising and falling walls of water. Instead, the waves are in the form of greater and smaller concentrations, these varying concentrations forming successive pulses such as is indicated in Fig. 4.

The distance between successive pulses, which is called the wave-length of the light, determines the color the eye sees when the light reaches it. The distance between the pulses determines the wave-length of the light, and this in turn, determines what the eye sees when the light reaches it. In the case of light, these wave-lengths are almost unbelievably short.

Light travels through space at the same speed that an electrical impulse travels through a wire or an electromagnetic wave moves through space. This is at the speed of approximately 186,000 miles per second. Actually the speed is just slightly higher than this, but for all practical purposes it is considered to be 186,000 miles per second. This also figures out to be approximately 300,000,000 meters per second.

Section 4. **WAVE-LENGTH VERSUS FREQUENCY**

There is a direct relationship between the length of a wave and the frequency of the waves. The *wave-length*, as was mentioned in your first lesson, is measured as being that distance between the crest of one wave and the crest of the next. It can also be thought of as being the distance between corresponding points on two successive waves.

The *frequency* means the number of waves which pass a given point during one unit of time. In practice this means the number of waves which pass a given point during each *second* of time. In the case of electromagnetic waves, let us take the hypothetical case of *one* wave passing a given

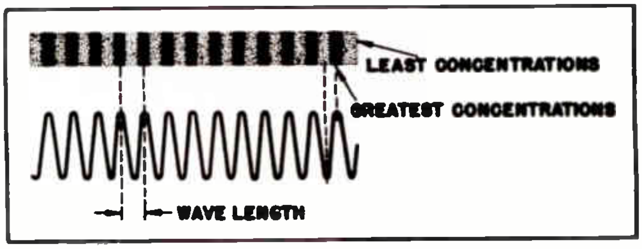

Fig. 4. Successive Pulses of Light Follow Each Other in Rapid Succession. The Distance Between the Pulses are Called the Wave-Length.

point each second. That would be the same as one cycle per second. But if only one wave passed each second it would mean that the wave would have to be 186,000 miles or 300,000,000 meters long. Such a wave could be said to have a wave-length of 300,000,000 meters and a frequency of one cycle.

If 60 such waves passed a given point each second, such as would be the case of ordinary 60-cycle A-C power, the frequency would be 60 cycles per second and the wave-length would be 300,000,000 meters divided by 60, or 5,000,000 meters. 5,000,000 meters is a little less than 3000 miles.

In the case of a 1000-cycle audio note, there would be a frequency of 1000 cycles per second. The wave-length, that is the distance between the peak of one wave and the peak of the next, would amount to 300,000,000 divided by 1000, which is 300,000. This means that an A-C voltage having a frequency of 1000 cycles would have a wave-length of 300,000 meters.

From these examples it begins to become evident that as the frequency increases, the length of the wave becomes less. A frequency of 500,000 cycles per second, which is just below the AM broadcast band, would have a wave-length of 600 meters. A frequency of 1,500,000 cycles, which is near the upper limit of the AM broadcast band, would have a wave-length of 200 meters. A frequency of 50 megacycles, which is just below the lowest television band, would have a wave-length of 6 meters. A frequency of 100 megacycles, which is near the center of the FM broadcast band, would have a wave-length of 3 meters.

It must have occurred to you by this time that it would be possible to work out a simple formula for use in converting from wave-length to frequency, or from frequency to wave-length. And such, of course, is true. Such a formula has been worked out.

In using the formula the little letter f has been used to represent frequency, just as it has been used in so much of our work so far. The Greek letter Lambda (λ) is used to represent the wave-length. Since in electrical, radio and television work most measurements are taken in meters, centimeters and millimeters, it is customary to use as a conversion factor that distance an electrical or electromagnetic wave will travel in a second of time. As was mentioned previously, such a wave will travel 300,000,000 meters during each second of time. The formula is set up as:

$$\text{Wave-length } (\lambda) = \frac{300{,}000{,}000}{\text{frequency (in cycles)}}$$

The formula can be reversed, of course, so as to obtain the frequency when the wave-length is known. When that is the case, the formula would be:

$$\text{Frequency (in cycles)} = \frac{300{,}000{,}000}{\text{Wave-length (in meters)}}$$

In most radio and television work it is customary to work with kilocycles and megacycles rather than with mere cycles per second. When that is done it becomes possible to shorten the formula somewhat by using smaller figures. This reduces the possibility of error when making calculations. When using kilocycles, the formula is changed to read:

$$\text{Frequency (in k.c.)} = \frac{300{,}000}{\text{Wave-length (in meters)}}$$

If the frequency is known in kilocycles, the wave-length can be quickly found by reversing the formula:

$$\text{Wave-length (in meters)} = \frac{300{,}000}{\text{Frequency (in k.c.)}}$$

If megacycles were used in the formula, the conversion factor would be changed to 300 instead of the 300,000 for kilocycles and the 300,000,000 used for cycles per second.

All of these formulas will be used with increasing frequency. Most radio and television men memorize them so thoroughly they can usually work out conversion problems in their heads without need for using pencil and paper. You will find it useful to jot them down in your little notebook at this time so you will have them handy whenever you need them. Before long you will find you, too, know them so well that you will not have to look them up when you need to use them.

Section 5. ANGSTROM UNITS

It is time we got back to the thing we were discussing when we digressed for a discussion of the relationship between frequency and wave-length. That is the frequency of light waves. By continuing a study of what happens to the wave-length as the frequency increases, you will find that at the higher frequencies the wave-length becomes extremely short.

When a frequency of 300 megacycles is attained, the wave-length will have decreased to 1 meter. Increasing the frequency still higher to 30,000 megacycles, which is a frequency often used in radar work, the wave-length will have decreased to one centimeter, or .01 meter. One centimeter is equal to about .4 inch. That is a little less than 1/2 inch.

But the wave-length of light is still much shorter even than this. The wave-length of blue-green light is about 1/50,000th of an inch in length. This is such a short wave-length that most people have trouble grasping its significance when first introduced to it. Most mechanical work is fitted to tolerances of the magnitude of 1/1000th of an inch. But blue-green light has a wave-length so short that 50 waves occupy only 1/1000th of an inch.

Other parts of the color spectrum of light have even shorter wave-lengths. The wave-length of violet is only 1/61,000th of an inch long. The frequency of violet is the highest to which the human eye is capable of responding. This is not to say that there are no colors with a higher frequency than violet. There are colors in that region, but the human eye is unable to see them. They are called *ultra-violet*.

The lowest frequency to which the human eye will respond is that of red which has a wave-length of 1/38,000th of an inch. Here again it should be stressed that just because the human eye cannot detect colors with a lower frequency than that of red, we should not deceive ourselves into believing there are no colors present in that region. As a matter of fact, the frequency spectrum of color goes down much lower than that of red. These colors we call *infra-red*.

It is rather inconvenient to use fractions when measuring things, or when using them in formulas. To get around this inconvenience, scientists have brought into existence a new unit of measure for application to the wave-lengths of visible light. Scientists have created a measuring unit called the *Angstrom Unit*. The unit was named after a Swedish scientist who did much important work in the field of light.

The Angstrom Unit is an exceedingly small unit of measure. It is equal to 0.00000001 centimeters, and is the same as saying 39/ten-billionths of an inch in length. By the use of the Angstrom Unit we can use whole numbers when working with light rather than the tiny fractions we must use if we cling to the inch as the unit of measure. Instead of saying blue-green has a wave-length of 1/50,000th of an inch, we can say that it has a wave-length of 5080 Angstrom Units. Violet would have a wave-length of 4150 Angstrom Units, which is merely another way of saying 1/61,000th of an inch. In the same manner, red has a wave-length of 6600 Angstrom Units, which is equivalent to the 1/38,000th of an inch we mentioned before.

Section 6. ENERGY OF LIGHT

Earlier in this lesson we mentioned the fact that light was a form of energy. As a matter of fact, the energy in each photon of light is directly proportional to the frequency of the light. This means that by doubling the frequency of the light, the amount of energy present would be doubled. By the same token, halving the frequency would halve the energy. This phenomenon is called *Planck's Law of Radiation.* Planck even went so far as to figure out the number by which frequency must be multiplied in order to determine the exact amount of energy per photon.

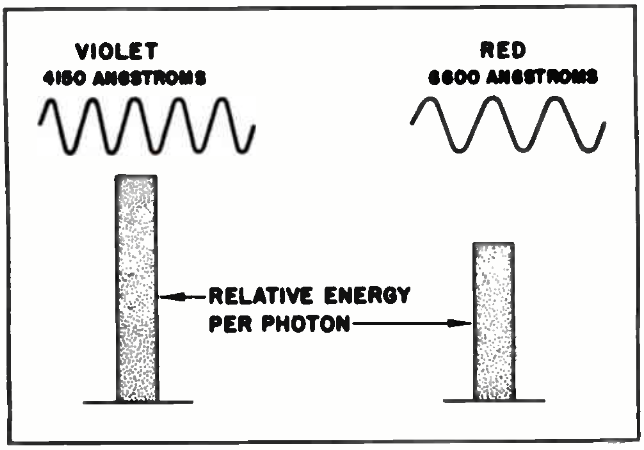

Fig.5. The Energy Per Photon in Inversely Proportional to the Wave-Length.

Since the energy of light is *directly* proportional to the frequency, it follows as a natural consequence that it will be *inversely* proportional to the wave-length. This means that the greater the wave-length the less is the energy per photon, and that the shorter the wave-length, the greater will be the energy per photon. To illustrate this fact, Fig. 5 shows how the energy of violet light is much greater than that of red light. We do not fully understand just why this should be. It is one of the things arranged for us by nature.

Section 7. THE RADIATION SPECTRUM

While it is not absolutely essential to our problem at hand, nevertheless it is interesting to know something of the frequency spectrum which exists for the frequencies above those used in radio and television work. Understanding something of them makes radio and television work interesting, and at the same time more understandable.

Generally speaking, the frequencies used for "radio" work extend from what are called the "long waves" used for long distance international telephone work up to the extremely short waves called the "micro-waves". The so-called "long waves" occupy the frequency band which is below the AM broadcast band; that is, the band of frequencies below 550,000 cycles.

Above the broadcast band we find what are commonly called the "short waves". These extend up to about 28. to 30 megacycles. These are frequencies which can, under proper conditions, travel for extremely long distances around the world. They are the frequencies which are capable of being reflected back and forth between the earth and the Ionosphere.

Above the "short wave" band, and extending up to about 300 megacycles, is a band of frequencies which are now generally called the "very high frequencies". These frequencies are used for FM broadcasting, television broadcasting, aircraft-to-ground and aircraft-to-aircraft communication, police work, public utility communication, taxicab dispatching, truck dispatching, some kinds of marine work, landing and marker beams for aircraft, and similar uses.

At one time much of this band was commonly called the "ultra high frequencies". Even now the point of demarcation between the very high frequencies and the ultra high frequencies is not entirely clear. The FCC has laid out definite frequency ranges which mark the limits of each band, but since these are different from those with which most old time radio men are familiar, some confusion is the rather inescapable result.

The "ultra high frequencies" is a band which extends from about 300 megacycles up to about 3000 megacycles. Some portions of this band have been set aside by the FCC for experimental work in television, particularly for experiments directed toward the perfecting of new and improved color television. Other frequencies have been set aside as a so-called "citizens band" where short range civilian transceivers (combination transmitters and receiver) are permitted without a license; this is the only portion of the radio spectrum where transmitters are permitted to operate without a license. Still other parts of the band are set aside for secret military work. And others for use by radio amateurs.

Extending upward from the "ultra high frequency" band, and possibly including part of it, is what is called the "micro-wave"

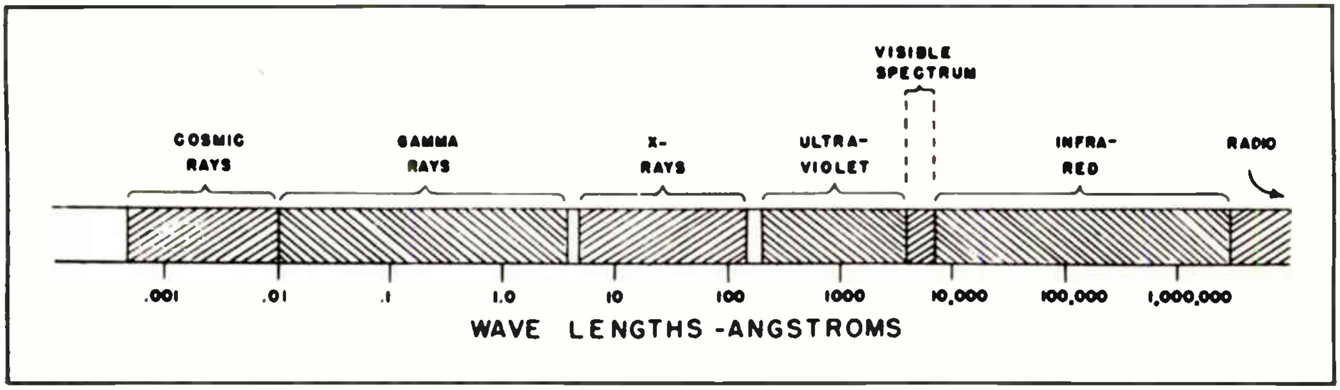

Fig. 6. The Radiation Spectrum Above Those of Radio Waves.

band of frequencies. It is not within the scope of our studies to go into a discussion of the micro-waves. These are frequencies which have wave-lengths so short they are only fractions of a meter in length.

Micro-waves are regularly used in radar work. They are now also being used more and more by the commercial wire companies, such as the American Telephone and Telegraph Co., for the transmission of telephone conversations between cities. When so used, they are usually called "Micro-wave Relay" systems. In operating such a system, the companies build high towers on top of which are located the antennas for the receiving and sending of signals. The towers are located so as to be within line-of-sight of each other. Several networks of such micro-wave communications are now in operation within the United States. They extend in several directions from New York. They touch several large cities such as Cleveland, Chicago and Milwaukee. Plans are now being made to extend them throughout the country. In addition to telephone conversation, it will be found that many radio and television network programs are carried from city to city by means of the micro-wave systems.

Extending above the bands of what are called "radio" frequencies are several others, including those of the infra-red region, light and others. Fig. 6 shows in graphical form the location, arrangement and extent of these bands of extremely short waves. The chart shows the *radiation spectrum* from the radio waves through what are called the "cosmic rays". You should exercise considerable care in studying the chart. It is not arranged in a linear manner. In order to cover such a tremendously wide range of frequencies, it uses what is called a "logarithmic" scale. Using the logarithmic scale, each principal division represents 10 times the value of the one to the left, or 1/10 the value of the division to the right.

Cosmic rays, which have a wave-length between about 0.0005 and 0.01 Angstrom Units, are a form of radiation which seems to come to the earth from outer space. Their source is not known at the present time. They cannot be traced to the sun, the stars, or to any other known celestial sources. However, we need not concern ourselves about them since in our work they are of little importance. They are merely mentioned here to show how they fit in with the general plan of frequency arrangements.

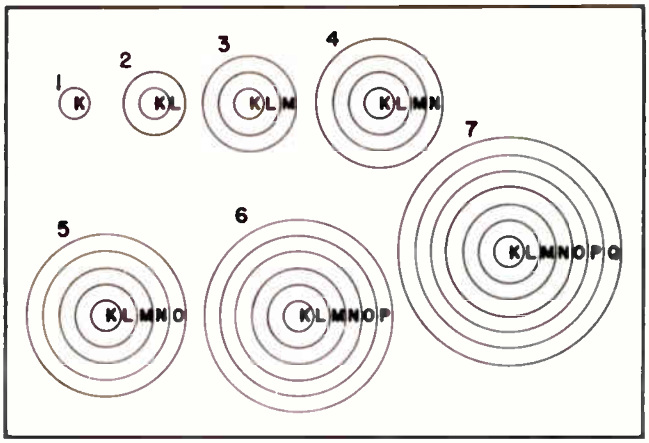

Fig. 7. How the Atoms of Various Materials Arrange Themselves in Orbits, or Shells.

Section 8. HOW LIGHT AFFECTS A PHOTO-EMISSIVE SURFACE

To clearly understand how a substance is affected by light to the extent that it will emit electrons, it is necessary to go back to our study of the atom and its electrons. You will recall from your earlier studies that atoms are composed of one or more electrons and one or more protons. Sometimes this arrangement is complicated by the inclusion of one or more neutrons, but the neutrons need not concern us in our present studies.

The electrons arrange themselves in orbits which surround the protons composing the nucleus. The electrons are constantly moving in these orbits, constantly circling the nucleus. These orbits, or shells as they are more commonly called, are arranged in concentric layers surrounding the nucleus with one or more electrons following the same orbit, or occupying the same shell as is the more customary method of thinking of them. The inner orbit, or shell, may have one or two electrons, the next orbit may have up to eight electrons. If the atom is one of the heavier elements having a considerable number of electrons, these extra electrons will occupy additional orbits outside the first two. (See Fig. 7.)

Fig. 8 shows the arrangement of the electrons in the atoms of some of the better known elements. Note that in the case of sodium there is only one electron in the outer-most shell. Fig. 9 shows the arrangement of several adjacent atoms of sodium, each of which has a single electron in the outer-most shell. This condition of a single electron in the outer-most shell is

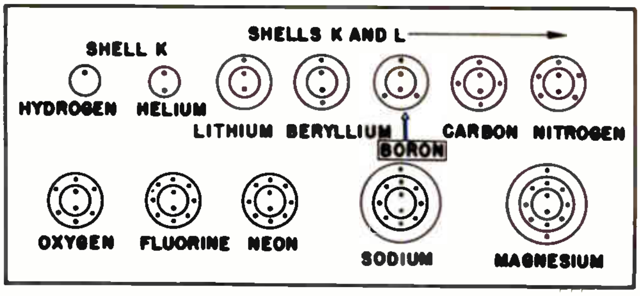

Fig.8. As Each Space Shell is Filled with Its Complement of Electrons, More Shells are Added. Additional Electrons Mean Different Atom Weights, thus Different Elements.

a significant one, and gives rise to the condition in which photo-electric electronic emission can take place.

The liberation of electrons from a substance by the action of light is called *photo-emission*. The substance itself -- the element -- is spoken of as being *photo-emissive*. The surface from which emission takes place is called a *photo-emissive surface*.

One of the elements which possesses photo-emissive properties, and which has been used in photo-emissive work is sodium. It will be noted by referring back to Fig. 9 that each of the atoms of sodium has a single electron all by itself in the outer orbit, or shell. Those single electrons are traveling around the nucleus at a high rate of speed at all times. The kinetic energy and inertia, resulting from this high speed is almost enough to tear the electron away from the nucleus. But unless aided by some additional force, the electron will continue to stay in its own orbit. It might be said that the outer electron has a relatively high amount of energy. It has almost enough to break away from the atom, leave the surface of the mass of sodium and thus become a *photo-electron* -- an electron which has been emitted from the surface.

Such is the condition which exists under most circumstances. Now suppose a small amount of energy is added to that of the electron -- energy which can be received from a beam of light. The small amount of energy contained in the endless pulses of a beam of light is sufficient to cause the electron to leave the surface of the sodium and emerge into the space surrounding it.

This situation is often expressed in another way: The energy of light, added to the energy already possessed by the electron, is enough to cause the electron to emerge into space.

Sodium is one element, as we have mentioned, which possesses a photo-emissive surface. However, it is not generally used in photo-electric work. We have used it here for the purpose of explanation because it is an element which is reasonably familiar to every person. In searching for an element which is most useful in photo-electric work, it is desirable to obtain one which has only one electron in the outer orbit, or shell, and which has a large number of shells, thus placing the electron as far as possible from the central nucleus.

Lithium, potassium, rubidium and cesium are all elements in addition to sodium which have only one electron in the outer shell, or orbit. Each of these possesses more or less photo-emissive qualities. Listed with their number of shells, they would be like this:

Lithium	2 shells
Sodium	3 shells
Potassium	4 shells
Rubidium	5 shells
Cesium	6 shells
Virginium	7 shells

The element Virginium is a recently discovered element. Its possibilities have not been explored very thoroughly, and relatively little is known about it. For that reason it has not yet assumed any important place in the photo-electric field. Uranium could be listed in this category, but it possesses other characteristics which reduce its usefulness in photo-electric work.

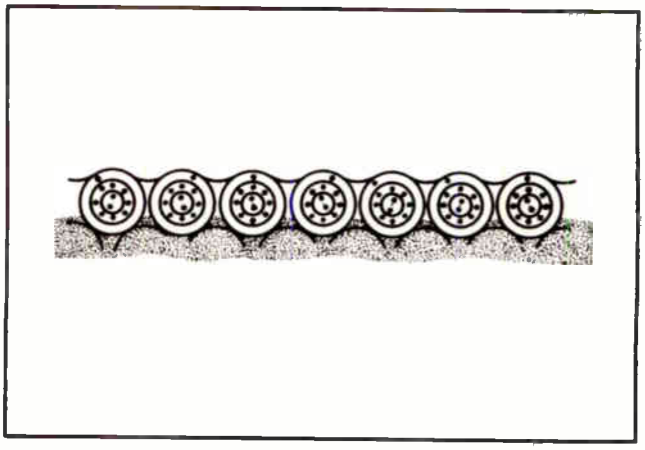

Fig.9. Arrangement of Electrons in Atoms of Sodium.

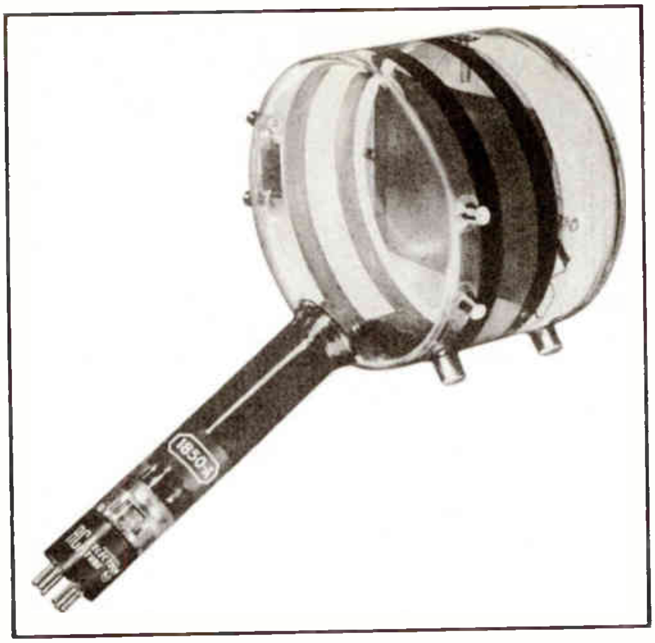

Fig. 10. An Iconoscope.

Of the other mentioned elements, Lithium requires the most energy in order to allow its electrons to emerge into space from the outer orbit. Cesium, on the other hand, requires the least energy. It seems natural, therefore, that cesium is the element which has received the most attention in photo-electric work.

It has become the general practice in photo-electric work to use cesium, or cesium oxide, to coat the surface of the cathodes in photo-emissive phototubes. When light strikes the cathode, electrons will be emitted from the cathode and attracted to the more positive anode of the tube. Except for the fact that heat is not applied to the cathode, and that the electron emission varies with variations in the intensity of the light, the action of phototubes are quite similar to the action of other electron tubes.

Our description here of the natural phenomenon known as photo-electric emission is of necessity very short and sketchy. Yet it is enough to enable you to follow our explanation of the action which takes place in a television camera when the camera is focused on a lighted scene.

Section 9. HOW TELEVISION CAMERA TUBES OPERATE

One of the most important elements of a television camera is the camera tube itself. Fig. 10 is a picture of an Iconoscope, a camera tube developed by RCA. It has been widely used, and still finds much favor among broadcasters.

The Iconoscope is used to change an illuminated scene into a succession of electrical impulses. In construction, the Iconoscope consists of a circular piece of clear glass which will allow light to pass through into the interior of the tube. At the back of the tube is a mosaic plate. The mosaic plate is one of the most essential parts of the camera tube, and is the part which actually changes the energy of the light from the viewed scene into the electrical impulses needed to modulate the transmitter carrier.

The mosaic plate is about 3 inches by 4 inches in size. On the front surface, the part which faces the viewed scene, it is covered by minute globules of a photo-sensitive material. Each of the globules are extremely small, smaller than can be distinguished by the human eye, and each are electrically insulated from all the others. Further than this, the globules are also insulated from the metal of the plate itself. Fig. 11 indicates how the photo-sensitive globules are at the front of the mosaic plate, yet are not in electrical contact with it.

Fig. 12 shows how reflected light from a lighted object is passed through a lens and focused upon the mosaic plate at the back of the Iconoscope tube. As the light falls upon the photo-sensitive globules of material on the face of the mosaic plate,

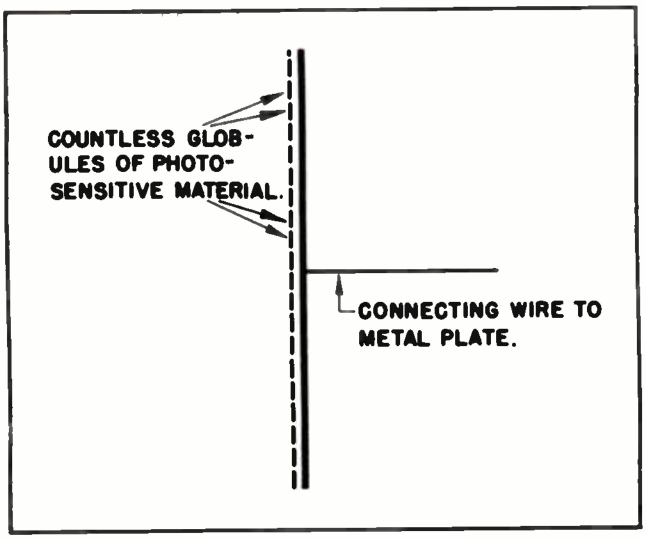

Fig. 11. Photo-Electric Coating on a Mosaic Plate for an Iconoscope.

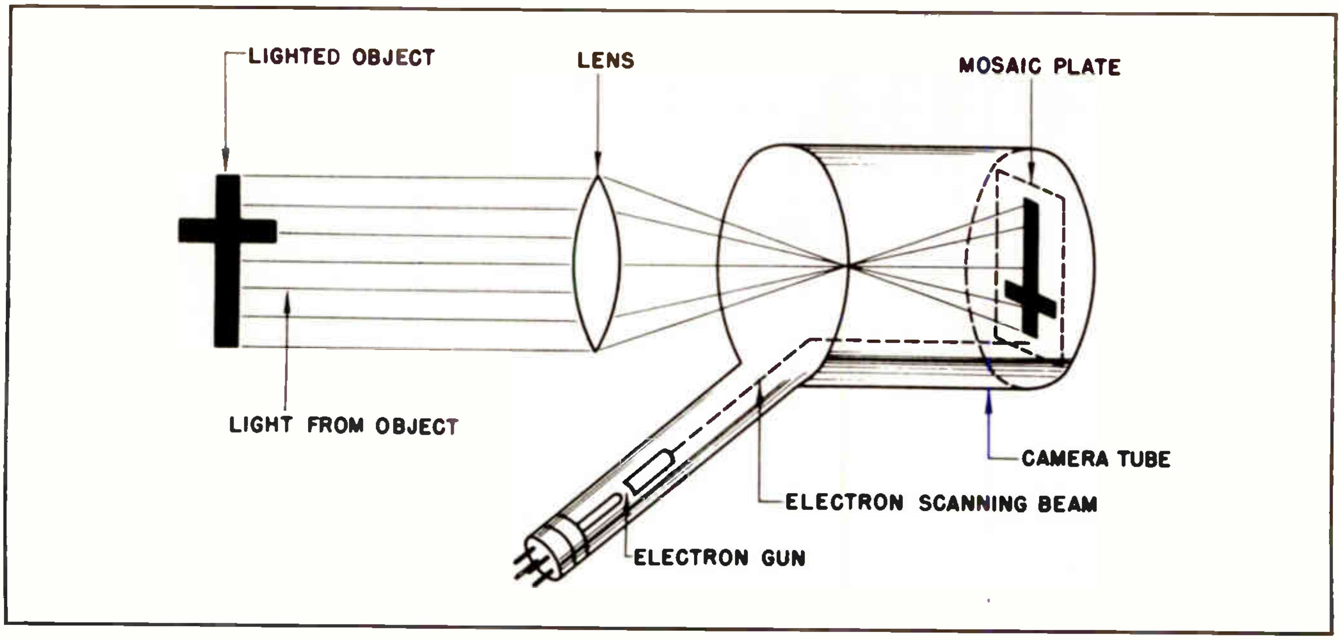

Fig. 12. Diagrammatic Arrangement of the Elements in an Iconoscope.

electrons will be emitted from each of the globules as is shown in Fig. 13. The emission of the electrons will make the photoelectrical globules individually more positive than they would be if no light had fallen upon them. Relatively speaking, the loss of the electrons through emission is a comparatively slow process. And since light is falling upon all the many globules of photoelectric material, most of them will be more or less positive with respect to the plate at their back. It should be thoroughly understood that each of these globules are positive because they have lost electrons through emission.

All of the globules of photo-emissive material will not have lost the same number of electrons through emission. This is because the same amount of light will not fall upon all the globules. If the light from a brilliantly lighted part of the viewed object falls upon a certain portion of the mosaic, the globules at that point will give up many more electrons than would some other portion of the mosaic which does not receive so much light; some portion which is focused upon some poorly illuminated portion of the viewed scene.

It might be that some of the globules of the mosaic may be 8 or 10 volts positive with respect to the metal plate while other globules may be only 1 or 2 volts positive. And this condition will exist all over the face of the mosaic. The voltage difference between the globules of photo-sensitive material and the metal plate behind them will in all cases depend upon the amount of light which falls upon each particular particle of material.

We can see now where we have set up a condition where varying amounts of voltage represent the varying gradations of light which are reflected from a lighted scene or object. These voltage differences exist all over the surface of the mosaic, with the voltages being the greatest where the light concentration is the strongest, and least where the light is weakest.

But the mere presence of the existing static voltages on the mosaic plate are of little use so long as they are confined to the plate. They must be transferred to places outside the Iconoscope tube. If we could erase each of those voltage differences, one by one, the loss of the voltage would be noticeable for a moment on the plate at the rear of the mosaic. As the voltage on each globule was erased, it would affect the electrical balance on the metal plate behind it. By erasing the voltage, globule by globule, in a straight line across the face of the mosaic, we would set up a series of voltage changes in the connecting wire to the plate, the voltage varying according to the voltage charge on each globule as it was erased.

As the voltage was erased on a globule which had been well lighted, there would be a sharp change in the voltage on the plate at the rear. But when the voltage was erased on a globule which had been focused on a shadow in the viewed scene, there would be much less change in the voltage on the metal plate at the rear. From this it should be reasonably clear that by progressively erasing the voltage differences which exist between each of the many globules and the metal plate, we will set up a series of voltage changes on the metal plate which correspond exactly to the degree of light which fell upon the globules. These voltage changes can then be impressed upon the grid of a vacuum tube and greatly amplified to whatever value is needed.

The next problem is: How are we going to erase these voltage differences which exist between each of the many globules and the metal plate behind them? First, it should be remembered that these voltage differences are caused by a deficiency of electrons on each of the globules, a deficiency which has been caused by the emission of electrons due to the photoelectric effect of the materials composing the globules. If we are going to erase the voltage difference, our problem boils down to that of supplying the missing electrons back to each of the globules on the mosaic.

This problem is solved by the simple expedient of focusing an electron beam on the mosaic plate and allowing it to sweep back and forth across the face of the mosaic, line by line, until the entire surface of the mosaic has been swept. Since the electron beam supplies the necessary missing electrons, the globules are each brought back into an electrical balance as the beam sweeps over them. Each globule will take only enough electrons from the beam to set up an electrical balance; excess electrons cannot be acquired by the globules.

The electron beam will divide the face of the mosaic plate into 525 lines. It will sweep across the face 262.5 times while it is making one sweep from the top to the bottom. Then it will start in again and make a second sweep, this time sweeping those lines missed during the first trip from the top to the bottom. This sweeping action is very similar to that described in an earlier lesson when we were discussing the cathode-ray tube. The electron beam will make 60 trips from the top of the mosaic to the bottom, each second. Since it takes two trips to completely sweep the mosaic, it means that the mosaic will be swept completely clean 30 times each second, making 30 frames each second.

In our preceding description we spoke of the globules of photo-sensitive material being mounted on, but insulated from, a metal plate. This was used at that time to simplify our description. In actual construction, however, the mosaic plate is a very thin piece of mica. On one side of the mica is mounted the many small globules of photo-sensitive material. These are usually tiny deposits of silver which are covered with cesium oxide, or with pure cesium. The back of the thin mica sheet is coated with colloidal graphite which is used as the conducting material for the signal plate. Each individual globule of silver-cesium has a diameter of less than 1/1000th of an inch. Each is insulated from its neighbors by the mica.

In our study of cathode-ray tubes we learned that the deflection of the electron beam could be accomplished in either of two ways: By means of electrostatic plates inside the tube itself, or by means of magnetic deflection coils on the outside of the neck of the tube. The same thing is true in the case of the Iconoscope camera tube. Types 1848, 1849 and 1850 Iconoscope tubes all use magnetic deflection. When using these tubes, the magnetic deflection coils surround the neck of the tube near the point where the neck joins the main body of the tube.

RCA builds another type of Iconoscope called type 5527 which uses both electrostatic deflection and electrostatic focus.

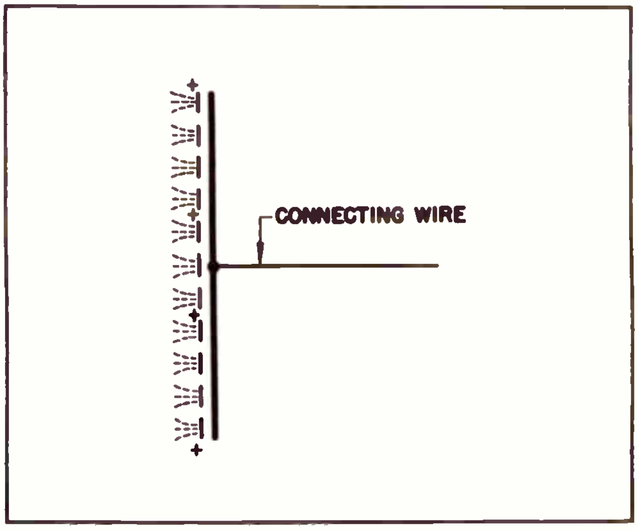

Fig. 13. Electronic Emission from the Photo-Sensitive Elements on the Mosaic of an Iconoscope.

This is a smaller tube than those using magnetic deflection, being only about 9 inches in length, and does not possess the large bulbous end such as we have previously described.

The Iconoscope has good sensitivity to light, and has been employed to good advantage by the Television Industry ever since it was introduced by its inventor, Dr. V. K. Zworykin. However, it does have a limitation in the form of "shading" which can create undesirable effects unless carefully controlled. This "shading" amounts to large areas of varying brightness levels which are not contained in the original image. This is brought about as a result of the redistribution of secondary electrons which have been emitted from the mosaic plate, then returned to the mosaic where they are not wanted. When these electrons return to the mosaic plate, they do so in a pattern which is not uniform. Consequently they produce an uneven distribution of the charge on the various globules on the mosaic which is an addition to, and different from, the charge on the mosaic which was produced by the lighted image. The result of all this is undesirable signal variations in the output of the tube as the electron beam passes over the mosaic plate.

The spurious shading is often called *black-spot* or *dark-spot* signal because it is often generated by scanning the mosaic plate with the electron beam even when no light is reaching the plate.

The spurious shading is inherent in the Iconoscope tube. It can be minimized, however, by employing relatively low values of beam current; that is, by reducing the intensity of the electron scanning beam. This is done at the expense of efficiency in picking up a useful camera signal, but is generally reasonably effective. Since the output of the tube is reduced in order to avoid the undesirable shading, it means that more amplification is necessary to build up the signal to desirable values. Despite this weakness of the Iconoscope tube it has enjoyed genuine popularity, and is widely used.

Section 10. **THE IMAGE ORTHICON**

When the human eye views a scene it sees all the colors ranging from red through green to violet which are reflected by the objects in the scene. Thus the human eye can see such colors as red, orange, yellow, green, blue, indigo and violet. Furthermore, it can see gradations between these colors, and combinations of them. Even a color blind person will see the scene as various gradations of gray, and white and black, the gradations varying according to the colors.

Fig. 14. An Image Orthicon.

But the human eye does not see light reflections which are in the form of ultra-violet light. The ultra-violet light, if strong enough, may affect the eye, and even injure it. Such light will also cause sunburn where it falls upon the unprotected skin. But the eye is incapable of actually "seeing" such light. Neither can the human eye see objects which reflect the infra-red light. The inability of the human eye to see infra-red light is taken advantage of in many ways in industry and in warfare. During the second world war, special searchlights sent out beams of infra-red light, the reflection of which was picked up through special telescopes sensitive to infra-red and then changed into visible light. In this manner it was possible to watch things on a battlefield without the enemy being aware he was watched. Infra-red light is also used in burglar alarms. The light is not visible to the human eye, but photoelectric tubes are sensitive to that light.

In photography and photoelectric work, as well as when working with television cameras, the inability of the human eye to see ultra-violet and infra-red light often poses certain problems. The mere fact that the human eye does not "see" certain portions of the color spectrum, does not mean that those portions of the spectrum do not exist.

They do exist. And many photographic films, photoelectric tubes and television camera tubes "see" that light and translate it into shadings of gray which the eye, in turn, can see. The result of this is that a scene which looks one way to the human eye may look entirely different on a photographic film, or when viewed by a television camera.

Experienced photographers are well aware of these things. Color photographs which are taken early in the morning or late in the afternoon tend to have a strong reddish cast, for example. Since the sun is nearer the horizon it travels through a larger portion of the earth's atmosphere before it reaches the surface of the earth where the photograph is to be taken. In passing through so much of the atmosphere, more of the ultra-violet rays and the higher-frequency colors will be filtered out than is the case when the sun is more nearly overhead. This means that more of the red and the infra-red rays (which are not so susceptible to the filtering action) reach the earth. The infra-red rays penetrate through heavy mist, smoke and other obscurances which prevent the passage of the visible light. The eye cannot see the infra-red rays, but they register on the film in the camera and tend to give it a strongly reddish tint.

Continued laboratory experiments over the years have shown us how to create chemicals which are particularly sensitive to certain portions of the color spectrum. Some of these have a peak sensitivity in the ultra-violet region, yet are almost completely insensitive to red and infra-red. Others are exceptionally sensitive to red and infra-red, yet virtually insensitive to blue, violet and ultra-violet. Still others reach their peak sensitivity in the region of green but lose much of their sensitivity to colors which are at either end of the color spectrum from green. These last mentioned ones have a sensitivity to the color spectrum which closely parallels that of the human eye. They "see" pretty much the same ranges, and gradations, of colors as the human eye sees.

The limitations of the Iconoscope camera tube led to continued experiments which it was hoped would overcome them. P. T. Farnsworth invented a tube which he called the Image Dissector. The construction of that tube avoided the problem of shading which is inherent in the Iconoscope. The image dissector tube is capable of providing a picture which has excellent contrast, minute detail, and uniformity of shading when there is enough light available for the televised scene. When used with a high-quality lens of large diameter, and when the scene to be televised is lighted to a brilliance of 1000 foot-candles or higher, the camera can be used as a direct pick-up for televising studio scenes.

But it should be noted that this is an extremely high level of illumination. The need for such a high level of illumination has limited the use of this tube to certain specialized purposes. It is highly useful in televising motion picture film. There the necessary high level of illumination can be easily attained. When so used, the televised film has remarkable clarity.

Neither the Iconoscope nor the Image Dissector were the complete answer to the television broadcaster's dream of the perfect camera tube. Although the Iconoscope has a light sensitivity much greater than that of the Image Dissector tube, and can be used to transmit excellent pictures under proper light conditions when used in the television studio, it soon became apparent that camera tubes with much greater sensitivity were needed. It became more and more desirable to televise scenes which could not be lighted under regulated conditions, such as those which exist in the studios.

Much work was directed toward the end of creating television camera tubes which could provide clearer pictures with a lower level of illumination. The result of these experiments are the image iconoscope, the orthiconoscope, and the image orthicon. The image orthicon (see Fig. 14), now gives the most promise of providing good pictures under all kinds of lighting conditions.

The type 2P23 Image Orthicon was introduced in 1946. It was intended for use in remote pick-up work. It had two drawbacks in that it had a rather low signal-to-noise ratio and its gray-scale color rendition was rather unfaithful due to its sensitivity to the infra-red. Nevertheless, its versatility in picking up scenes having wide ranges of illumination quickly led to its almost universal adoption for use in making remote pick-ups.

Continued experiments and further development greatly improved its signal-to-noise ratio. But the color rendition was still troublesome. This matter of color was

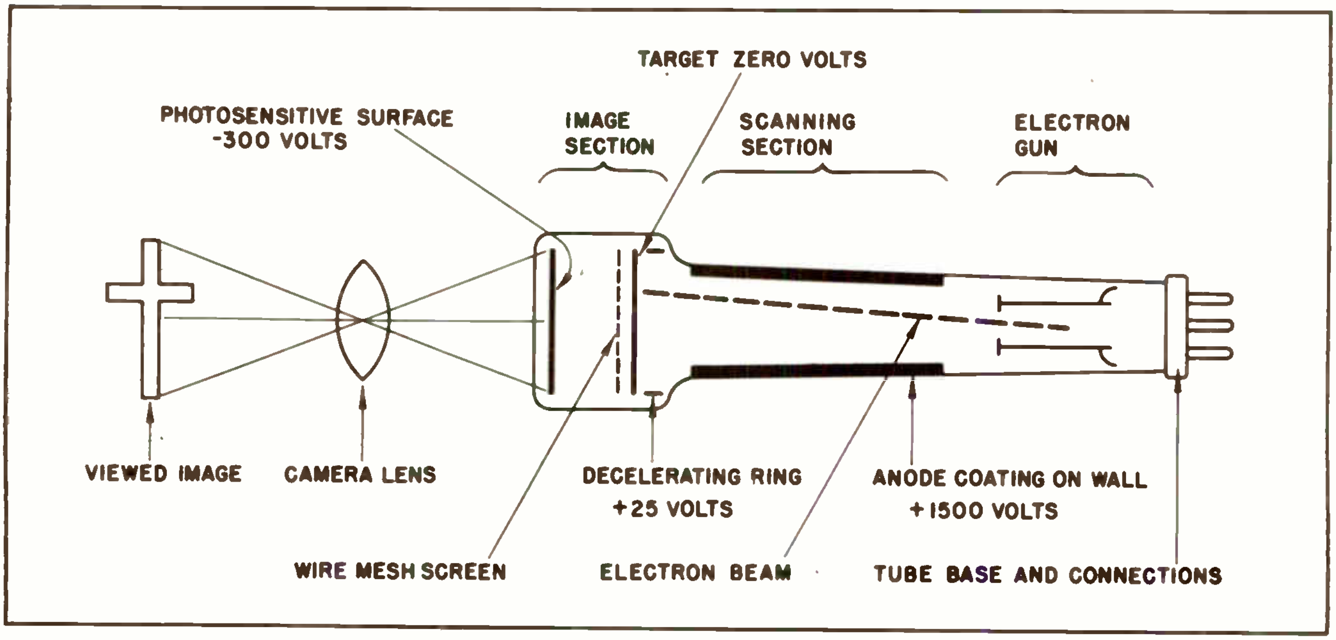

Fig.15. Some of the Essential Elements of an Image Orthicon.

particularly troublesome when the tube was used for studio work. Much of the illumination in studios is from incandescent lamps and light from incandescent lamps is notorious for its high content of infra-red. In some cases infra-red from tungsten-filament incandescent lamps runs as high as 80 to 90 percent of the light. Under these conditions the output signal from the image orthicon sometimes created some rather grotesque effects.

In 1947 the type 5655 Image Orthicon tube was brought out to fill the urgent need for a tube of that type for use in studio work. By using a photo-surface which had no infra-red response, a great improvement was achieved in the color rendition. Furthermore, the signal-to-noise ratio was considerably improved. However, using a photo-surface which was not sensitive to infra-red lowered the overall sensitivity of the tube considerably below that of the 2P23 tube, particularly when used under incandescent light. Because of this, it became necessary to use more light when using the 5655 tube in the studio than when using the 2P23 tube. Studio lighting levels of 200 to 300 foot-candles of incandescent light of 150 to 200 foot-candles of fluorescent light were needed to obtain the proper depth of focus. Even so, this was much less light than that needed by the image dissector tube.

In 1948 a still newer type of Image Orthicon camera tube was introduced. The newer tube, the type 5769 Image Orthicon, used the same target structure as that used in the 2P23 but used the photo-surface of the 5655. The newer tube, type 5769, has been widely used for both remote pick-up and in the studio. In the studio it is preferred by many over the 5655 because it requires less light, and because of its ability to handle a wide range of illumination.

Although the 5655 and the 5769 have much better color rendition than the 2P23 they labor under the handicap of having only about one-third the sensitivity of the 2P23, when used under incandescent lighting. Under fluorescent lighting, or when used outdoors, the sensitivity is more nearly comparable. But they also have another shortcoming which must always be considered when using these tubes. They have a color spectral response which is peaked in the blue region of the color spectrum. This means they are more sensitive to blue colors than any other, and that their sensitivity falls off as the colors differ from that of blue. This means that facial tones, which are largely in the yellow and red region, tend to come out too dark. For example, light beards, when televised, tend to come out almost black. Women with a flesh-tinted make-up, or who use rouge a bit heavily, appear to be bearded. In the studio this can be overcome by using proper make-up, but in certain other cases, it is decidedly undesirable.

Experience with the first three Image Orthicons pointed the need for a high-sensitivity photo-surface which more closely matches the response of the eye. In 1949 RCA came out with a still newer Image Orthicon, the type 5820, which uses the wider-spaced, lower-capacitance target structure of the 2P23 and 5769. This newer tube has proven to be especially useful for remote pick-ups. Further than this, it is often preferred for studio work because of its ability to handle wide ranges of illumination.

The spectral color curve of the 5820 follows very closely that of the human eye, and scenes viewed by it will appear almost normal under nearly all conditions. One exception is that where a picture of various colored objects are viewed by the camera without a light filter. When viewing such a picture it can be noted that while the reds and yellows appear normal on the screen the blues and greens appear somewhat lighter to the tube than to the eye. This can be compensated for by the use of a color filter, which will bring the reproduction very nearly to the eye level. The use of the filter will reduce the sensitivity only about one lens stop on the lens of the camera. This is much the same condition which prevails when using a color filter with a movie camera or a still camera.

The closeness of the spectral response to that of the human eye makes the problem of scenery and actor make-up a much simpler one. In general, if lighting and makeup look satisfactory to the eye, the camera will give a good rendition of the color. This makes it possible to make any changes with the eye without need for televising the scene.

The higher sensitivity of the 5820 poses some problems in its use. With a lens aperture of f:2.8 it is possible to obtain a usable picture with only 1 or 2 foot-candles of illumination. The makers of the tube warn that such low levels of illumination should be used only when no other means can be used to obtain the picture. To obtain a good depth of focus they warn that a light level of 20 to 30 foot-candles of illumination should be used.

Section 11. CONSTRUCTION OF THE IMAGE ORTHICON

The construction and mode of operation of the image orthicon differs somewhat from that of the Iconoscope which was described earlier in this lesson. Moreover, its operation is a little more difficult to understand when one is first introduced to it.

In the Iconoscope, you will recall, the light from the viewed scene struck the photo-sensitive surface and caused the emission of electrons. The electrons in that case were emitted back in the direction from which the light came.

In the case of the image orthicon tube, this mixing of the incoming light and the emitted electrons is avoided. The light enters at the front of the tube as indicated in Figs. 15 and 17, while the electrons are emitted so as to move away from the light.

Fig. 15 is an outline diagram of an image orthicon tube. Note how the light enters at the front of the tube. The light falls upon a transparent sheet of glass as shown in Fig. 16. The light passes through the glass and strikes the photo-sensitive globules on the back of the glass. The globules of photo-sensitive material then emit electrons which, in turn, move toward the back of the tube toward a wire mesh screen. The wire mesh screen is shown in Figs. 15 and 17, and acts very much like the screen grid in any other kind of vacuum tube. The screen mesh is at approximately zero potential insofar as voltage is concerned. But the photo-sensitive material is approximately 300 volts negative. This has the effect of making the wire mesh screen highly positive with respect to the photo-sensitive surface. All this causes the electrons to move from the photo-sensitive surface toward the wire screen.

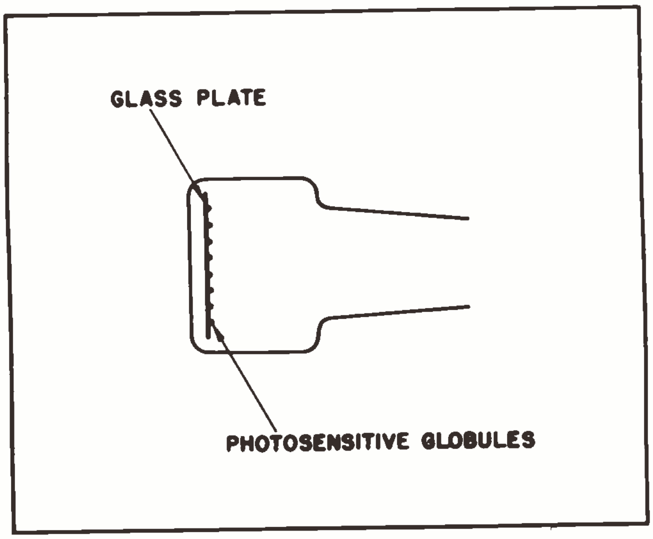

Fig. 16. Photo-Sensitive Globules on the Glass Plate of an Image Orthicon.

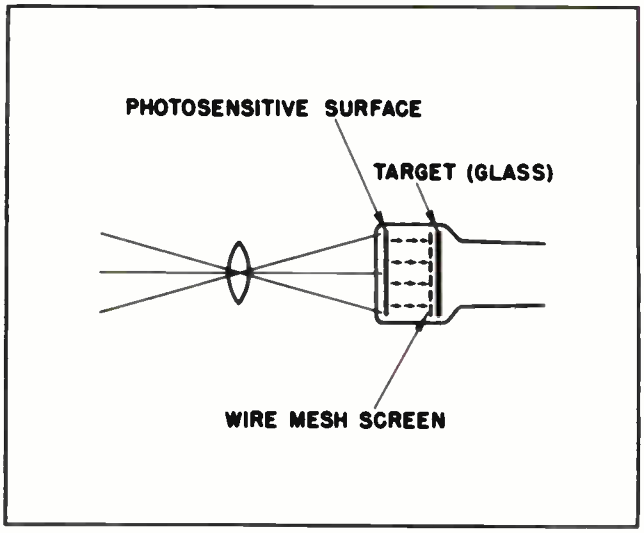

Fig. 17. How the Emitted Electrons Move from the Photo-Sensitive Surface Toward the Target Plate.

The electrons acquire a high velocity in moving toward the wire screen, so high that most of them pass right through the open spaces of the screen. The screen has from 500 to 1000 meshes per inch, and the open spaces between the wires account for about 70 percent of the total space of the screen. This permits the majority of the electrons to pass right on through the meshes of the screen and strike the target plate which is located immediately behind the screen. The electrons strike this target plate with terrific force due to the high kinetic energy they have acquired in their passage from the photo-sensitive surface.

The target plate, which is composed of a peculiar kind of low-resistance glass, is separated from the wire mesh by only .002 inch. That is two 1/1000th of an inch.

When the high velocity electrons strike the target plate they knock other electrons loose from the target in the form of secondary emission. The glass used there is a semi-conductive material from which it is possible to dislodge secondary electrons if the velocity of the striking electrons is great enough.

The secondary electrons which are knocked from the semi-conductive glass are attracted to the higher potential of the wire mesh screen.

Due to the high electrostatic field which exists between the wire mesh screen and the photo-sensitive surface, the electrons which are emitted from the photo-sensitive surface are attracted virtually straight back to the portion of the screen immediately behind that particular spot. If a large amount of light falls upon one particular spot of the photo-sensitive surface, that surface will emit a relatively large amount of electrons which, in turn, will move directly to that portion of the wire screen which is nearest that location. The same condition will be existing over the other portions of each surface. The result is that electrons will be removed from the surface of the target plate glass in almost direct proportion to the amount of light falling upon the photo-sensitive material nearest to it. Figs. 17 and 18 show how the electrons move from the photo-sensitive surface toward the target plate, and how the secondary electrons move from the target plate toward the wire mesh screen.

It was previously mentioned that the glass from which the target is made is a very peculiar kind of material. It is semi-conductive. As the high-velocity electrons strike the surface of the glass some secondary electrons are knocked off. The resistance of the glass is so great that electrons from adjacent areas on the same surface find great difficulty in moving during the 1/30 second of time between the scanning frames to take the place of those which were knocked loose. Further than this, the adjacent areas themselves are also losing electrons due to secondary emission, and thus probably have none to spare. But due to the semi-conductive nature of the glass it is possible

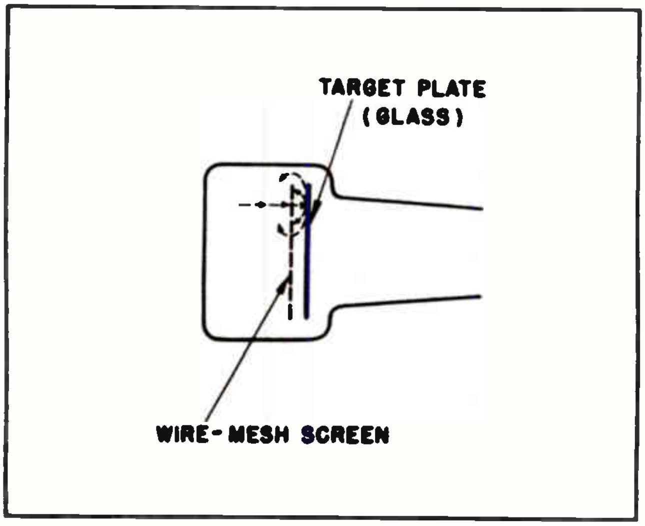

Fig. 18. How Secondary Emission Takes Plates from the Target Plate of the Image Orthicon.

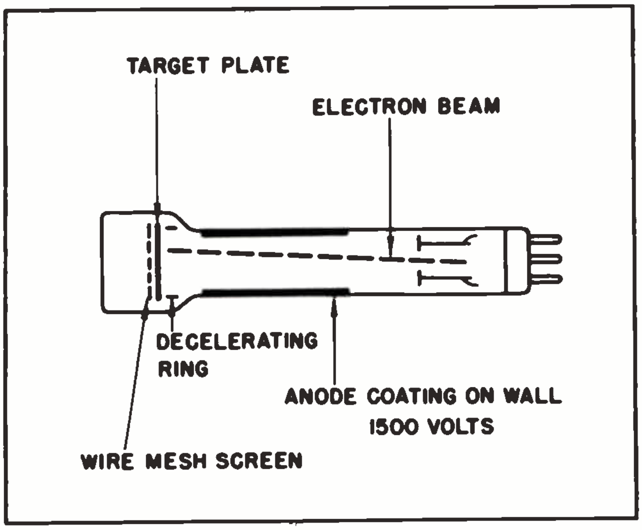

Fig. 19. The Electrostatic Field Within an Image Orthicon.

for electrons from the other surface to slowly make their way through the glass and thus partially make up for those which have been lost through secondary emission. In this manner the positive static charge built up on one side of the target plate due to the action of secondary emission is transferred to the side of the target plate facing the electron gun.

In most other electronic devices we have studied, in which an electron beam has been involved, we have found the electrons from the beam striking the target at a high velocity. Now we are to be introduced to a somewhat different kind of beam. The electrons leave the electron gun and are formed into a beam in much the same manner as any other beam. The beam is accelerated under the influence of the 1500 positive volts of the anode coating on the walls of the tube. This imparts a high velocity to the electrons in the beam.

But as the electrons in the beam pass beyond the anode coating on the wall of the tube they enter another electrostatic field which exists between the positive 1500 volts of the anode and the positive 25 volts of the decelerating ring. This field is exactly the reverse of the one they were in a moment before. The result of this is that they are quickly decelerated, and lose speed very rapidly. In fact, by the time the beam reaches the surface of the target plate the electrons have practically ceased moving. Then they start moving in the other direction under the influence of the reverse electrostatic field which exists between the 1500-volt and the 25-volt decelerating ring.

However, at the instant when the beam is reversing direction, the electrons in the beam are very near the surface of the target plate. Since the surface of the target plate is somewhat positive, due to its having lost electrons through secondary emission on the other side of the plate, the target plate will tend to attract enough electrons from the beam to balance out its electrostatic condition. The other electrons in the beam, those which have not been used to bring the target plate into electrical balance, will return toward the electron gun -- still in the form of a beam. But the returning beam will not be the same unvarying stream of electrons which moved from the electron gun toward the target plate. Essentially it will now be a modulated beam, a beam having a varying strength, or a varying magnitude.

When the beam returns and strikes the metal disks surrounding the electron gun, the electrons will have again regained a high velocity. When they strike the metal disks near the electron gun, another example of secondary emission will occur. The secondary electrons knocked loose here will be put through a multiplier action involving a number of dynodes. We have not had occasion to study dynodes and electron multiplier action, and since we do not need a knowledge of them right now, we will not become involved in such a discussion at this time. Suffice it to say that the output of the returning electrons are then fed to an

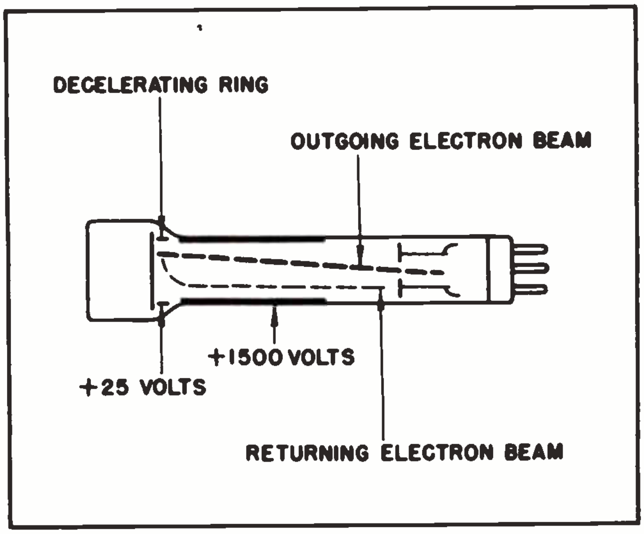

Fig. 20. How the Electron Beam is Decelerated and Reversed.

amplifier system where the voltage is greatly magnified. The voltage changes taken from the tube will faithfully reproduce the visual image which falls upon the photo-sensitive surface of the camera tube.

The camera tubes which we have discussed here are not the only ones which have been devised for television work. However, they are among the most important, and are the ones most widely used. Since it is not the purpose of this course to cover all the details of the problems which are encountered in the transmission of television programs, there is little need to delve too deeply into the technical details involved there. It is believed that the brief discussion devoted here to television cameras will make the subject of television receivers somewhat more easy to understand.

NOTES FOR REFERENCE

Both electrostatic and electromagnetic deflection is used with television camera tubes. The tendency seems to be to favor electromagnetic deflection, and most of the newer camera tubes use magnetic deflection.

Photo-electricity covers the study of that field in which light is capable of affecting an electrical circuit so that a change in current flow, voltage or resistance takes place. The most important field of photo-electricity at the present time involves photo-emissive materials.

The ability of any material to emit electrons under the influence of light comes about through the nature of the atomic structure of the material. Only those materials which have only one or two electrons in the outer orbit of the atomic structure are of any importance in photoelectric work. Only the heavier atoms, those with a large number of electrons such as cesium, virginium and uranium are of any practical value in such work.

Cesium is the most widely used photo-emissive material.

The three most widely used television camera tubes are the Iconoscope, the Image Dissector and the Image Orthicon.

The Iconoscope is a fairly sensitive tube but has the drawback of having the defect known as *shading*.

The Image Dissector is a high fidelity tube which produces a remarkably good contrast and an excellent picture. But it has the drawback of requiring a very high level of illumination.

The Image Orthicon gives promise of providing the good resolution and high contrast of the Image Dissector coupled with the sensitivity of the Iconoscope. In some cases the Image Orthicon has a sensitivity even greater than that of the Iconoscope, but unless the lighting conditions are right, trouble can be encountered from poor color rendition. Even that is now being corrected.

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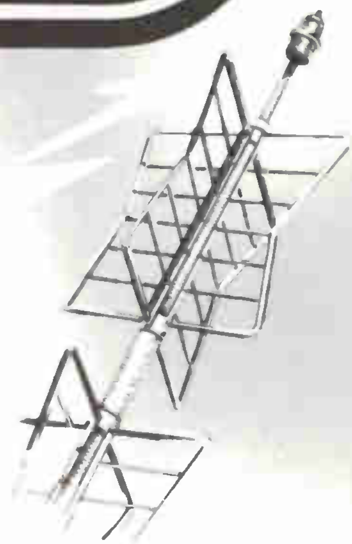

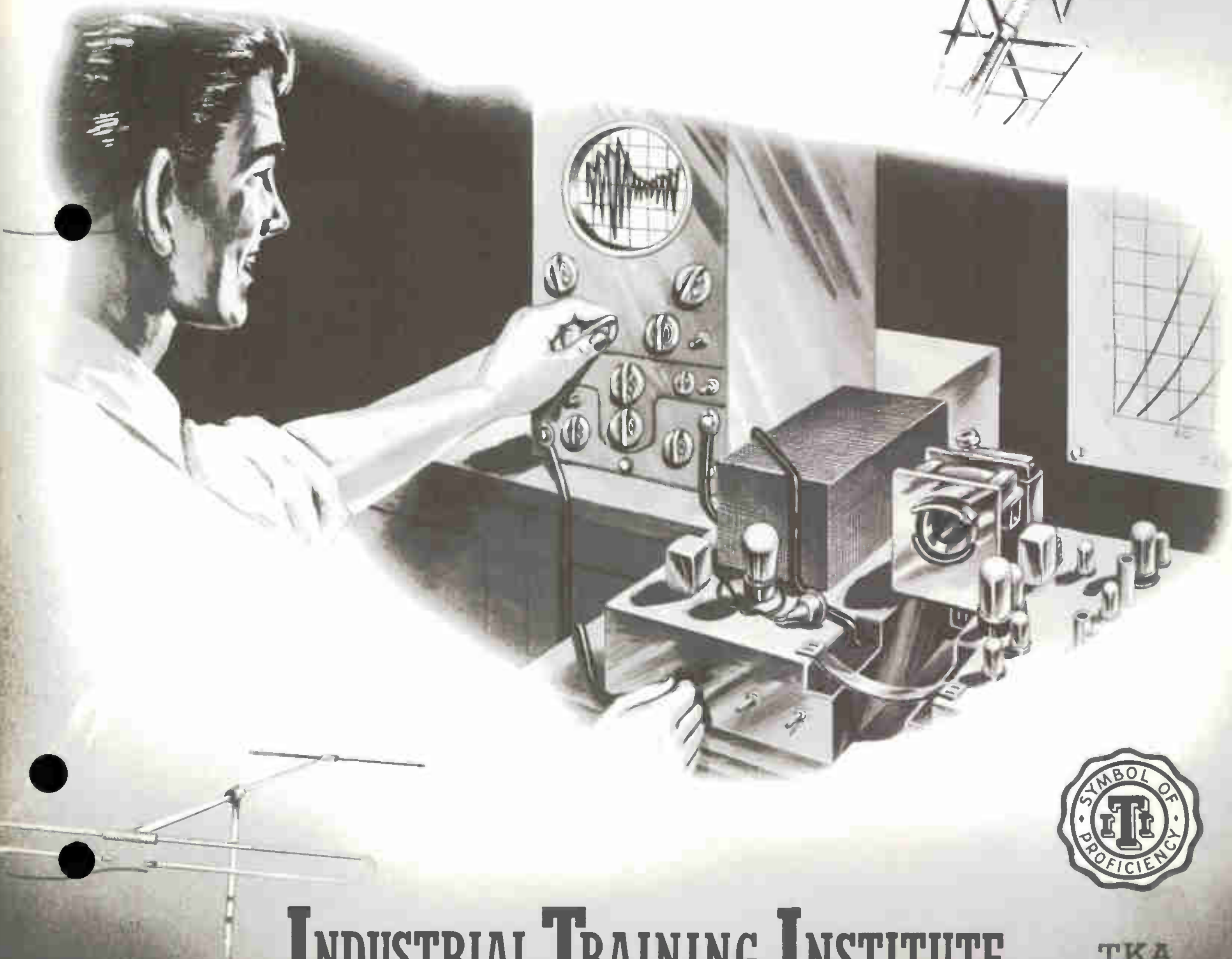

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TECHNICAL TRAINING SERVICE

REVISED 1952

RADIO TELEVISION

TELEVISION CAMERA CIRCUITS

Contents: Introduction - Camera Mixing Channels - The Camera Chain - Camera Control Circuits - Mixing and Amplifier Control - The Action of the Clipper Circuit - Notes for Reference.

Section 1. INTRODUCTION

In our previous lesson we discussed briefly a few of the more important actions which take place in a television camera tube, and explained how the impulses of light energy can be converted into impulses of electrical energy. It is rather obvious to any technically minded person that the camera alone is no more capable of transmitting a video signal than a radio microphone is capable of transmitting a radio sound signal. In each case the camera and the microphone is only one component in a vast array of electrical

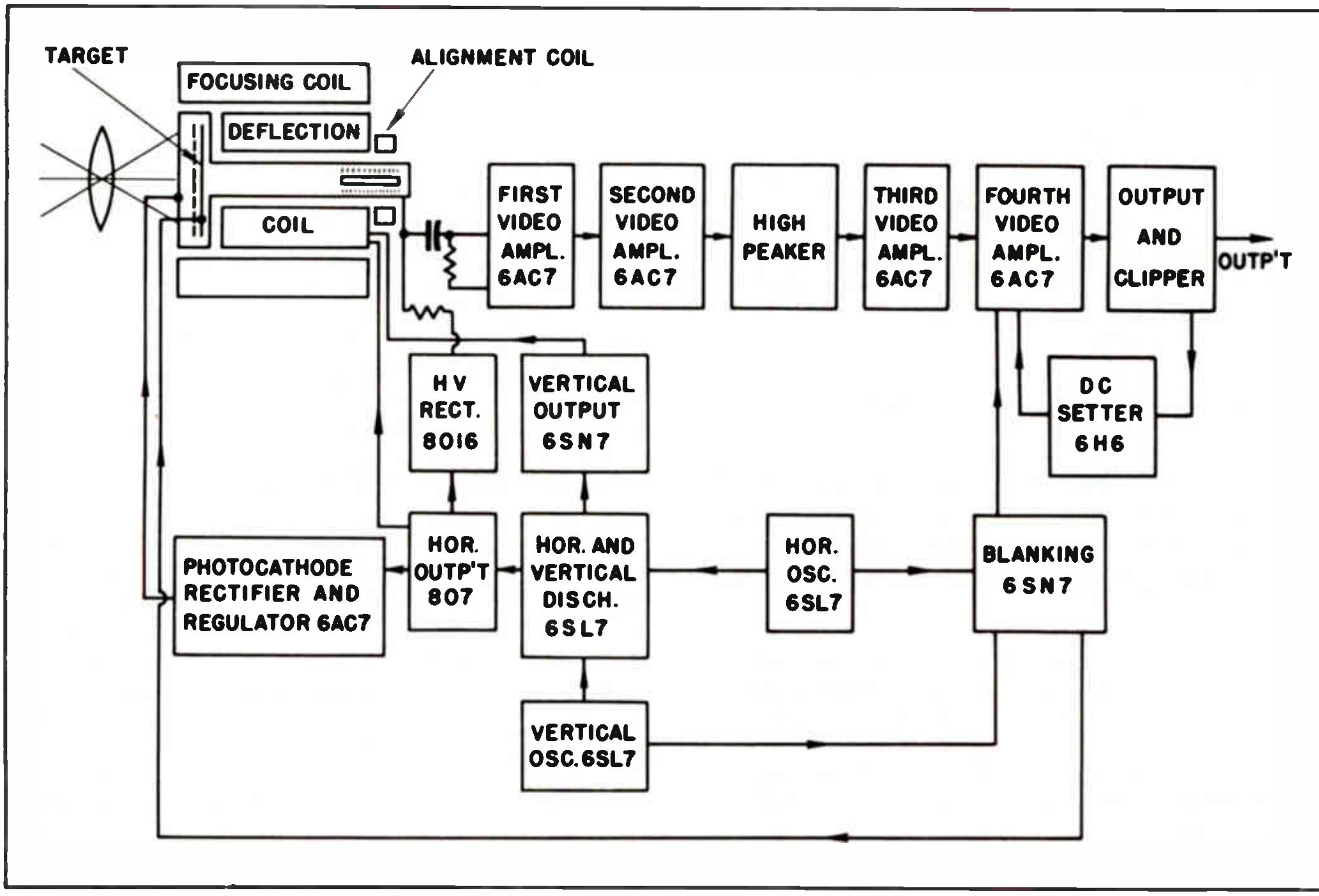

Fig. 1. Block Diagram of Circuits in a Television Camera.

and electronic equipment. As a matter of fact, our previous discussion did not extend so far as to include the camera as a whole. Our remarks were restricted almost solely to the operation of the camera tube. A functioning camera consists of considerably more than the tube alone, just as the oscilloscope consists of much more than the cathode ray tube alone. All this is true, notwithstanding the fact that the tube is the important element which makes the camera itself possible.

An operating camera must include, in addition to the main tube, such important elements as horizontal deflection circuits, vertical deflection circuits, high voltage rectifier, video amplifier circuits, photo cathode rectifier and regulator, blanking circuit, peaking circuits, etc. The relationship of these circuits to each other is shown in the block diagram of Fig. 1.

Some twelve to fifteen vacuum tubes are commonly used in the television camera in addition to the main camera tube itself. Some of the newer and more elaborate television cameras use even more tubes. Television engineers and designers are constantly striving to improve the quality of the signal which is put out by the cameras. Usually improvements are brought about by adding additional vacuum tubes, each of which performs some specialized function.

The associated components shown in Fig. 1 are those needed for the proper functioning of an Image Orthicon camera tube. Those needed for use with the Iconoscope are slightly different, but in most essentials are quite similar.

Section 2. CAMERA MIXING CHANNELS

Anyone who has ever witnessed a radio broadcast is aware that the pickup of the sound for the program is not dependent upon a single microphone. In most studio set-ups microphones will be found scattered all around the studio.

Even those persons who have never had the opportunity to witness a studio broadcast of a Radio program are well aware of the fact that more than one microphone is necessary for the proper production of the program. An example of this is in the broadcasting of a baseball or football game. The main announcer will be calling the plays from a booth high above the field, but periodically the play will be switched to an announcer down on the field, or under the stands, or somewhere else within the park. It is clearly obvious to any listener that one microphone is being used in the announcer's booth and another down on the field.

Many other radio programs depend upon special arrangements of the microphones for the effectiveness of the program. The announcer often tells his listening audience that he is going to switch the program to another microphone located at some distant point. Sometimes the program is switched from one city to another in fairly rapid succession; on occasions, it is actually switched from one country to another. Sometimes a musical program is faded out while an announcer's voice is faded in to make an announcement or statement of some kind.

All of these things require mixing circuits, or mixing channels as they are often called. A special monitoring board or table, arranged in the form of a control console, is used to make these switches possible. Two or more microphones, or lines to distant microphones and amplifiers, are brought into the console. Often there will be many microphones brought into a single console. The engineer who is controlling the program can then bring in whatever microphone is wanted, and connect it directly to the amplifier which feeds the signal to the transmitter in the form of modulation.

In much the same way any person who has ever watched a television program on a television receiver is well aware that more than one camera is needed to properly televise a program, or scene. If one single camera was depended upon to televise the program the program would soon become so monotonous, few viewers could stand to watch the receiver. To break such monotony the scene is televised from several angles and from several distances by several cameras.

The engineer at the control monitor will pick up the signal from one camera for a few seconds and feed it to the transmitter where it is used to modulate the signal being radiated out through space. Then the engineer will pick up the signal from another camera which is viewing the scene from a somewhat different angle and use that to modulate the transmitter carrier. By thus switching the program from camera to camera, and from angle to angle, the attention of the viewer is held and there is not the loss of interest such as would result from a continuous viewing of a scene from a single angle.

Most cameras have a pair of little red or green pilot lights on the front. These are on while the signal is being fed from that camera to the transmitter. This permits the actors, and others, to know which camera is picking up the program at any particular time.

Switching the program from one camera to another accomplishes another purpose. It permits the moving of the cameras from point to point while not being used. An example of this is that one camera will be used to view a scene from a particular angle. As soon as it is off the air the operator can move that camera to another location and be ready to view the scene from another angle as soon as the control monitor wishes to use it.

It might be thought that the problem of switching from one camera to another would be a simple matter which could be accomplished by the simple process of opening one switch and closing another one. But the problem cannot be solved quite so simply.

It should be remembered that we are dealing with electrical currents and voltages of comparatively low values and at extremely high frequencies. At frequencies such as are used in television work, even the modulation frequencies, the capacity which would exist between the two blades of an open switch would be sufficient to pass a comparatively strong signal. More than this the matter of matching the impedances are such that care should be taken to avoid upsetting the matching of a balanced circuit. Should there be a tendency toward upsetting the balance by changing the impedance of one channel the balance should be restored by simultaneously changing the impedance of another channel.

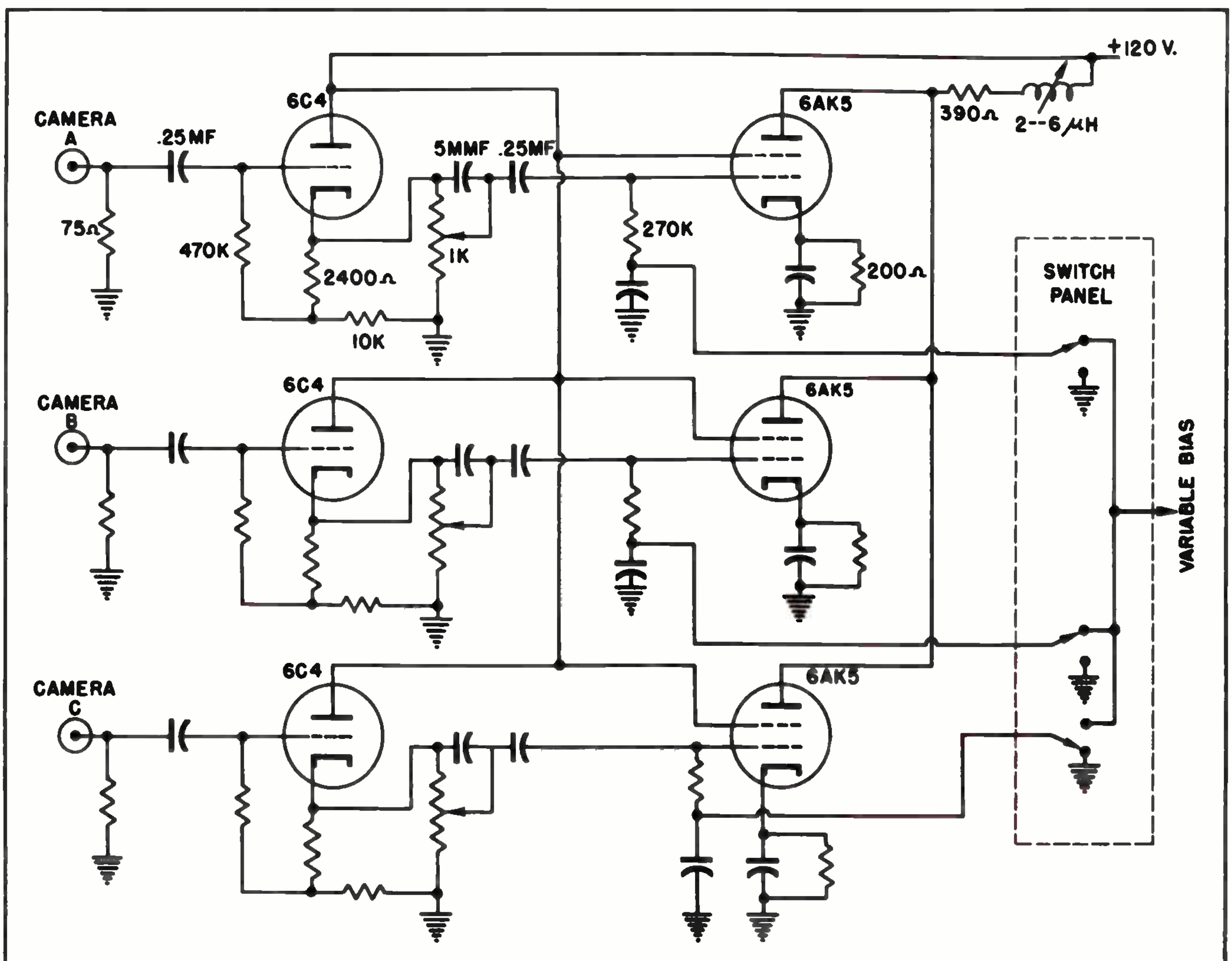

Fig.2. Diagram of Three-Channel Mixer Circuit.

All these problems can be solved by the use of electronic mixing circuits. In such a mixing circuit the signals from the various cameras are coupled by means of vacuum tubes to the amplifiers leading to the transmitter. Fig. 2 is a schematic diagram of a three-channel mixing-monitor. The 6AK5 tubes act as mixer-amplifiers. They are each coupled to the cameras by means of a cathode follower circuit. The cathode follower circuits are built around the 6C4 tubes.

The 390-ohm resistor and the variable *2 to 6* microhenry inductance shown in the upper right hand corner of the diagram act as a load in the plate circuit of the pentode amplifier tubes.

While in operation each of the cameras will be feeding signals through the connecting line to the grid of the 6C4 triode tube to which it is connected. There is no load in the anode of any of the triodes, the signal being tapped off the 2400-ohm resistor in the cathode circuit of the tube. While the cathode follower does not provide any amplification of the signal it does make possible the coupling of the signal from the camera to the pentode without any distortion being introduced.

The grid of each pentode can be connected, through a switch in the switch panel, with a source of variable bias or with ground. When connected to the variable bias the tube can be completely blocked out due to a cut-off bias being applied to the grid, or can be only partially blocked, just as the operator desires. This arrangement makes it possible to increase the bias on one tube as the bias is reduced on another, thus creating what is called a *lap dissolve*. A lap dissolve is where one scene is faded out and another faded in. By making various connections, and various arrangements of the switches and other controls, the operator is able to use any or all of the three cameras.

It should not be thought that only three cameras can ever be used at one time in television broadcast work. Dumont manufactures a four-channel mixer-amplifier and monitor which they call their type 5031-A. It employs four channels and mounts a 7-inch television picture tube on the front panel so the picture can be observed at all times by the operator. The picture tube monitors the signal output of the mixer-amplifier so the operator can determine the amount of bias to insert into the tubes to create the exact effect he wants to achieve.

In addition to the 7-inch picture tube the monitor also has a small 3-inch waveform monitor mounted on the front panel. The 3-inch monitor is nothing more nor less than a cathode ray tube similar to those used in oscilloscopes. Its purpose is to enable the operator to observe the video waveform at all times and thus be on the alert to prevent distortion creeping into the broadcast program.

Section 3. **THE CAMERA CHAIN**

Strictly speaking, the mixer-amplifier is probably not a part of the television camera circuit. Nevertheless it is a part of the camera chain. The camera chain is that part of a television broadcasting system which includes one camera, its pre-amplifier, the camera's scanning and control equipment, and the monitoring equipment. Since the monitoring equipment is often combined with the mixer-amplifier it seems proper to include a description of it at this time.

Fig. 3 gives a general idea of the arrangement of some of the components which go to compose a camera chain. Inside the camera itself are the camera tube, the pre-amplifier, and the blanking amplifier. In addition to the circuits and components actually contained inside the housing of the camera itself, other circuits are brought into it. The two most important of these are the signals from the vertical deflection amplifier and from the horizontal deflection amplifier.

Since these two deflection control impulses are brought in from the outside it can be seen that these controlling impulses do not originate in the camera itself. On the contrary they originate in the control room or in the equipment room. They originate in what is called the *synchronizing generator*.

The synchronizing generator generates synchronizing pulses which control both the camera and the receiver. Since two or more cameras are usually used to televise a program it is understandable that a central synchronizing control is preferable to having the synchronizing pulses for any part of the program originate in the camera which is doing the actual viewing. By using a central synchronizing control it is possible to have all the cameras, the transmitter, and the receiver all synchronized together. This would scarcely

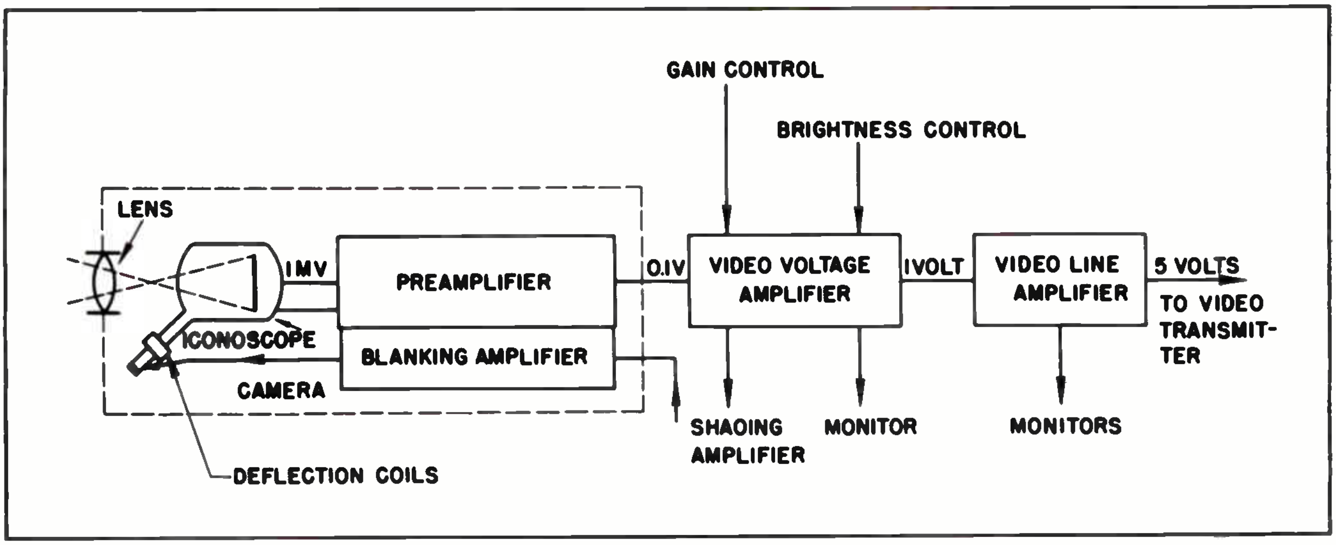

Fig.3. Block Diagram of the Camera Chain.

be possible if each camera originated its own synchronizing pulses.

Fig. 3 also gives a good idea of the amplitude level of the video signal at the various places where it moves from one amplifier to another. The signal at the Iconoscope where it is introduced to the preamplifier is about 1 mv. That of the Image Orthicon is somewhat higher due to the action of the electron multiplier circuits included in that camera tube.

The signal is amplified some more after it leaves the preamplifier. The purpose of the preamplifier is to raise the very small value of the signal when it leaves the camera tube to a value that will allow it to be transmitted over a cable to the control room. The signal from the tube itself is so weak that it could easily be lost in transmission unless its level was raised somewhat. The level of the signal is raised to about 0.1 volt when it leaves the preamplifier.

In the video amplifiers in the control booth the signal is amplified some more. After being amplified there, part of the signal is attenuated by the action of the gain control and some of it is lost due to the action of the brightness control. Part of the signal is fed from there to a monitoring control, and some is tapped off and lost due to other needs. But the signal still has a volume level of about 1 volt when it leaves the control amplifier and is sent to the video line amplifier.

The video line amplifier raises the level of the volume still higher. But here again part of the gain is tapped off for various purposes, including part which is fed to another monitor. However, when the signal leaves the line amplifier its strength has been raised to about 5 volts.

Section 4. **CAMERA CONTROL CIRCUITS**

From the foregoing explanation it can be seen that the camera chain refers to those circuits which deal directly with the passage of the video signal itself. But in order to successfully produce the video signal a number of other special circuits are necessary. Most of these others deal with the deflection and synchronizing circuits. The main portion of these latter circuits are located outside the camera, but the output of the circuits are fed into the television camera where they are used.

Although the deflection voltages or currents used for scanning the mosaic of the camera tube target are almost as essential to the perfect reproduction of a picture as the tube itself, these voltages or currents do not originate in the camera. Instead they are created in special circuits outside the camera, with only the voltage pulses, or the current pulses, being brought into the camera. When electrostatic deflection is used in the camera tube the control pulses are brought into the camera in the form of voltage pulses. But when magnetic deflection is used the control pulses are brought into the camera in the form of current pulses.

In order to get a clear idea of the interdependence of all the various circuits used

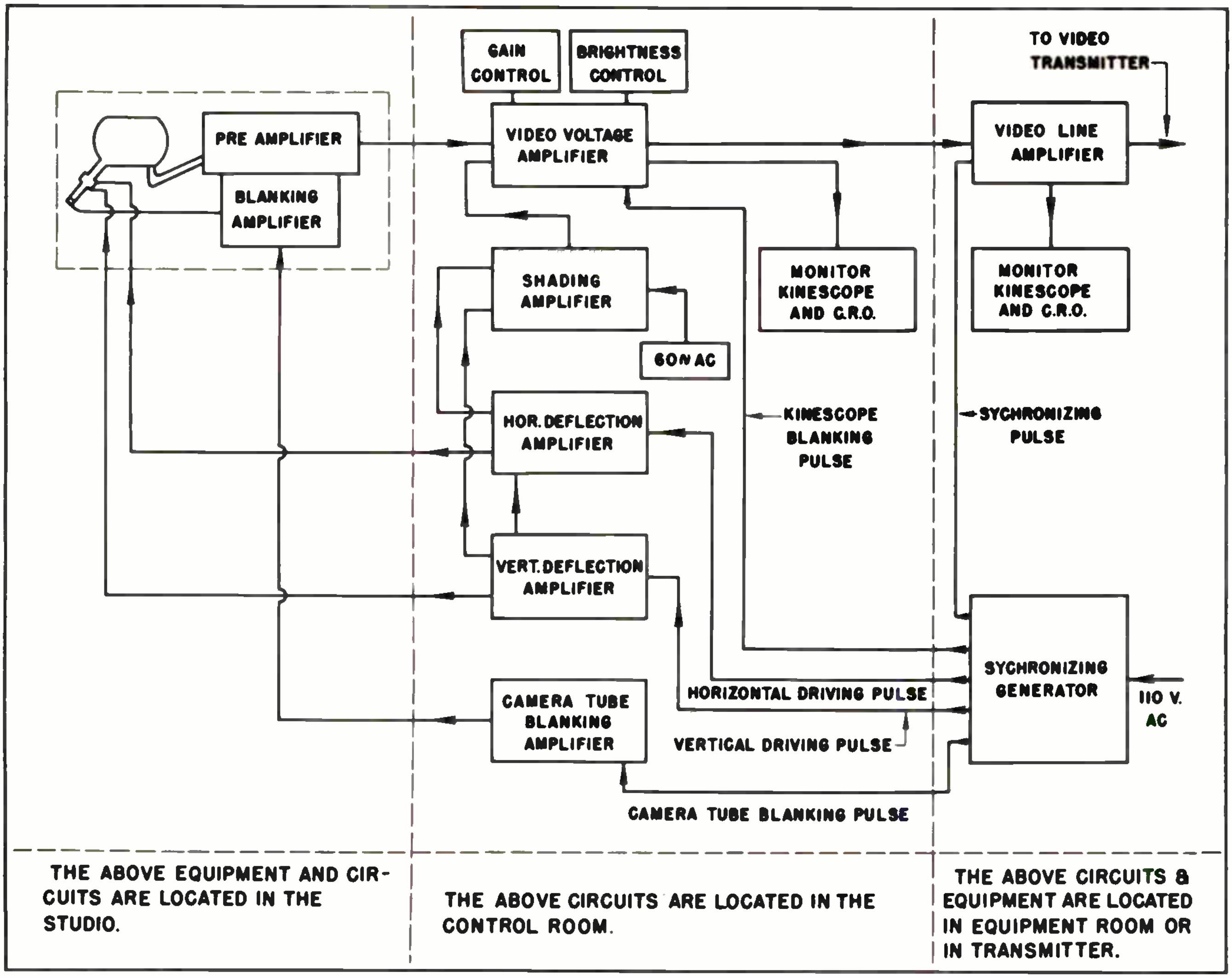

Fig.4. Block Diagram of All the Circuits Between the Camera and the Transmitter.

in and around the television camera, or we could say used to produce the *composite* video signal, we have prepared a block outline of those circuits. This block outline shows the path of the video signal through the camera chain much as that of Fig. 3; but in Fig. 4 we show where each of the scanning impulses are originated and how they are controlled by a central master synchronizing control. The master synchronizing generator can be thought of somewhat as a dispatcher on a large railroad who acts to synchronize the movement of all the trains within a vast network of main rail lines. The dispatcher keeps all the trains running in a coordinated manner so that each reaches certain predetermined spots to meet or pass other trains, all working together on an exact time schedule.

In much the same manner the synchronizing generator of a television transmitting station controls all the cameras in all its studios, and all the cameras on remote pickups, plus all the television receivers which are tuned to that station. It keeps the scanning beams of all the many camera tubes and the picture tubes moving in exact synchronism with each other.

The manner in which it keeps all the thousands of beams moving in synchronism with each other resembles, to a certain extent, the function of a gun-pointing controller used to control the movement of a battery of anti-aircraft guns. Most young men who were in the second World War, and many who were not, have seen batteries of four of these guns waving their muzzles back and forth as they followed the movement of a fast moving airplane. All the gun muzzles move in the same direction at the same time, all under the control of a central gun-pointing controller.

In much the same manner the synchronizing generator of a television transmitter causes the scanning beams in camera tubes and the scanning beams in the receiver's picture tubes to move back and forth as well as up and down -- all in perfect synchronism with all of the others.

In Fig. 4 we can follow the method by which these synchronizing pulses are introduced to the places where they are needed. It can be seen by studying Fig. 4 that the synchronizing generator receives power from the 110 volt A-C power line, then feeds synchronizing pulses to at least five other locations. In some equipment it is possible to find such pulses being fed to some additional equipment.

One synchronizing pulse is fed to the video line amplifier. It is the synchronizing pulse which is sent out through the air to the receiver. That pulse is placed on top of the blanking pulse which is fed to the video amplifier in the control room. The blanking pulse temporarily blots out, or blanks, the modulated video voltage during the instant of retrace. While the picture is temporarily blanked out during its passage through the video line amplifier the synchronizing pulse is impressed upon the carrier.

You will note that another function of the synchronizing generator is to feed a horizontal driving pulse to the horizontal deflection amplifier.

The horizontal deflection amplifier is a sawtooth amplifier designed to create a sawtooth wave form which is needed to move the scanning beam of the camera tube back and forth in a horizontal direction. If the camera tube uses magnetic deflection, as is the practice in the majority of cases, the horizontal deflection amplifier will create a current pulse having a sawtooth wave form. This pulse is then fed to the horizontal deflection coils which surround the neck of the camera tube. If the tube uses electrostatic deflection the horizontal deflection amplifier creates a sawtooth voltage form which is then fed to the horizontal deflection plates of the camera tube.

The sawtooth oscillator used in the horizontal deflection amplifier will be designed to have a frequency slightly under 15,750 cycles per second. Usually such oscillator is designed to have a natural operating frequency about 10% under that of the frequency which is needed to move the electron beam in the camera tube. The horizontal driving pulse from the synchronizing generator will have a frequency of exactly 15,750 cycles per second. This means that each cycle of the synchronizing pulse is slightly shorter than the natural frequency of the sawtooth oscillator in the deflection amplifier.

To put all this in other words, the pulse from the synchronizing generator will come along just a fraction of a second before the oscillator tube would discharge through its own action. Thus on each cycle the horizontal deflection oscillator will be speeded up by the synchronizing pulse just enough to keep it constantly in step with the synchronizing generator. This action keeps the horizontal oscillator moving back and forth at exactly 15,750 cycles per second, and in exact synchronism with the thousands of other oscillators which are synchronized with the synchronizing generator.

In addition to the synchronizing pulse fed to the video line amplifier and the horizontal deflection oscillator, and the blanking pulse fed to the video voltage amplifier, the synchronizing generator also feeds a vertical driving pulse to the vertical deflection amplifier. It might be mentioned at this time that the synchronizing generator is locked in with the 60-cycle A-C frequency of the local power company. Thus the vertical synchronizing pulses are always in exact step with the power line frequency of the local power company. This is used to initiate the driving pulse to the vertical deflection oscillator which moves the scanning beam up and down vertically within the camera tube.

The vertical deflection amplifier is also a sawtooth oscillator. It has a natural frequency just under 60 cycles per second. If left alone to oscillate by itself, without any triggering impulses to move it along faster, it would oscillate at a frequency of about 54 or 55 cycles per second. But near the peak of each cycle, just before the tube would naturally discharge, the driving pulse from the synchronizing generator comes along and trips the tube. This causes the relaxation portion of the cycle to start just a trifle sooner than would have been the case if the triggering impulse were absent.

Here again it can be seen that the synchronizing pulse from the synchronizing generator

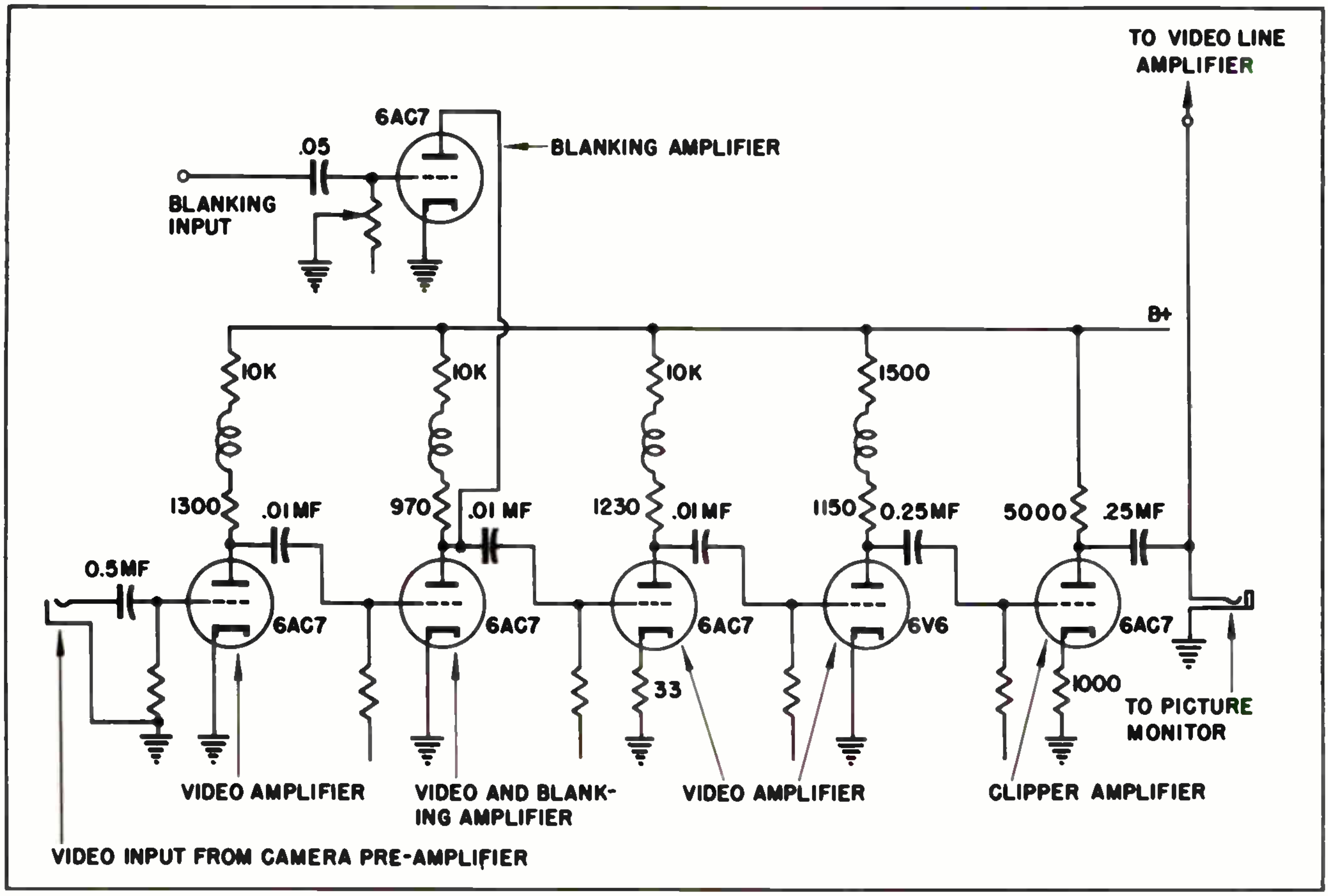

Fig.5. Simplified Diagram of Video Amplifier Circuits Which Follow the Camera Pre-Amplifier.

serves to keep the electron beam moving up and down vertically over the face of the light sensitive plate of the camera tube in exact synchronism with all the other electron beams controlled by the same generator.

Section 5. **MIXING AND AMPLIFIER CONTROL**

It is interesting to see how the various voltages are mixed in with the video signal and how the combined, or *composite*, signal is then amplified. Fig. 5 indicates in a simplified form something of the manner in which this action is brought about. The diagram in Fig. 5 is not complete in many respects. The gain controls are not shown. Neither is the "pedestal height" control shown in the diagram. While the addition of such components to the diagram would have made it more complete they would also have made it more complex. And being more complex it would have been harder to understand.

The video signal from the camera pre-amplifier is brought into a jack which is indicated on the left side of the diagram. It is amplified by the 6AC7 amplifier tube. In the diagram the tubes are all shown as triodes. You already know that neither the 6AC7 nor the 6V6 is a triode. The 6AC7 was discussed at considerable length in earlier lessons since it is very often used as a mixer-converter tube. But it is also widely used in television work as an amplifier tube. The 6V6 is a beam power tube, very similar to the 6L6 but with somewhat less output power than the 6L6.

The extra grids in these tubes are not shown in the diagram of Fig. 5 since to do so would only serve to complicate the diagram without contributing anything to our present discussion.

It should be remembered that at the high frequencies used in television work, and the wide band covered by the video component, relatively little gain can be obtained in any single stage of amplification compared to that which could be obtained if the tube was being used at lower frequencies.

For this reason several stages of amplification are needed to obtain the same amount of amplification which could be obtained at lower frequencies in one stage.

The video signal is fed into the first tube and amplified. Then the output of the first stage is fed into the input of the second stage. Here it is amplified again. Now note what happens in the plate circuit of the second stage of amplification. The plate load of the second video amplifier consists of a 10,000 ohm resistor in series with another 970 ohm resistor and an inductance. The resistors provide the necessary load for the anode of the tube at the lower video frequencies, while the inductance takes over and adds to the load at the higher video frequencies.

But this same load is in the plate circuit of another tube, the blanking amplifier tube shown at the top of the diagram. Normally little or no current will flow in the anode circuit of the blanking amplifier. During such a normal period the second video amplifier tube would function just as though the blanking amplifier tube did not exist.

When the blanking amplifier tube receives a strong blanking pulse from the synchronizing generator over the path shown in Fig. 4 a strong flow of current will take place in the anode circuit of the blanking amplifier. The current from the anode of the blanking amplifier must flow through the 970-ohm resistor, the 10,000-ohm resistor and the inductance which are also in the anode circuit of the second video amplifier. This flow of current is so great that a large voltage drop is created across the resistors. This voltage drop reduces the positive anode voltage on the anode of the second video amplifier to such a point that the second video amplifier tube ceases to conduct.

It might be added that the effect of the blanking amplifier is not sufficient to completely cut off the video amplifier. As a matter of fact the output of the second video amplifier looks something like that of the levels shown in Fig. 6. The signal output of the tube will have a fairly high level as shown between the dotted lines which designate the normal amplification. Then when the anode voltage on the tube is reduced due to the action of the blanking amplifier the amplification level of the output signal will drop to a lower level as shown between the dotted lines designated as the blanking period. The video signal during the blanking period is both distorted

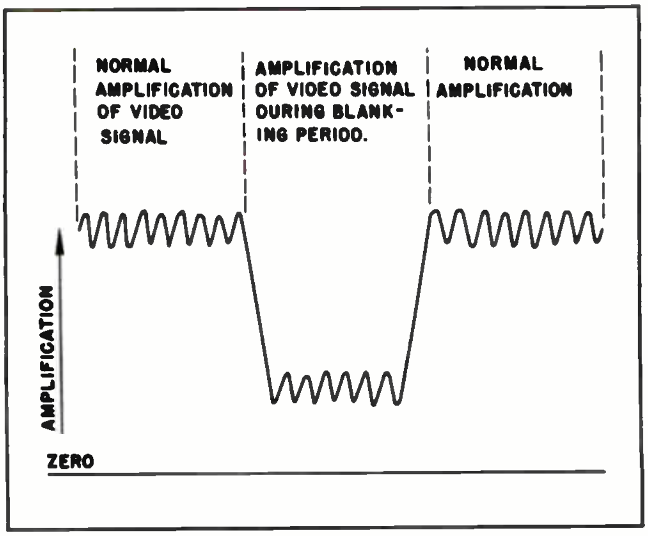

Fig.6. How the Blanking Pulse is Superimposed Upon the Video Voltage.

and spurious. For proper operation of the program it must be completely removed.

The removal of the spurious and distorted signals is accomplished by the clipper amplifier. This is the fifth stage of amplification shown in Fig. 5. The clipping action could possibly be accomplished in the third stage of amplification. But it should be remembered that the signal level at the third stage is still relatively low. In order to have an effective clipping action the signal level should be relatively high. So the signal is run through another stage of amplification.

It might be thought that four stages of amplification would be enough to raise the signal strength to a level sufficiently high to provide effective clipping action. And so, perhaps, it would. But now we have another condition to consider. That of phase.

You will recall from our previous studies that every time a signal is run through a stage of amplification the phase of the signal is inverted because of the action of the output being 180° out of phase with the input. So now we should take another look at our signal.

In Fig. 6 we find the undesirable portion of our signal is the low level portion. After the signal has been run through the third stage of amplification the signal output will be in the form shown in Fig. 7. The voltage swings of the video signal have been amplified. But the spurious video signal during the blanked portion of the

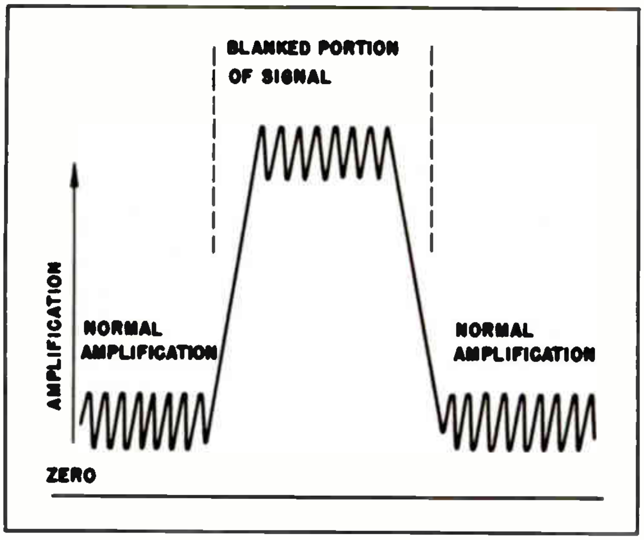

Fig.7. The Video Voltage, and the Superimposed Blanking Pulse, in the Standard Position.

output have also been amplified. More than this the entire signal has been inverted.

Now when this signal has been run through another stage of amplification, the fourth tube, the signal will again be inverted. It will appear at the output of tube number four in much the same form as at the output of tube number two, except that all elements of the signal will have been amplified. However, in the output of tube number four the undesirable portion of the signal will again be at a low level. And the low level elements are not in the proper position for effective clipping action.

A clipper circuit operates very much the same way the limiter circuit operates in an FM receiver. But where the limiter circuit operates to level the amplitude of the signal at both the top and the bottom the clipper circuit is designed to remove only one side of the signal. Fig. 8 shows how the tube is so biased that the spurious signal which remains in the blanking pulse is removed by the action of the upper knee of the characteristic curve of the tube.

If you are a little hazy on this action it might be well to go back and refresh your knowledge of vacuum tubes and vacuum tube amplification which was discussed in the earlier lessons. In fact it would not be a bad idea to go back and refresh your memory in any event. We are soon going to discuss some actions of vacuum tubes which were mentioned earlier, but which we have had no use for in our lessons up to this time.

Section 6. THE ACTION OF THE CLIPPER CIRCUIT

It might be wondered just what is the need for going through the process of "clipping off" to an average level the tops of the blanking pulses. Since these blanking pulses have been specifically designed to drive the grid of the picture tube so negative as to stop the passage of the electron beam it might be thought that no additional negative voltage, even though it is variable in nature, would be of any particular concern. And insofar as the electron beam is concerned it actually would not make any difference whether the blanking pulse was merely sufficiently negative or was abundantly negative.

But there is another matter to consider. The blanking pulse is sent out to "blank out" the signal at both the transmitter -- that is the camera -- and at the receiver. During the period in which the blanking pulse is dominant the picture will be completely removed, the electron beam will be

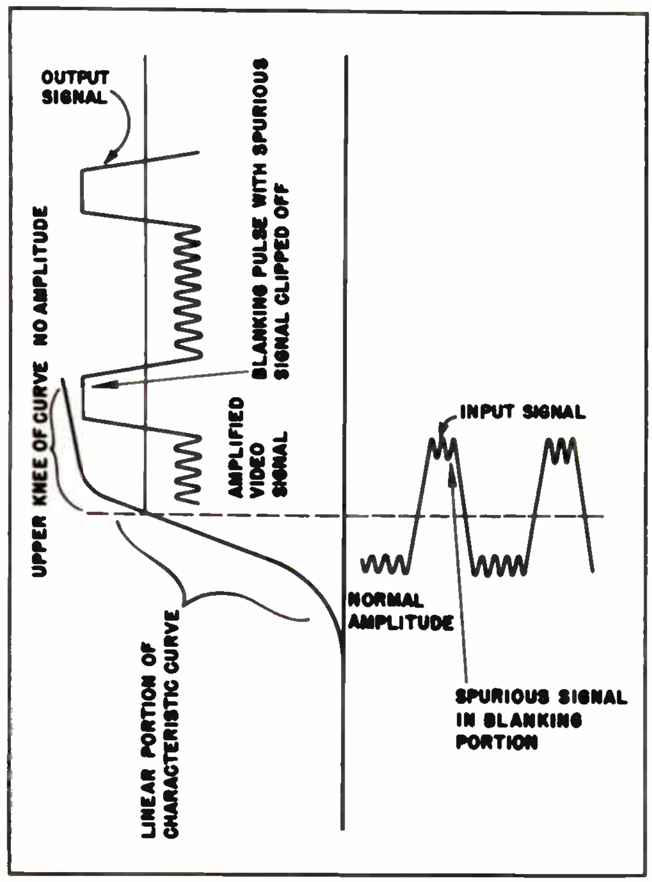

Fig.8. How the Spurious Voltage Variations on the Peak of the Blanking Pulses are Clipped Off.

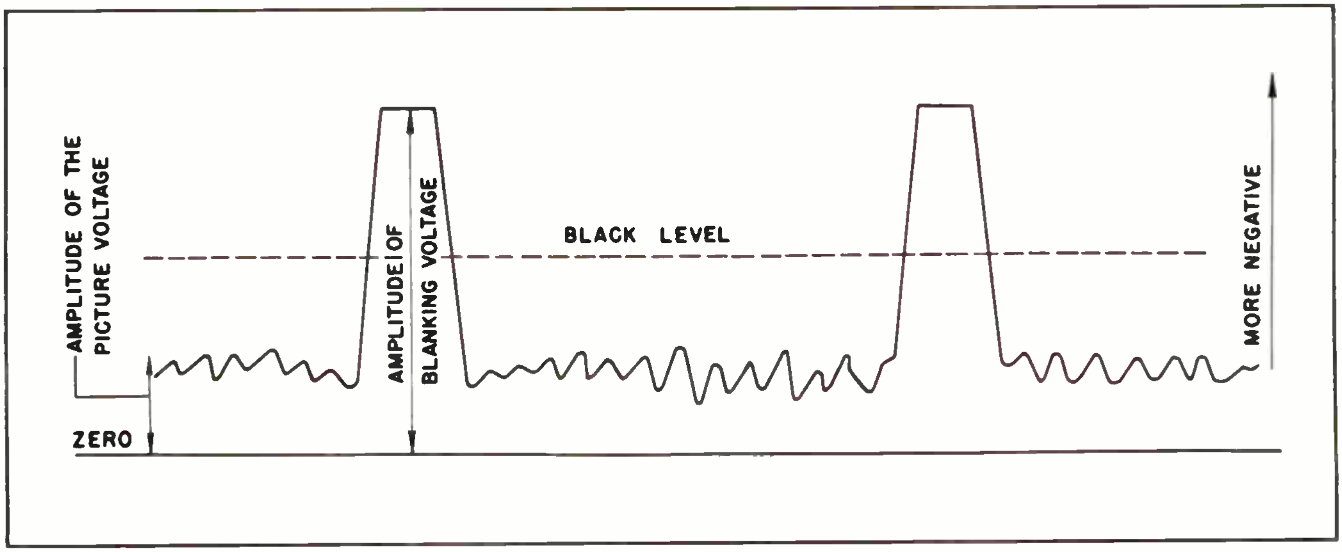

Fig.9. The Peak of the Blanking Pulses Reach Above the "Black Level". The Black Level is the Voltage Level at Which the Picture Fades From the Screen.

momentarily wiped out, and no picture of any kind will be present. The blanking interval is far too short for the eye to detect, but the actual fact is that during its existence the screen is momentarily blank insofar as the electron beam is concerned. During this interval the electron beam retraces its path across the face of the tube in preparation for starting another scanning line.

But another action takes place during the interval in which the electron beam is blanked out. That is the creation and transmission of the synchronizing pulse. The synchronizing pulse is the thing which keeps everything concerned with reproducing a picture in step with each other.

The synchronizing pulse keeps the camera tube (all camera tubes used in the one particular broadcast), the transmitter, all the monitoring scopes, as well as all the many thousands of television receivers operating in exact synchronism with each other so the scene which is being viewed can be reproduced exactly as viewed.

This synchronizing pulse is sent out during the short interval in which the blanking pulse has the electron beam wiped out. Since the synchronizing pulse performs such an important task in keeping so many things working together in such a perfect manner it stands to reason that it should have a reasonably stable base from which to work. And the tops of the blanking pulse voltages is the base from which it operates. (See Fig. 9.)

In Fig. 9 the height of the graph represents the value of the negative voltage. The higher the graph the more negative the voltage, and consequently the darker the picture. Once the voltage reaches a value approximately equal to the dotted line marked "black level" it will be so negative as to cut off the electron beam in most picture tubes and camera tubes. But to be on the safe side the blanking pulse is usually made somewhat more negative even than the value of the "black level". Doing so will insure the beam being completely extinguished during the retrace period.

Now we come to the reason why the top voltage of the blanking pulses should be a reasonably stable value. You will note by referring to Fig. 10 that an additional voltage pulse has been super-imposed upon the blanking pulse. This second pulse is the synchronizing pulse and is the pulse which keeps all elements of a television broadcast transmission studio and the many receivers all operating in exact unison together.

We have already explained how the blanking pulse is a pulse of negative voltage which is strong enough to completely wipe out the picture for the time necessary to allow the electron beam to retrace its path across the tube. A microscopically short instant after the electron beam has been blanked out another voltage pulse, still more negative, is super-imposed upon the blanking pulse. This second negative pulse is strong enough to affect the grid of a tube which had not been previously affected by the negative

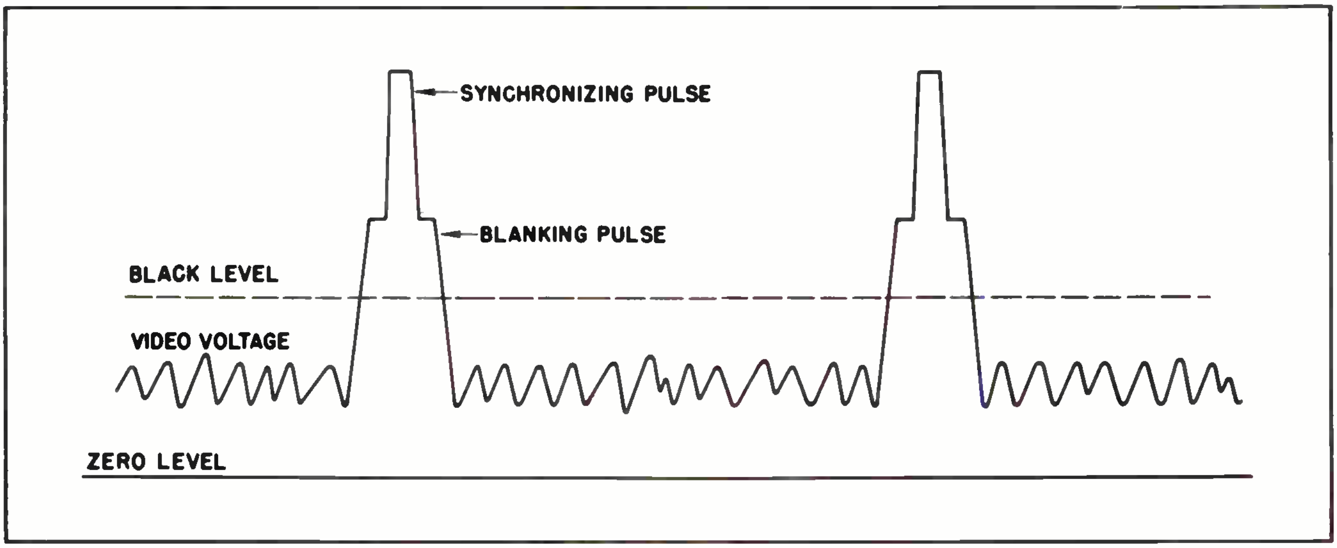

Fig.10. How the Synchronizing Pulse is Super-imposed on Top of the Blanking Pulse.

voltages of either the video signal nor the blanking pulse. But the synchronizing pulse is sufficiently negative to trip a tube and initiate the retrace of the electron beam.

This pulse is strong enough to trip, or "trigger", the retrace in the camera tubes and the picture tubes alike. And since all are tripped at exactly the same instant they will all retrace at the same time -- together.

It follows from all this that the synchronizing pulse should be strong enough to

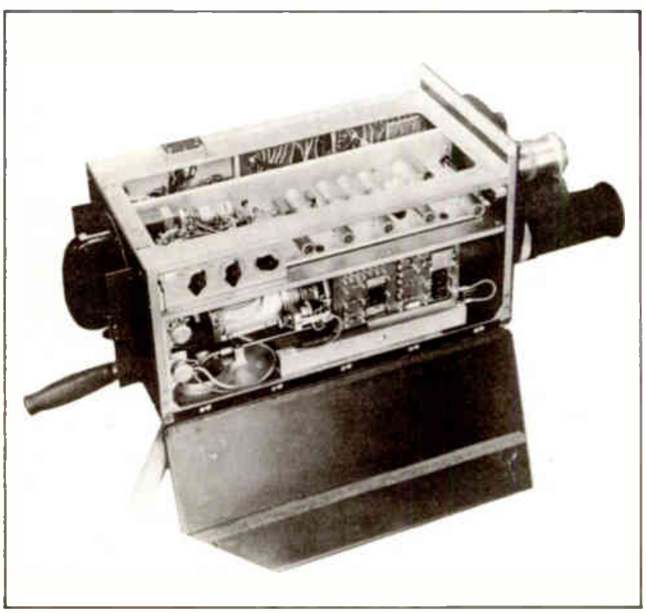

Fig.11. Interior View of a Television Camera. Note the Wiring and the Many Tubes Needed in the Camera. (Courtesy Allan B. Dumont Co.)

initiate the retrace. But the blanking pulse should not be negative enough to cause the same action. This means that the blanking pulse must be a pulse of negative voltage -- but just so negative, not more so. And that each blanking pulse should have the same value. This is where the clipping circuit comes in. The clipper keeps all the blanking voltage pulses exactly the same value.

The even height of all the blanking pulses makes an even, and convenient, base or platform for the synchronizing pulses. Since the height of all the blanking pulses is kept to an even, stable value the base for the synchronizing pulses will be even and stable.

The height of the blanking voltage is constantly under the control of the operator. By changing the value of the blanking pulse voltage the lightness or darkness of the picture can be easily controlled. The operator who is watching, or monitoring, the picture can adjust the control much in the same manner as in adjusting the volume on a radio receiver. What it amounts to is adjusting a potentiometer in the grid circuit of the clipper tube. Such adjustment determines the height of the blanking voltage.

From the contents of this lesson one might gain the impression that a television camera was an intricate and complex instrument. Such is indeed the case. There are many vacuum tubes contained within the case of any television camera. Some cameras are more elaborate than others. But even the most simple is quite complex. Fig. 11 gives some idea of the appearance of a television camera. The top and sides have been opened so a view of the interior of the camera can be obtained. The lenses for focusing the picture can be seen at the right end of the camera. Several lenses are usually carried on a turret arrangement so that distance shots, medium close-up shots and very close shots can be taken at the will of the cameraman.

A number of the amplifier tubes can be readily seen mounted on their special chassis. Also a resistor board for mounting several of the resistors and condensers used in the camera. A portion of the camera tube can be seen, but the view of that tube is not very clear. It is mounted directly behind the resistor board.

A television camera is an expensive piece of mechanism and is not something for novices to experiment with. The camera tube alone will cost in excess of $1000. The lenses used with such a camera can easily cost as much as the camera tube, and sometimes even more. It can be seen that a television camera can easily run in excess of $5000. and still not be one of the more elaborate pieces of mechanism.

NOTES FOR REFERENCE

A full and complete study of television cameras would fill an entire book. This lesson is intended merely as an introduction to that subject so that you may have a general overall picture of how such cameras operate.

In most television broadcasts it is necessary to use two or more cameras so that the view may be switched from angle to angle, and to vary the distance from which the televised scene is viewed. This is necessary to avoid tiring the viewing audience.

The voltage output of the television camera tube is extremely low. The amplifiers within the camera raise this low voltage to a higher value, but even so the voltage output of the camera is still so low that it must be greatly amplified before it is fed to the transmitter.

The process of switching from one camera to another is accomplished by means of electronic mixing circuits so the impedance of all the circuits can be kept under constant control.

Mixing channels used to switch from one camera to another can also be used to create *lap dissolves*.

A pair of red or green pilot lights are on the front of the television camera so that all the actors and others can know which camera is being used to modulate the transmitter.

The synchronizing generator acts as a control master to keep all units of both the transmitter and the receivers locked in synchronism with each other. Without the synchronizing pulses from the synchronizing generator the picture on the picture tube would be without form or pattern. In fact it would not be a picture, merely an aimless series of gray.

The synchronizing generator controls all the cameras as well as all the other elements of the transmitter and receivers.

NOTES

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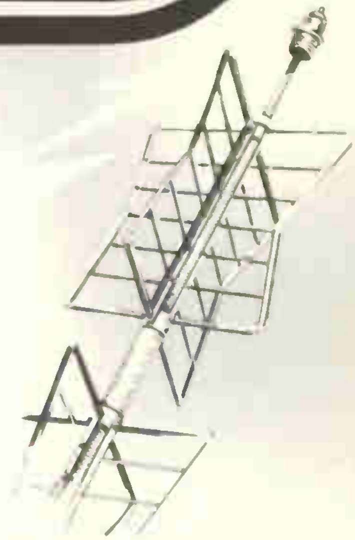

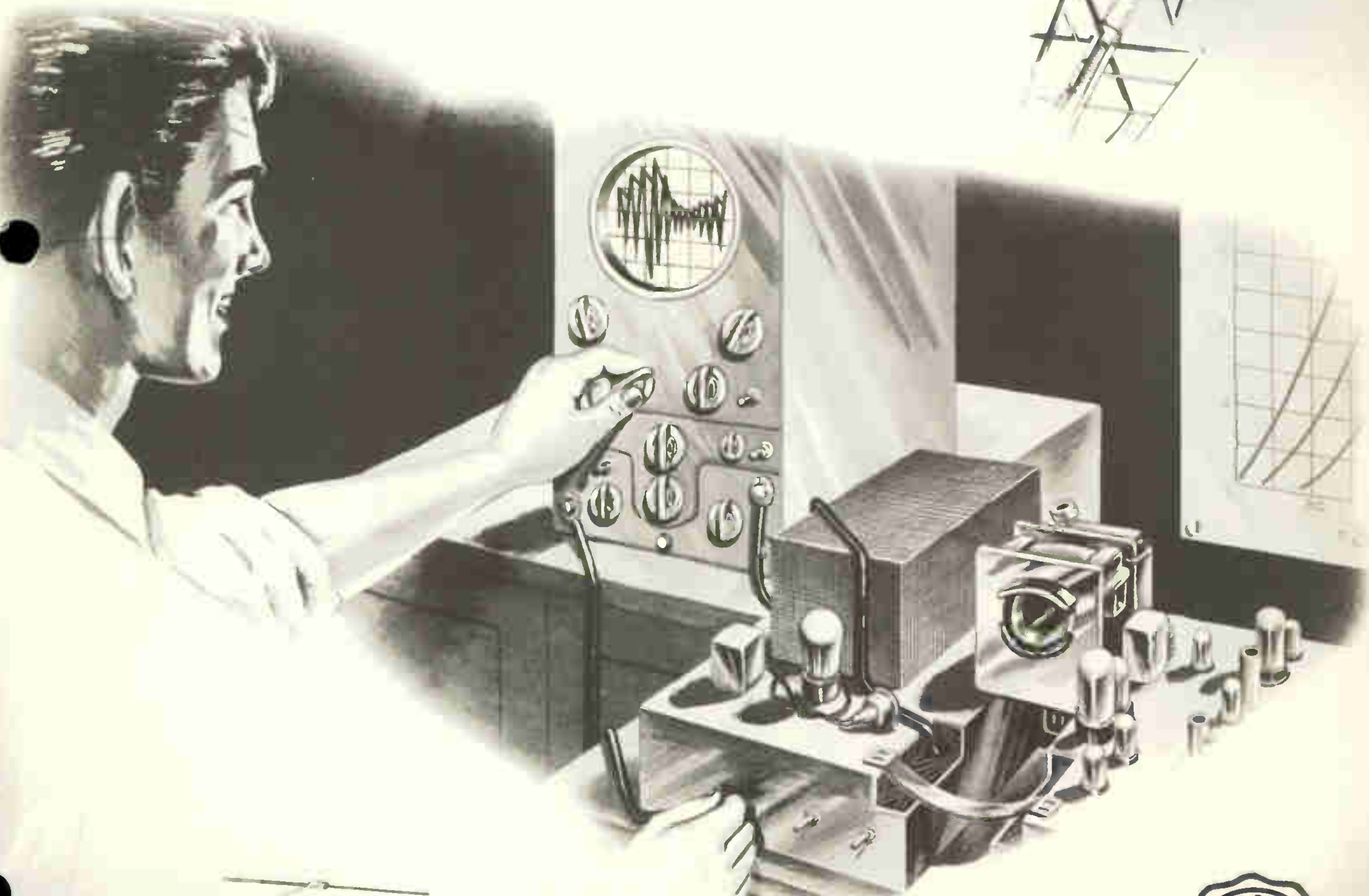

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INDUSTRIAL TRAINING INSTITUTE

TECHNICAL TRAINING SERVICE

REVISED 1954

RADIO TELEVISION

THE COMPOSITE SIGNAL

Contents: Information Carried by the Composite Video Signal — Make-up of Composite Video Signal — Polarity of Transmission — Maintenance of Black Level — Horizontal Blanking Period — Time Dimensions of Blanking and Sync Pulses — Applying Sync Pulses to Saw-tooth Oscillator — Vertical Movement of Beam — Comparative Time Elements of Vertical and Horizontal Movements — Sync Pulses Which Control Vertical Retrace — When Vertical Retrace Begins — Notes.

Section 1. INTRODUCTION

In the preceding lessons we discussed, briefly, a few of the essential steps necessary to create a video signal. We deliberately avoided going into that subject more deeply than was absolutely necessary to acquaint you with the manner in which a video signal is initiated, or created.

We touched on the part played by the camera —but only to the extent that would help you understand something of the nature of the video signal. It is the video signal which is important to a service technician — not the camera.

We touched on the synchronizing generator; but covered it in the same brief manner.

We believe it is desirable for you to know something of the part played by the synchronizing generator. We think you should have a general understanding of how it links together the many units concerned with the job of broadcasting and receiving a television program. However, we do not believe it is necessary for you to learn all the technical details connected with its operation.

We recognize that a thorough study of television cameras, and broadcast studio techniques, would be both interesting and informative. But we do not believe a full treatment of the subject has any place in a course of this kind.

To be really useful, a study of TV cameras and TV studio techniques should be undertaken only by a person who is already intimately associated with such work, or expects to get into

Figure 1. Composite Video Signal provides Electrical information needed by receiver to create picture. (Courtesy Sentinel Radio).

that work soon. To make such a course of study really worth while it would be necessary to go into the optical features of camera construction quite deeply. That is a highly technical subject which seems to have no place in a receiver service course such as this.

A radio and television serviceman has little need for a knowledge of TV camera work. We would be only wasting your time if we went into the subject very deeply. Our only purpose in touching on the subject at all is to explain how the composite video signal is created.

Section 2. INFORMATION CARRIED BY COMPOSITE VIDEO SIGNAL

The composite video signal used in television work is similar in some ways to the audio signal used in radio work. At the same time it is vastly different.

The audio signal in radio work is used to modulate the carrier; the same is true of the composite video signal in television.

The carrier signal is assigned the job of transporting the necessary intelligence from the transmitter to the receiver, but in radio it is the audio signal which actually embraces the intelligence itself.

An audio signal is a constantly varying AC voltage. The varying voltages of the audio signal represent, in an electrical form, the varying wave-forms of the original sound.

The electrical audio signal is created by the action of sound waves acting upon a suitable *transducer*.

In technical language a transducer is some type of device which can convert sound energy into electrical energy, or convert electrical energy into sound energy. A microphone is the most common device for converting sound into electrical signals, and a loudspeaker the most common device for converting electrical energy into sound. Both are called transducers.

The electrical audio signal is created as a direct result of sound energy. The same electrical audio signal can later be reconverted into sound energy by permitting it to act upon the proper electro-mechanical device.

The important point we are trying to make is that in radio the audio signal carries the intelligence it is desired to transmit from one location to another. Sometimes it carries the intelligence of speech, other times it carries the intelligence necessary to reproduce a passage of music, on other occasions it carries some other form of intelligence.

To transmit the electrical audio signal from one location to another by radiated power it is necessary to impress it on a carrier signal. To use our familiar radio terminology we say the audio signal is used to *modulate* the carrier signal. Fig. 2 suggests the manner in which a carrier signal is changed by modulating it with an audio signal.

The composite video signal represents the *intelligence* we are trying to transmit from the transmitter to the receiver. It represents, in electrical form, the information needed by a television receiver to recreate the scene viewed by a camera.

The composite video signal is impressed on the carrier signal in the form of a modulation. In a TV receiver the carrier signal is amplified by a process of conversion and I-F amplification similar to that used in radio receivers.

The composite video signal is separated from the carrier by a video detector, which is a type of demodulator. The action is almost identical with that followed in a radio receiver.

The composite video signal is then amplified in much the same manner the audio signal in a radio is amplified following the detector action.

While all these actions are quite similar to those which occur in a radio there are also some radical differences between the two types of signals.

In radio work the audio signal seldom ranges higher in frequency than 5000 cycles, although in FM radio work it may go as high as 15,000 cycles.

In television the composite video signal may have a frequency as high as 4,000,000 cycles and as low as 60 cycles. Even a casual comparison of the frequencies found in audio signals with

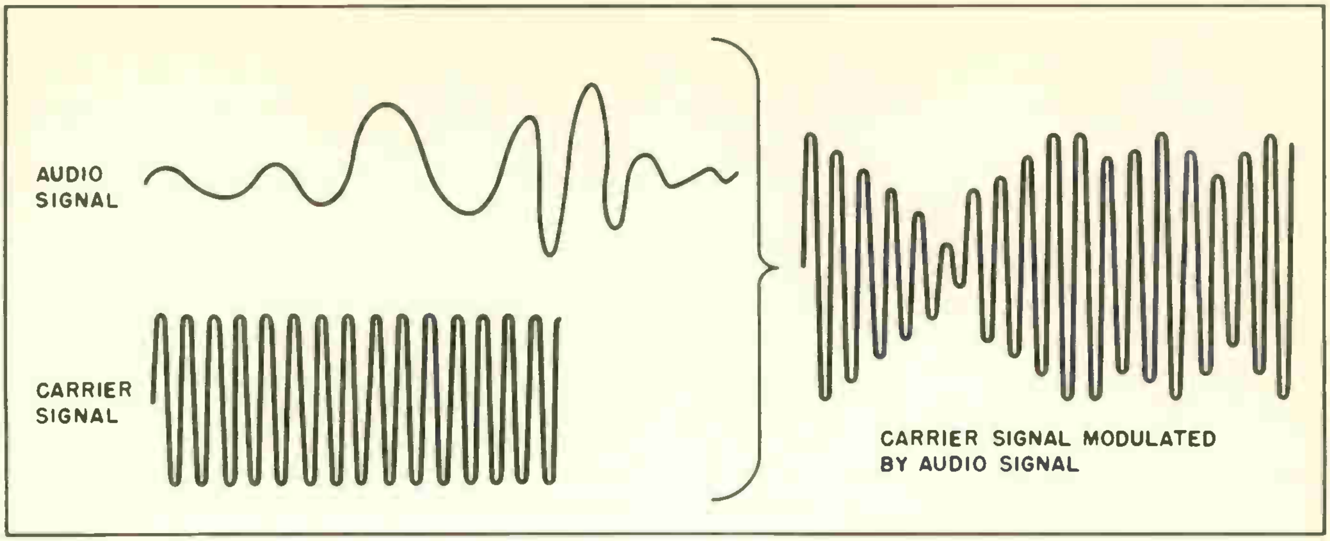

Figure 2. Audio Signal used to modulate RF carrier signal in ordinary radio.

those found in video signals emphasizes this important difference between them.

It is a relatively simple matter to devise circuits capable of handling and amplifying audio signals. This is because audio signal frequencies are embraced within a relatively narrow range.

Compare that narrow range of audio frequencies with the tremendously broad spread of frequencies in a composite video signal.

Since the frequencies in a composite video signal may be as low as 60 cycles per second, or as high as 4,000,000 cycles per second, this means a video circuit must be capable of accepting such a wide spread of frequencies. It must be capable of accepting and handling frequencies as low as the lowest audio signal and as high as those of RF carriers in short-wave radio work.

All of which means that in order to amplify a composite video signal we must use a circuit which combines features of a normal audio circuit with those of an RF amplifier circuit. When you recall the things you have learned about audio and RF circuits it will become increasingly clear to you that a video amplifier circuit must possess some rather complex features for it to perform the duties required of it.

Another difference exists between a composite video signal and an ordinary audio signal. That is the necessity for providing the synchronizing pulses which maintain the receiver circuits in step with those in the transmitter.

The synchronizing pulses, you must bear in mind, are a part of the composite video signal, a very important part of it. Oddly enough, the frequency of the Horizontal Sync pulses just about equals the highest audio frequencies. Thus, they are higher than most audio frequencies, but lower than most RF frequencies.

Section 3. MAKE-UP OF THE COMPOSITE VIDEO SIGNAL

In audio work the electrical audio signal is the connecting link between two types of transducers. It links the microphone, which is one form of transducer, with the loudspeaker, another form of transducer.

When sound waves strike the diaphragm of the microphone the diaphragm is caused to move — to vibrate. The physical movement of the diaphragm coincides precisely with the pressure of the sound waves upon it.

When two sound frequencies strike the diaphragm its physical movement is influenced by the *resultant* of the pressures from the two sounds. When several sound waves strike the diaphragm at the same time the exact degree of pressure on it at any given instant is a complex mixture — or *resultant* — of all those sound wave pressures. The diaphragm vibrates in a weird pattern.

The electrical audio signal produced in the microphone as a result of those sound wave pressures often assumes a complex, and constantly varying shape. The varying instantaneous shape of that electrical signal is called the electrical wave-form.

When that complex electrical wave-form acts upon a second transducer, which converts the electrical energy back into mechanical energy, the net result is to make the cone of the loudspeaker vibrate in precise unison with the diaphragm of the microphone. We can put that explanation into other words by saying that the electrical audio signal links the microphone with the loudspeaker, and causes their moving parts to vibrate in synchronism. The audio electrical signal acts to synchronize the loudspeaker cone with the microphone diaphragm.

The electrical action in audio work is simplified because the varying frequencies rarely exceed a range of 15,000 cycles.

The composite video signal in television work is closely similar to the electrical audio signal in sound work. It carries the intelligence needed to reproduce at the receiver a scene being viewed by the camera.

The composite video signal carries within itself all the intelligence required to reproduce the scene viewed by the camera. It is the connecting link — the electrical connecting link — between the camera and the picture tube. The camera, and its associated circuits, creates the composite video signal; the picture tube, and its circuits are guided by that signal and controlled by it.

The method used to transmit the composite video signal from the camera circuits to the receiver circuits is relatively unimportant. Just as electrical audio signals are often transmitted over telephone wires in the form of speech or music, so is the composite video signal frequently transmitted by means of connecting cable.

Because of the complex nature of the composite video signal, and the extremely wide range of frequencies involved in it, it must be transmitted over special types of low-loss cables which are insensitive to frequency variations. Nevertheless, the composite video signal can be transmitted over such cable, and often is so transmitted.

Some types of video work utilize the composite video signal only in this manner. Examples of such use are the "closed circuit" video systems. These include those used to teach new surgical techniques, by the railroads in specialized applications, and by industrial plants within their own premises; also those employed in closed circuit theater television.

Where the distance between the camera and the receiver is not great, and especially in those cases where the intelligence involved has limited usefulness, or has value to a limited number of persons, it is the regular practice to transmit the composite video signal over cables. Fig. 3 gives some idea of types of situations which involve the transmission of composite video signals over closed circuit cables.

The point we make with this explanation is that the composite video signal contains within itself all the information needed to reproduce at the receiver a scene viewed by the camera. It is the link between the camera and picture tube in much the same way an electrical audio signal links a microphone and loudspeaker.

The composite video signal contains all the sync pulses needed to maintain the sweep circuits of the receiver and camera in synchronism with each other. Also the blanking pulses used to keep the retrace lines from showing. Most important of all, it carries the intelligence necessary to recreate the scene being viewed.

The transmission of composite video signals over closed circuit cables is somewhat more complicated than we have indicated in Fig. 3, nevertheless that illustration conveys a reasonably good idea of how such transmission can be accomplished. In most closed circuit applications more than one camera is involved, and very often there are several receivers.

The graphic appearance of a composite video signal is shown in Fig. 4. The camera signal, with its constantly changing voltage, is clearly shown. It appears as a wavy line.

The camera signal is periodically blanked out by the interruptions of the blanking pulse. During the existence of the blanking pulse the

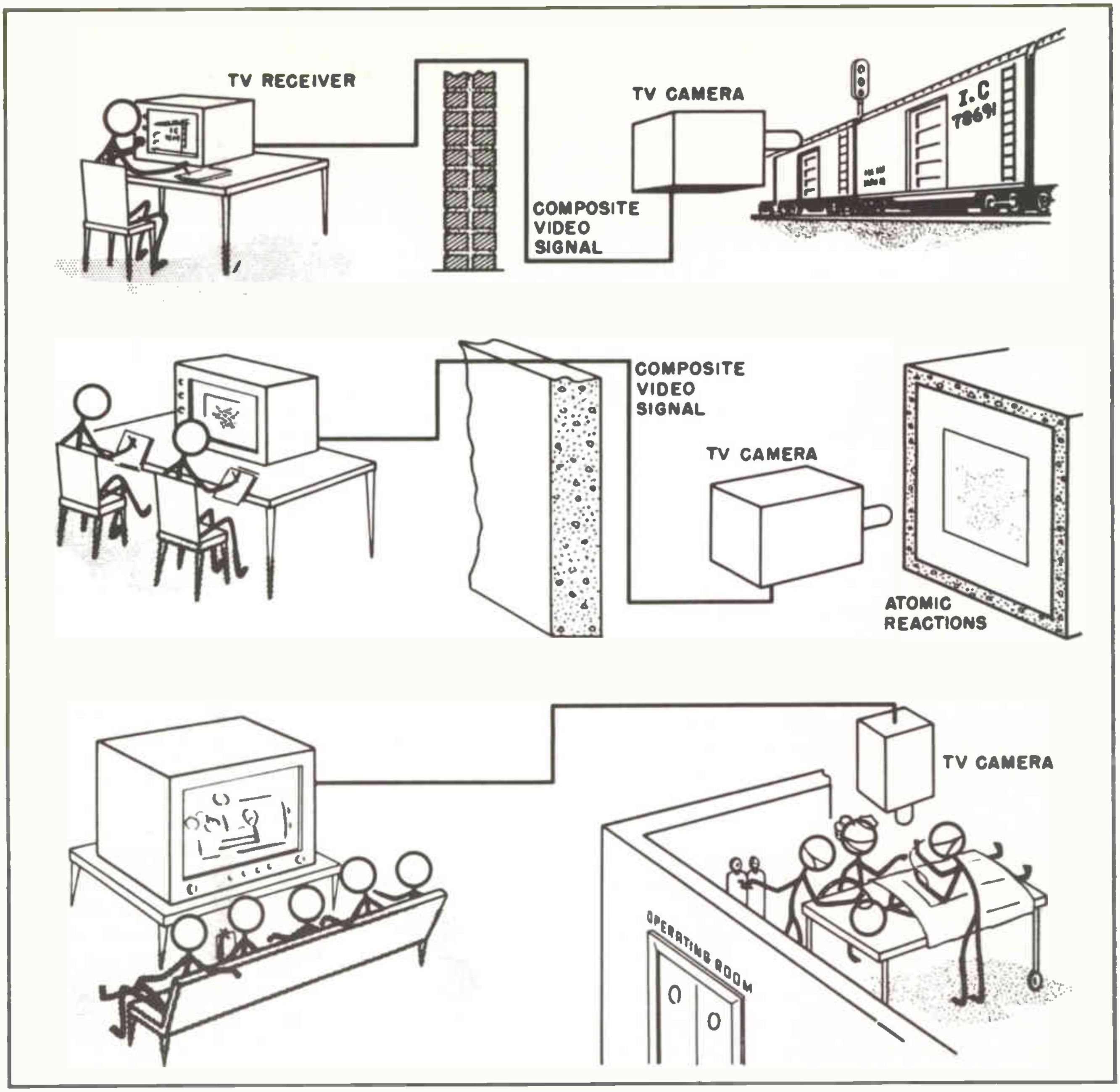

Figure 3. Transmission of Composite Video Signal over closed circuit cables.

camera signal is wiped out. During that period the camera signal is removed from the face of the screen.

The manner in which the synchronizing pulses are superimposed on the blanking pulses can also be seen. By carefully studying the graph of the composite signal it can be seen that the blanking voltage is first impressed on the camera signal, thus blanking it out. An instant later a synchronizing pulse is superimposed on the blanking pulse. The magnitude of the sharply rising sync pulse triggers the horizontal sweep circuit so it can begin its retrace movement.

The full amplitude of the composite video signal in Fig. 4 is indicated in terms of percent. The various magnitudes of signal voltage are indicated with respect to the peak voltage of the sync pulses.

The peak voltage of the sync pulses is represented as being 100% of signal strength. The peak voltage of the blanking pulse is shown to be 75%, meaning that the peak voltage of a

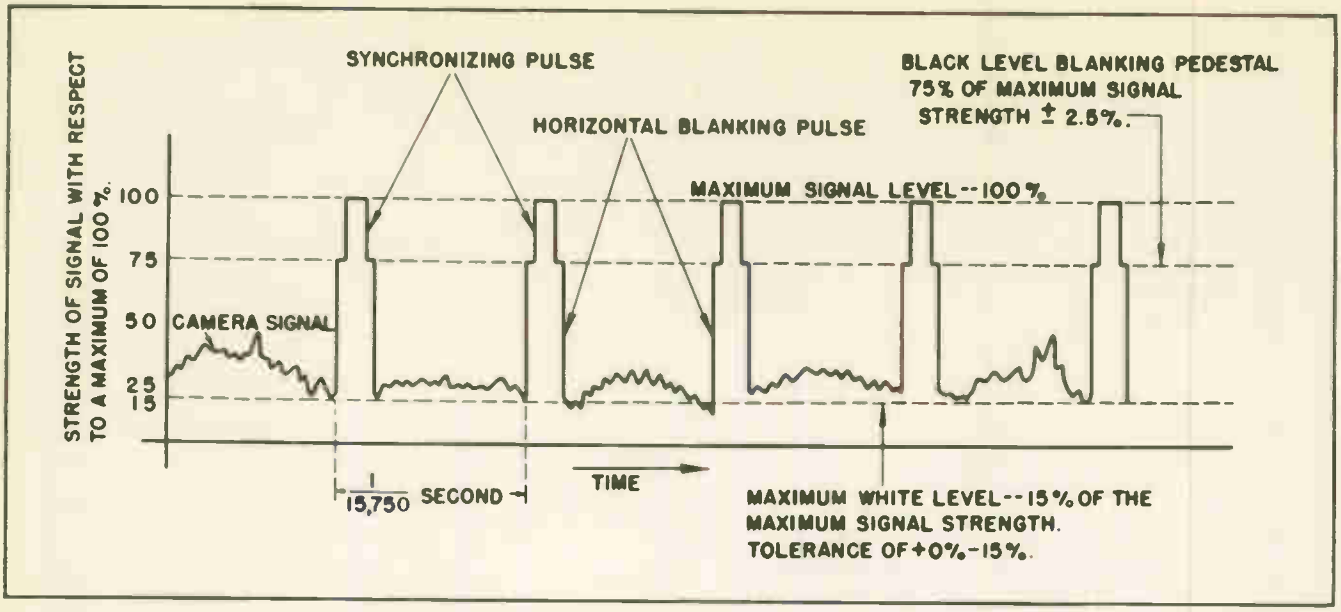

Figure 4. Portion of Composite Video Signal showing Blanking and Synchronizing Pulses superimposed on camera signal.

blanking pulse is 75% of the full peak voltage of the signal when the sync pulse is present.

The video signal, or to be more specific, the camera video signal, never exceeds 75% of the peak signal voltage. By the time the camera signal reaches 75% of maximum signal strength it is as black as it can go.

The amplitude of the video signal — or camera video signal — ranges from a brightness level of about 15% of the maximum signal strength to about 75% of the maximum strength. As mentioned in the preceding paragraph, 75% of the maximum signal strength represents the black level.

When the video voltage is only 15% of maximum strength we have brightness on the screen. When it rises to 75% of maximum strength we have blackness on the screen.

This explanation can be couched in somewhat different words; by using them it may be easier to understand what we are saying. A low signal voltage — a low camera signal voltage — has little effect on the strength of the electron beam in the picture tube, which means the beam produces a bright spot on the screen.

A strong signal voltage from the camera acts to restrict the electron beam in the picture tube, thus reducing the strength of the electron beam. A strong camera signal weakens the electron beam so there is only a weak trace on the screen, or no trace at all.

This all adds up to the fact that a weak camera signal voltage produces a bright picture element while a high signal voltage produces a dark picture element.

A study of Fig. 4 reveals that the camera signal varies in strength from a brightness level of about 15% to a maximum strength at the black level amounting to about 75% of the maximum signal level. This means the strength of the camera signal varies from a minimum of 15% to a maximum of 75%.

Since the camera signal uses no more than 75% of the maximum strength of the signal it leaves about 25% additional for the synchronizing pulses. Actually, the amplitude of the composite signal is divided into two sections. The lower 75% of the signal amplitude is devoted to the active camera signal. The remaining 25%, the higher voltage portion, is used for the synchronizing pulses.

Section 4. POLARITY OF TRANSMISSION

The composite video signal is normally used to modulate the video carrier in television transmission and reception. It is used to modulate the carrier in much the same way an audio

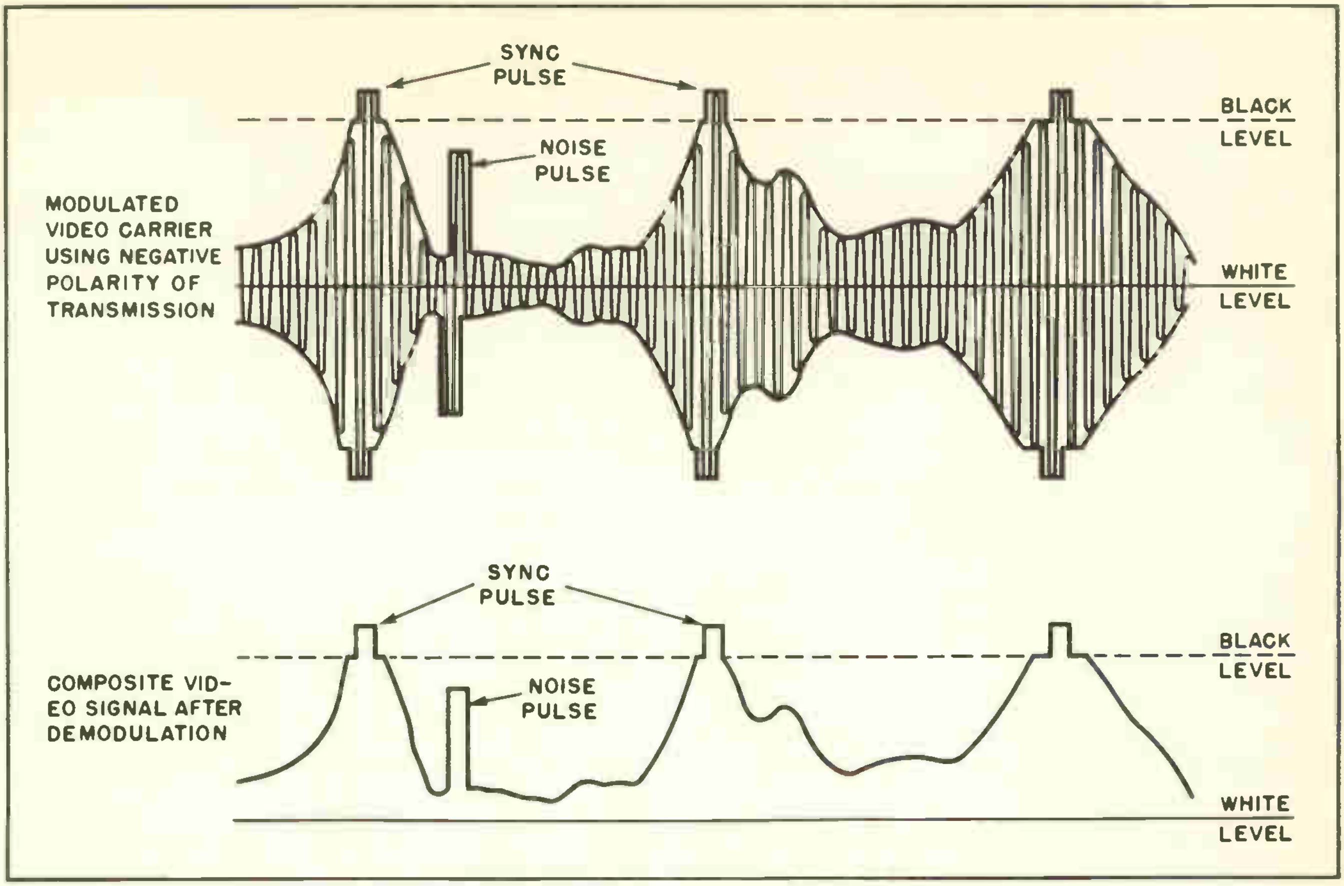

Figure 5. Negative Polarity of Transmission. Higher Signal Voltage places more Negative Voltage on Grid, making picture darker.

signal voltage is used to modulate the carrier in normal radio transmission.

The composite video frequency can be applied as a modulating voltage to the carrier in either of two different ways. It may be applied in what is called *negative polarity of transmission*, or in what is called *positive polarity of transmission*.

In the United States *negative polarity* of transmission is employed. We will describe both systems briefly so you will be acquainted with them. Thus, you will understand the differences between them when they are discussed in technical publications.

Fig. 5 shows the graphical envelope of a modulated carrier when the negative polarity system is employed. Below the graph of the modulated carrier is a graph showing the voltage of the composite video carrier after demodulation in the receiver.

In the negative system of transmission voltage peaks of the modulated envelope represent the darker elements of the composite video signal. The blanking pulses represent a high level of modulation, while the sync pulses represent an even higher level of modulation.

Voltage peaks, then, tend to make the picture darker.

The opposite situation prevails in the case of *positive polarity of transmission*. The graphical envelope of a modulated carrier when positive polarity is employed is shown in Fig. 6. It can be seen by studying the graph of the modulated envelope that the sync pulses represent the lowest level of modulation, which is in sharp contrast with the situation shown in Fig. 5.

The *negative polarity of transmission* system was adopted in the United States because "electrical noise" pulses picked up by the receiver would be less noticeable to the viewer. An electrical noise pulse picked up by the receiver when receiving a negative polarity transmission acts to momentarily darken a small spot in the picture.

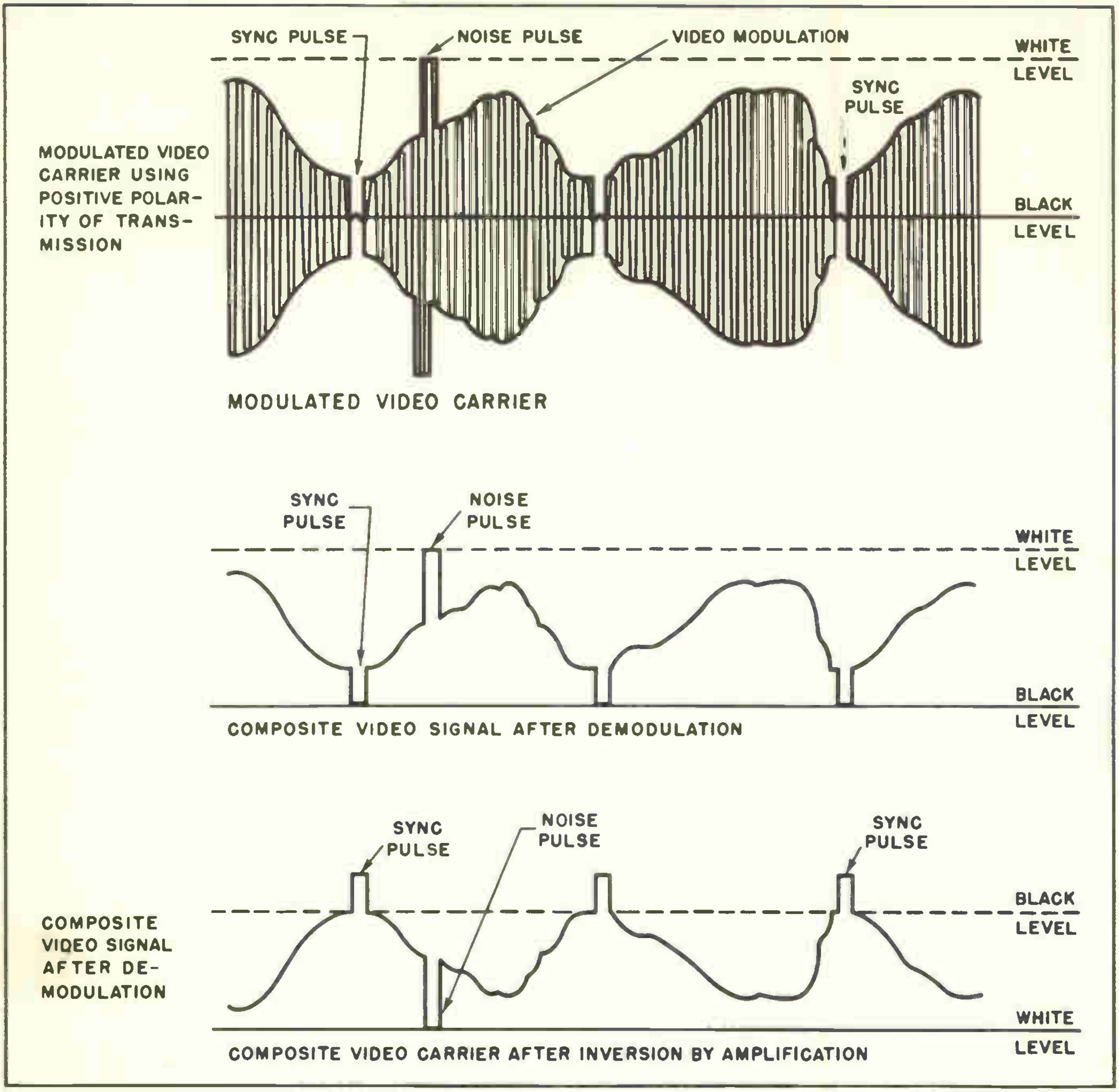

Figure 6. Positive Polarity of Transmission. Higher Signal Voltage places more Positive Voltage on Grid, making picture darker.

Experience has shown that a small *dark* spot in a picture is much less noticeable than a *bright* spot of the same size. This means that electrical noise is less noticeable, and less troublesome, when the composite video signal modulates the video carrier by using negative polarity of transmission.

The positive polarity of transmission has been favored by several other countries, particularly those in Europe. The advantage of the *positive polarity of transmission* is that noise pulses have less effect in knocking the receiver out of synchronism.

A strong noise pulse, when negative polarity is employed, can trigger the horizontal oscillator prematurely, and knock the horizontal circuits out of synchronism.

Manufacturers of receivers in the United States have used special locking circuits to avoid loss of synchronization due to electrical noise interference.

By employing special locking circuits U.S. manufacturers have succeeded in avoiding sync interference when negative polarity of transmission is used. At the same time they enjoy the benefit of less noise interference in the picture.

It is necessary to standardize on a system of transmission within any reception area. Receivers designed to work with one type of polarization will not work with the other. The FCC has standardized the polarity of transmission in the United States by requiring all television broadcasts to be modulated with negative polarity of transmission. Mexico and Canada use the same standards; so do most of the other Latin-American countries.

But, most of the European countries use positive polarity of transmission. Because of this few receivers designed for use within the United States can be used in Europe. For the same reason, few television receivers designed for use in Europe can be used in the United States.

There are other differences in the TV standards used in Europe which distinguish them from those which prevail in this country. Especially with respect to differences in line frequency. But the method of polarity modulation in transmission is one of the most important.

Section 5. MAINTENANCE OF BLACK LEVEL

The black level of the composite video signal is maintained at a constant value, and is independent of the picture information. In some types of receivers special circuits are necessary to maintain the black level at a constant value.

The reason this is true can be better understood when it is remembered that the zero level of the voltage in the composite video signal represents the brightest elements in the picture. The black level represents the peak voltages of the composite video signal.

Signal voltages we have studied in the past have all been symmetrical. By this we mean that in all the cases we have considered in previous lessons the voltages on the positive side of zero have been equal to, and balanced by, those on the negative side. Thus, they have tended to cancel each other, or to balance each other.

The composite video signal is not necessarily a symmetrical voltage. As a matter of fact it is asymmetrical (irregular) in form more often than it is symmetrical.

What this amounts to is that special attention must be paid to circuits which handle the video signal in a receiver to make certain the black level is held at a constant value. We will not explain the special circuits at this time, but we call your attention to the fact they exist so you can be aware of them.

The importance of maintaining the black level at a constant value lies partly in the fact that some definite signal strength in the composite video signal should make the picture black. Impressing on the grid of the picture tube a video voltage which is equivalent to 75% of the maximum peak should remove all brightness — make the picture black.

Varying values of voltage, then, between the minimum voltage and 75% of maximum voltage should create varying shades of black-and-white on the screen. Maximum whiteness is present when the magnitude of the signal drops to approximately 15% of maximum — the other extreme, a signal strength amounting to 75% of the signal peak results in blackness.

What this all adds up to is that any signal strength which exceeds 75% of the maximum peak is *blacker than black.* Such signal strength condition is sometimes called *infra-black.* This condition results from the picture tube grid being driven more negative than cut-off.

Referring back to Fig. 4 we can see that the blanking pulses coincide with the black region, while the synchronizing pulses penetrate into the *infra-black* region.

The blanking pulses drive the composite video signal to a voltage level equivalent to 75% of the maximum peak. The blanking pulses occur at the end of each active trace; they occur in preparation for the retrace.

The blanking pulse voltage level is equivalent to the black level. The signal voltage strength during the existence of the blanking pulse is just sufficient to hold the picture at the black level.

While the picture is held at the "black" level by the blanking pulse, the composite video signal suddenly goes still further negative. That sudden, sharp negative pulse is the *synchronizing pulse.*

The synchronizing pulse, which triggers the saw-tooth oscillators to initiate the retrace movement of the electron beam, drives the signal grid of the picture tube *blacker than black.* Since the picture tube is already blanked out by the negative blanking pulse voltage on the grid, the additional negative voltage of the sync pulse has no effect on the composition of the picture.

A better understanding of the manner in which the composite video signal affects the picture tube can be obtained if we follow the signal through several successive lines. In Fig. 7 we have a graph of the composite video signal. It is similar in most respects to that shown in Fig. 4.

The graph represents the voltage changes which occur in the signal as time passes. In this case, the graph covers a period of 5/15,750th of a second, which is equivalent to the amount of time needed for the electron beam to scan five successive horizontal lines.

Starting at zero time in the diagram, we would start at the left-hand side of the picture as well as the left-hand side of the diagram. At the instant shown the signal is in the white region of the signal voltage, and is rising irregularly.

As the scanning beam moves from the left side of the screen toward the right, the voltage level of the signal rises irregularly to a peak, meaning the picture becomes irregularly darker until it reaches a dark spot. Then it starts growing brighter.

The picture continues to grow irregularly brighter as that particular line is scanned until, at the right side of the picture, it reaches its maximum brightness just before the blanking pulse blanks out the camera signal completely.

During the movement of the beam from the left of the picture to the right the varying voltage of the camera signal represents the varying shadings of light and dark scanned by the beam at the camera tube. The varying signal voltage actually consists of varying elements of picture information being applied to the picture tube grid.

At the end of the first line of picture information the beam reaches the right side of the picture tube screen. At that instant a blanking pulse arrives. The blanking pulse causes the signal voltage to rise sharply, sufficiently to blank out the picture on the tube.

The action of the blanking pulse is to place on the picture tube grid a negative voltage sufficiently strong to blot out the electron beam. This extinguishes the beam so it no longer strikes the fluorescent material on the screen.

An instant after the blanking pulse is imposed on the grid of the picture tube a synchronizing pulse comes along. Note that the sync pulse makes the grid still more negative; it drives the voltage deeply into the infra-black region.

Since this is blacker than black, and since the picture tube is already blanked out, the sync pulse is not visible on the screen. But the sync pulse is strong enough to affect a triggering circuit which trips the sawtooth oscillator controlling the sweep circuit.

When the sync pulse trips the sweep circuit it results in the retrace of the electron beam. The beam moves very rapidly from the right side of the tube to the left. (Actually, the electron beam is blanked out during this retrace, but the deflection circuits create voltages and currents of such nature that the beam would be retraced if it were alive.)

The blanking voltage remains impressed on the grid of the tube long enough to allow the beam to retrace the full distance to the left side of the screen.

After sufficient time elapses to permit the synchronizing pulse to die out, and enough time for the beam to retrace completely across the face of the screen the blanking voltage is removed. When the blanking voltage is removed, the scanning beam is again at the left side of the screen and ready to start the second active line. Quite often the scanning beam is already moving to start a new trace before the blanking voltage is removed.

Fig. 7 shows the level of the video signal

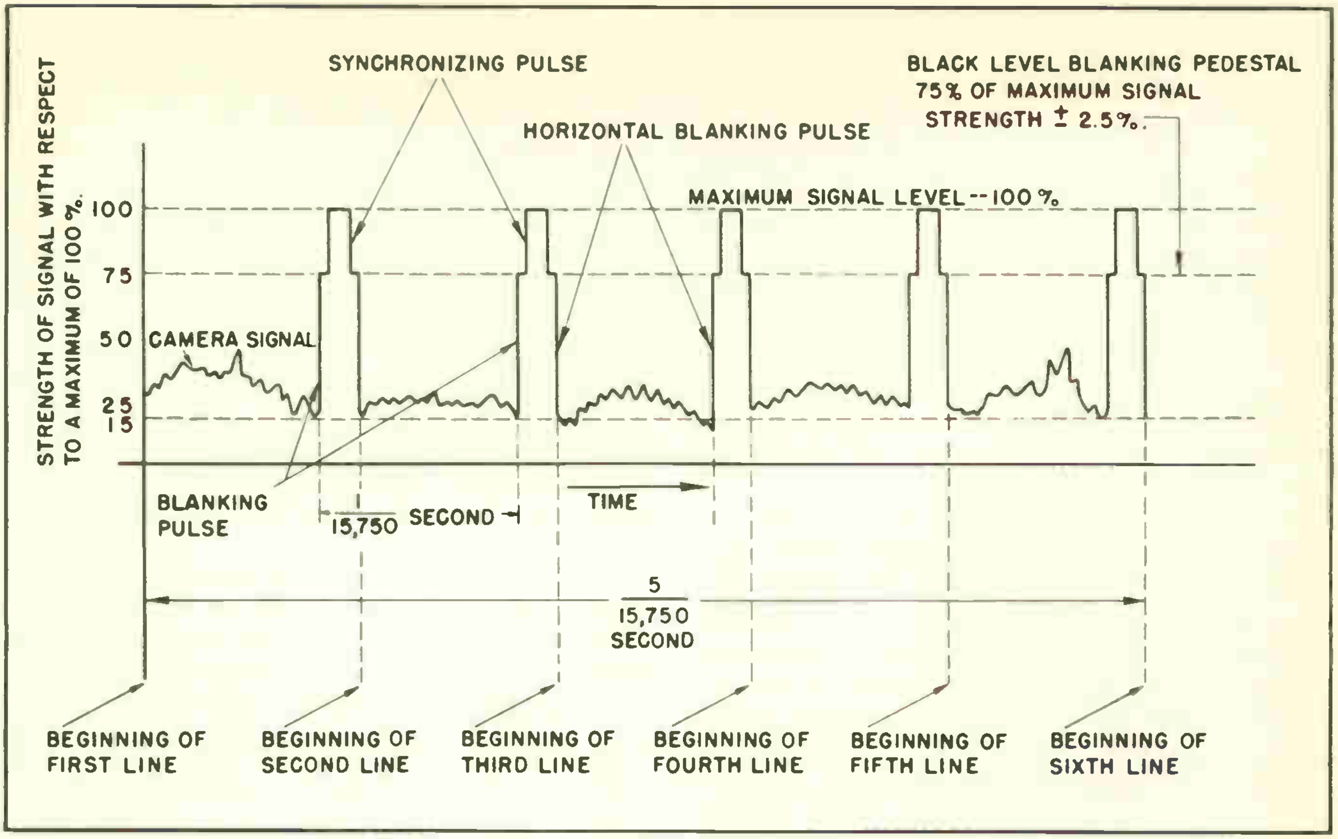

Figure 7. Composite Video Signal for five consecutive lines on picture tube screen.

voltage at the beginning of the second line.

The second line is traced in the same manner as the first one. At the end of the line the camera signal is again blanked out. Another synchronizing pulse starts the beam on its retrace. The camera signal remains blanked out until the third line is started.

Fig. 7 shows how the trace movement of the third line is started, and how it ends with another blanking pulse. Then the fourth line, and so on.

Line after line is traced, and retraced, in the same manner. The beam is blanked out at the end of each trace. Immediately after the camera signal is blanked out a sync pulse causes the beam to start its retrace.

There is a time lapse of 1/15,750th of a second between the beginning of one blanking pulse and the beginning of the next. This is to be expected since you already know the horizontal oscillator causes the scanning beam to make 15,750 trips across the face of the screen each second.

Section 6. HORIZONTAL BLANKING PERIOD

Some of the items of information explained in this lesson are not absolutely essential to the receiver service technician. Many technicians become reasonably capable without fully understanding some of these technical details.

Nevertheless, it is convenient for a serviceman to know as many of these things as it is possible for him to remember.

The composite video signal is created at the camera in the transmitting studio. The blanking and synchronizing pulses are created there. The serviceman has no control over them, and has nothing to do with their creation.

Nothing the serviceman can do can change the shape, duration or magnitude of either the blanking pulses or the synchronizing pulses. That is all the function of the transmitter equipment.

But the more a serviceman knows about the formation and creation of the composite video signal, and its component pulses, the more intelligently he can attack the various problems which face him in everyday service work. While we readily admit that some of the information included here is not vitally necessary, the fact remains that the more a serviceman knows about these things the easier his work will be.

The FCC has created specific standards regarding the transmission of TV signals by radio. We have already mentioned some of them, we will mention others as we progress.

At the moment we will direct our attention to the standards prescribed for the horizontal blanking period, and the blanking pulse.

In all frankness we must admit that many servicemen do a satisfactory job without ever knowing very much about the blanking pulses. They know there are such things, and in a general way the duties they perform. But they know little about their duration, rate of rise and fall, or their relationship to the other standard elements in a composite video signal.

We believe it is to your advantage to know something of the rigid standards which govern the formation and dimensions of the blanking and sync pulses. It gives you a far better understanding of the general scheme of things, even though you never have occasion to work in a TV studio where the pulses are created.

By obtaining a reasonably accurate understanding of blanking and sync pulse formation and dimensions at this time you will find the more technical details of color television easier to understand.

The so-called "color burst", which is used to control the color content in color TV, is superimposed on the blanking pulse. The creation and handling of that color burst is extremely importtant in color television, and is often difficult to understand. If you already have a good understanding of blanking and sync pulses you will not have that to learn when you get into color television.

Let us first turn our attention to the frequency of the blanking periods. In Fig. 8 we have expanded one of the cycles shown in Fig. 7 so we can study the action of the composite video signal during the scanning of a single line.

Note, first of all, that the elapsed time between the beginning of one blanking period and the beginning of the next amounts to 1/15,750th of a second. In Fig. 8, we have shown the elapsed time between the beginning of one sync pulse and the beginning of the next. But the same period of time exists between any given point in one cycle and the corresponding point in the following cycle.

In Fig. 8 we have designated the length of a horizontal cycle with the letter *H*.

Try to get clearly in mind what the letter *H* is intended to represent. We will be using it quite often in other sections of this lesson; also in other lessons which follow.

Designation of the letter *H* to represent one cycle of the horizontal sweep did not originate with us. It is used widely throughout the entire television industry, although such custom is not quite so definitely standardized as some of the other customs.

In Fig. 8 we show the letter *H* is equivalent to the lapse of time between the beginning of one sync pulse and the beginning of the following one. Since *H* is equal to 1/15,750th of a second it also represents the lapse of time between the beginning of one blanking pulse and the beginning of the next; or, the end of one blanking pulse and the end of the next.

In plain words, the letter *H* represents the lapse of time between any given instant during one horizontal cycle and the corresponding instant in the following one. *H* represents one horizontal sweep cycle.

The shape, size, duration, and other physical features of the blanking and sync pulses are directly related to *H*. The FCC has directed that the physical characteristics of those pulses are to be measured in terms of percentage of *H*.

For example, in Fig. 8 we see that the duration of the first blanking pulse is equivalent to 0.18H, or 18% of the entire horizontal sweep cycle. To be more exact, the duration of the blanking pulse *shall not exceed* 18% of the complete horizontal cycle.

The FCC says the blanking pulse shall not be longer than 18% of one horizontal sweep cycle, nor shorter than 14% of a sweep cycle. Expressed in terms of *H*, this means the duration of a blanking pulse shall not be greater than 0.18H nor less than 0.14H.

Normally the blanking pulse averages about 0.16H, or about 16% of one full horizontal sweep.

In other lessons we have explained the length of one complete horizontal sweep. Since the horizontal sweep goes through 15,750 cycles per second, this means that each horizontal sweep is approximately 63.5 microseconds long — this also means that *H* is equivalent to approximately 63.5 microseconds.

Since the blanking pulse is equal to a period ranging from 0.14H to 0.18H it is easy to figure the duration of the blanking pulse in terms of microseconds. The minimum length of the blanking pulse would be 14% of 63.5 microseconds, and the maximum length 18% of 63.5 microseconds.

In terms of microseconds this means the blanking pulse would have a duration of not less than 8.9 microseconds and not more than 11.4 microseconds.

At first glance this might seem that the blanking pulse keeps the camera signal blanked out an unnecessarily long period of time. If so, you should keep in mind the activities which take place during that blanking period.

The picture is blanked out just before the trace reaches the right side of the screen. Such action provides a blanking action before the arrival of the synchronizing pulse. Further, it provides a voltage pedestal on which the sync pulse rests — a voltage pedestal which has a constant voltage level on which to base the sync pulse. By basing the sync pulses on a constant voltage level each of the successive sync pulses start from the same level, thus making them all alike.

The blanking pulse is present during the existence of the sync pulse. This is most desirable, since it keeps the picture blanked during the retrace period. It prevents the possibility of horizontal retrace lines appearing on the screen. Horizontal retrace lines could seriously interfere with the picture.

The blanking pulse period which precedes the

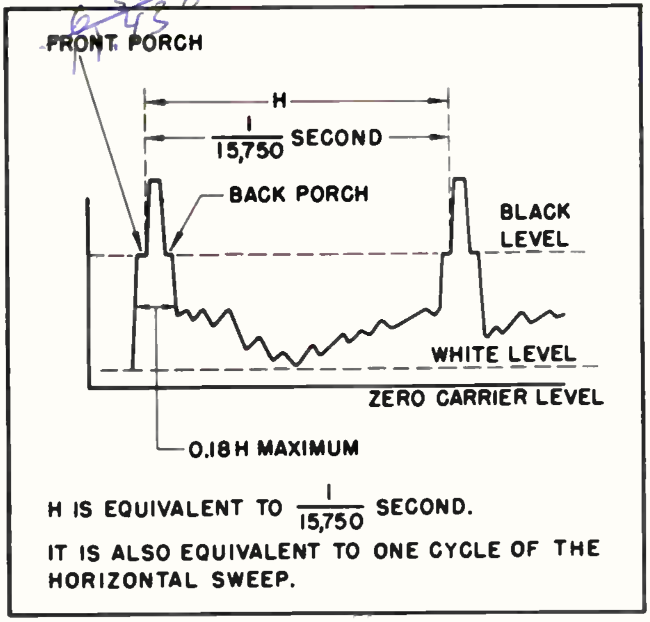

Figure 8. H represents duration of Horizontal Sweep cycle.

arrival of the sync pulse is commonly referred to as the "front porch". That is a colloquial term which crept into television terminology during the early days, and has stuck.

The term is derived from the appearance of the graph of a composite video signal. After the rise of the blanking voltage pulse is graphed there is a short interval during which the blanking voltage remains stable. In the process of graphing the signal voltage the momentarily stable voltage is represented as a short horizontal line.

Fig. 8 clearly indicates the presence, and position, of the "front porch".

After the sync pulse has passed, the blanking pulse continues to maintain the picture in a blanked out condition. The continued presence of the blanking pulse insures that the picture will remain blanked out during the entire period of the retrace. It also blanks out a very short period at the beginning of each horizontal trace.

Blanking the picture just before the arrival of the sync pulse, and keeping it blanked a short time after the sync pulse has been removed, keeps the beginning of all the lines and the end of all the lines in perfect alignment with each other.

Like the blanking interval before the arrival of the sync pulse, the short blanking interval which follows the sync pulse is graphed so the voltage level is shown as a short horizontal line. That interval has come to be known as the "back porch" in the language of the television world. The presence, and location, of the back porch is shown in Fig. 8.

The "back porch" of the blanking pulse has little significance in black-and-white television other than that it assures the blanking of the picture during the entire period of the retrace. In color television, however, it assumes major significance. This fact was mentioned previously, and will be touched on again later.

Section 7. TIME DIMENSIONS OF BLANKING AND SYNC PULSES

While we are discussing the blanking and sync pulses it is just as well we describe their dimensions in terms of time. It is scarcely likely you will find it necessary to actually know these details, but knowing them will help you better understand the duties they perform.

If you later decide to make a study of color television you will find a detailed knowledge of these pulse dimensions extremely convenient.

Fig. 9 provides a pretty good idea of the relationships of the various parts of the blanking and sync pulses with each other. The duration of the various intervals involved with the pulses is expressed in terms of *H. The actual* times, in terms of microseconds, can be easily figured by converting the percentages of *H* directly into microseconds.

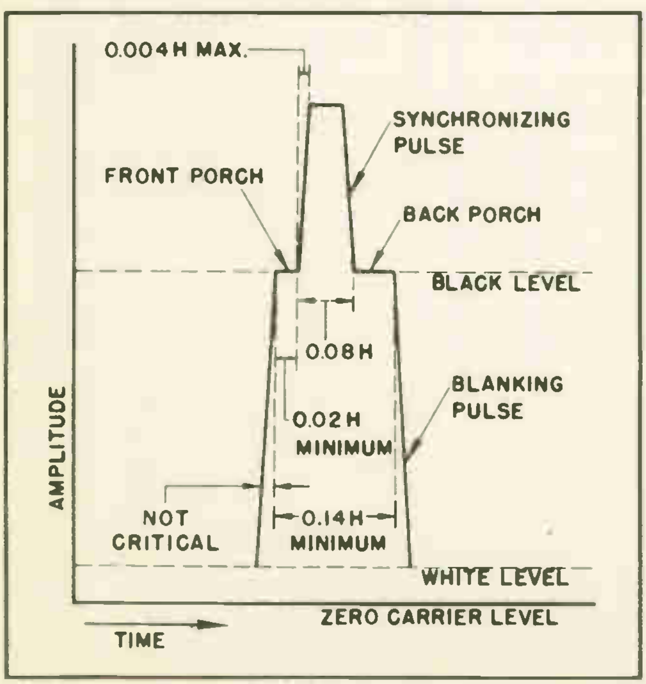

Figure 9. Time relationships of various parts of Blanking and Sync pulses.

The rise of the blanking pulse voltage is not covered by any definite standards. In practice the voltage of the pulse is caused to rise as rapidly as is practical.

If the rise of the voltage at the leading edge of the blanking pulse is very sharp the picture is blanked out very sharply at the right side of the screen. If the rise of the blanking pulse voltage is less abrupt the blanking line at the right of the picture will be slightly blurred rather than very sharp.

But the abruptness of the pulse voltage rise at the beginning of the blanking pulse is never a matter of serious concern.

Once the blanking pulse voltage rises to its proper value it tends to level off. The leveling off begins the period known as the "front porch". The front porch was mentioned in the preceding section, and shown in Fig. 8. It is again shown in Fig. 9.

The duration of the "front porch" is rigidly controlled. It must have a minimum length of 0.02H. This is equal to 2% of 63.5 microseconds, or approximately 1.3 microseconds.

The duration of the front porch, a matter we have already mentioned, forms the pedestal on which the sync pulse is later superimposed.

Next comes another sharp and sudden rise in the voltage. This is the rise of the voltage at the leading edge of the sync pulse.

Refer to the graph in Fig. 9. There you can see the voltage rises at the leading edge of the blanking pulse. Then it levels off for a short period during the interval of the front porch. Then comes another sharp rise of the voltage at the leading edge of the sync pulse.

The rise of the voltage for the sync pulse is another matter of critical importance. It is extremely important that the voltage rise as suddenly and sharply as circuit design will permit. The more sharply that voltage can rise the truer will be the alignment of the successive horizontal lines with each other.

The leading edge of the sync pulse provides the signal to start the horizontal retrace. As the voltage rises from the level of the blanking pulse pedestal to the sync pulse peak it acts to trigger the horizontal oscillator into beginning its retrace.

The shorter the period of time during which that sync pulse voltage rises the more closely the successive horizontal lines can be aligned with each other.

For that reason every effort is made to cause that voltage to rise as nearly instantaneously as is possible. The faster the voltage rises to a peak the steeper the graph of the voltage at the leading edge of the pulse.

Fig. 9 shows that the voltage at the leading edge of the sync pulse must rise from the base of the blanking pulse pedestal to its peak of the sync pulse in 0.4% of 63.5 microseconds.

This figures out to about one-quarter of a microsecond, or one four-millionths of a second. In practice the sync pulse voltage rises more sharply than that.

The duration of the sync pulse from the beginning of its rise to the end of its decay, must not be more than 0.08H. That is 8% of 63.5 microseconds, and figures to about 5 microseconds. To put this in other words — the total duration of the sync pulse is approximately 5 microseconds.

Which leaves the time duration of the "back porch".

Fig. 9 does not show any time dimensions for the back porch. But it is not difficult to figure it out.

The front porch has a duration of 0.02H; the sync pulse a duration of 0.08H. Adding them together makes a total of 0.1H. This is the length in time of those two intervals of the pulses.

Since the graph shows the blanking pulse pedestal has a minimum length of 0.14H it is not difficult to calculate the length of the back porch. It is merely necessary to subtract 0.1H from 0.14H, which gives us a period of 0.04H as the minimum length of time of the back porch. Since the average length of the blanking pulse is closer to 0.16H than 0.14H, the back porch usually is closer to 0.06H than 0.04H.

Let us emphasize again that all *these details are not essential requirements* for a man who intends to concentrate on ordinary black-and-white television servicing. They do, however, become increasingly important for the man who later intends to take up the study of color.

In color television it is necessary to maintain the frequency of a local oscillator in the receiver in exact synchronism with a reference oscillator in the transmitter. In order to do so the frequency of the local oscillator is compared with that of the one at the transmitter just before the beginning of the sweep of each horizontal line.

That comparison is brought about by means of what is called a "color burst". The color burst consists of not less than 8 cycles of a 3.58-megacycle signal. The 8 cycles of reference signal locks the local oscillator — which has a precise frequency of 3.579545 megaycles — into exact synchronism with the reference oscillator at the transmitter which operates on the same frequency.

The 8-cycle "color burst" is superimposed on the "back porch" of the blanking pulse. Since the time interval of the back porch amounts to not less than 0.04H, or approximately 2.5 microseconds, there is ample time for those 8 cycles at that frequency.

Fig. 10 shows how the 8 synchronizing cycles of the "color burst" are superimposed on the back porch of the blanking pulse in color television.

It should be kept in mind that the time duration of the back porch can be lengthened without otherwise disturbing the content of the picture, or creating other interference.

Placing the synchronizing "color burst" at that location does not interfere with any of the other synchronizing functions if the color broadcast is being picked up on a black-and-white receiver.

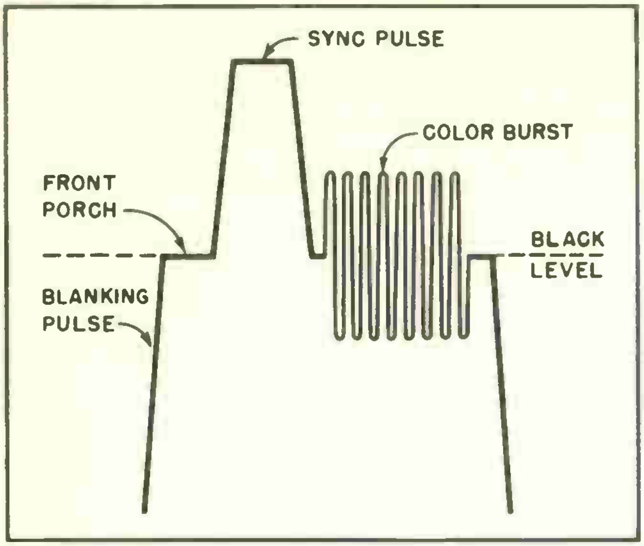

Figure 10. How "Color Burst" in color television is superimposed on Back Porch of Blanking Pulse.

It utilizes a portion of the blanking pulse which is not otherwise used for anything other than blanking the picture at the left edge of the screen.

Section 8. APPLYING SYNC PULSES TO SAW-TOOTH OSCILLATOR

So we will not lose sight of the purpose of the things we are studying, suppose we take a quick look at a saw-tooth oscillator, and note the manner in which the sync pulses are applied to it.

The saw-tooth oscillator is necessary in order to provide the correct wave-forms to the sweep voltage so the electron beam is moved back and forth across the screen of the picture tube in the proper manner. To keep the beam in the picture tube moving back and forth in unison with the one in the camera it is necessary to link them together in some manner, and thus control their movements.

That is the purpose for which we use the sync pulses.

Saw-tooth oscillators, at least most of them, have a free-running frequency of some definite value. That frequency is determined by the values of the frequency-governing components in the oscillator circuit.

We have explained saw-tooth oscillators in previous lessons. It scarcely seems necessary to go into them again at this time. If their action is not clear to you it would be well to go back and review the lessons where they were explained.

The saw-tooth oscillators used in television work are normally designed so the free-running frequency is slightly lower than the 15,750-cycle sweep frequency of the horizontal sweep.

To speed up the frequency of the oscillator, so it will keep in step with all the other sweep oscillators with which it must be synchronized, a triggering pulse is applied to the oscillator in some manner. The exact manner in which that triggering pulse is applied to the oscillator depends to a considerable degree on the type of circuits involved in any given receiver.

Fig. 11 has a diagram of a multivibrator oscillator, which is capable of generating a saw-tooth wave-form when the component values are properly selected.

The oscillator would normally have a free-running frequency slightly lower than 15,750 cycles per second.

When a synchronizing pulse is applied to the grid of the first tube of the saw-tooth oscillator it causes that tube to start its cycle slightly sooner than it would normally. By triggering each cycle the oscillator is locked in synchronism with the synchronizing pulses.

By applying the same synchronizing pulses to two or more saw-tooth oscillators they can all be locked together so they all work in unison. This is the secret of television transmission. The synchronizing generator at the transmitter locks together tens of thousands of television receivers so their saw-tooth oscillators operate in unison with the saw-tooth oscillators in the camera.

The synchronizing pulses reach the saw-tooth oscillators in each of the receivers through the medium of the composite video signal. Fig. 11 shows how the sharp, rising voltage in the sync pulse starts the retrace action in a saw-tooth oscillator. In Fig. 11 we are concerned with a multivibrator type of a saw-tooth oscillator. But the synchronizing pulses can be applied to other types of saw-tooth oscillators, and lock them into synchronism in a similar manner.

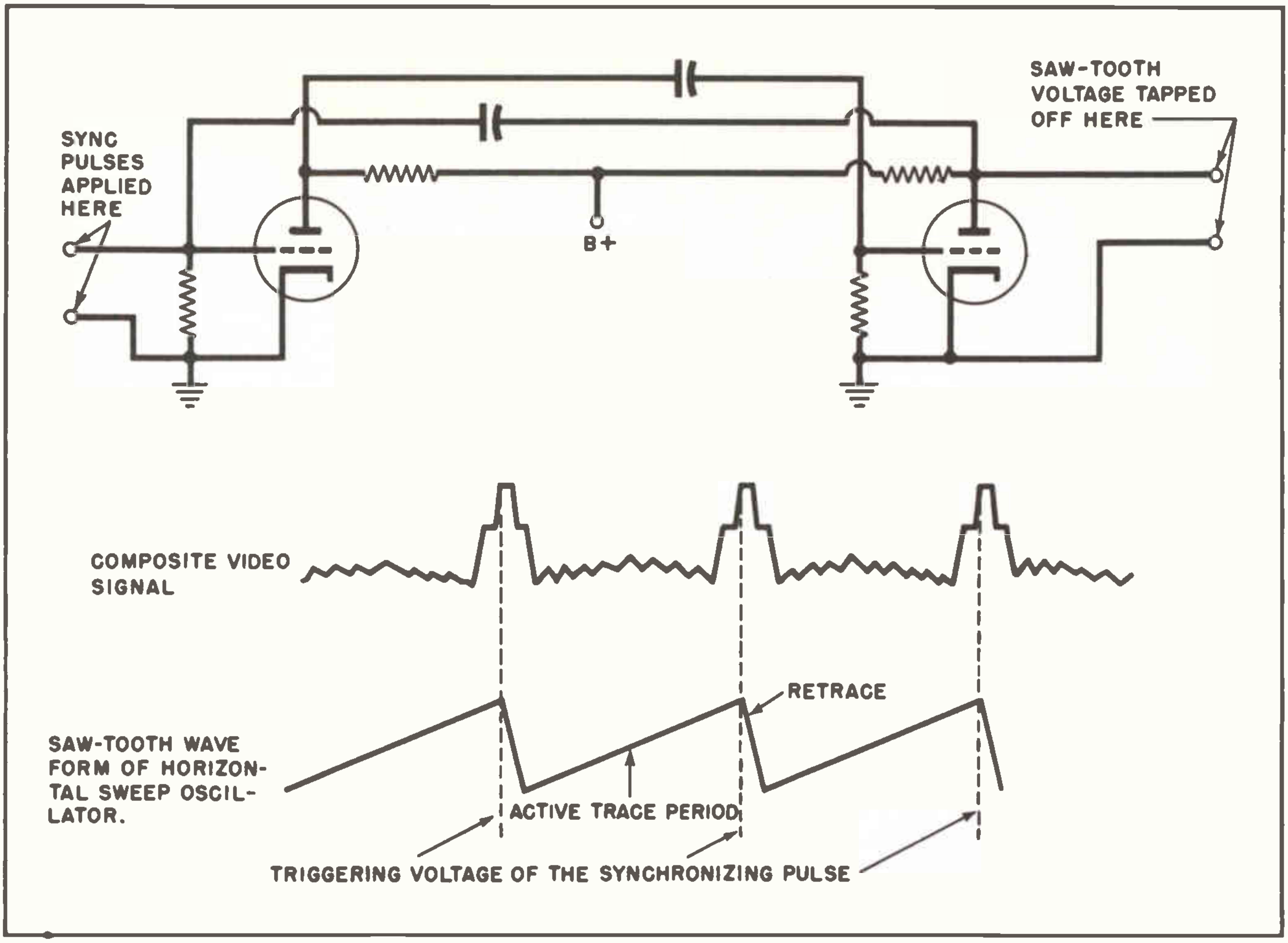

Figure 11. How Sync Pulses in Composite Video Signal Trigger Horizontal Sweep Oscillator.

Section 9. VERTICAL MOVEMENT OF BEAM

The composite video signal contains information in the form of voltage pulses which act to control the vertical movement of the beam as well as the horizontal movement. We have touched on the horizontal control exerted by the voltage pulses in the composite video signal; it is now time to direct some of our attention to the action controlling the vertical movement.

The electron beam must be moved downward across the face of the screen at the same time the horizontal sweep oscillator is moving it horizontally across the screen. But the beam makes many trips horizontally across the screen while it is moving once from top to bottom.

Were it not for the vertical movement the horizontal sweep would merely move the beam back and forth in a straight line. All that could then be seen would be a single horizontal bright line across the face of the screen, much like that in Fig. 12.

The normal procedure followed in the United States is for the beam to be moved downward slightly during each horizontal trace. The beam moves horizontally from the left side of the screen to the right; during the same time it moves downward slightly so the beam at the right side of the screen is slightly lower than at the left.

A rather exaggerated illustration of this condition is shown in Fig. 13. It is easier to follow the description of what is going on by observing Fig. 13 than would be true if the trace of the beam were drawn to actual scale.

After the beam reaches the right side of the screen, after tracing the first line, it quickly returns to the left side under the influence of the retrace voltages generated by the horizontal sweep oscillator. But the beam will strike the

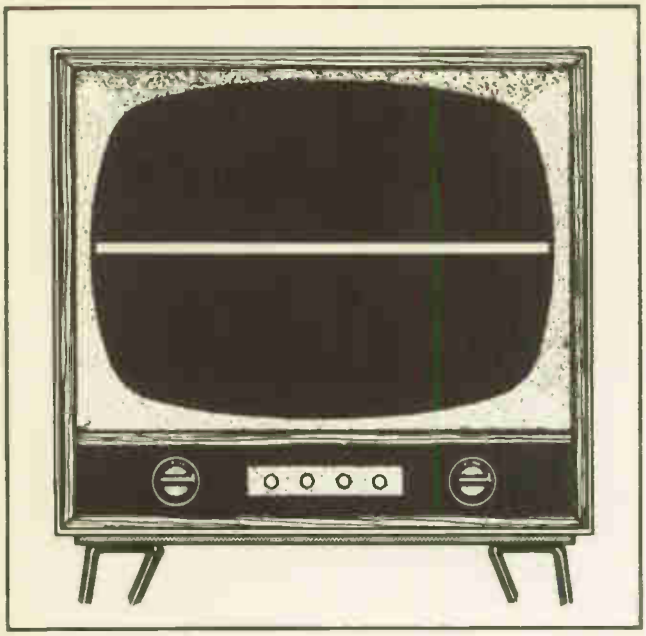

Figure 12. Lack of Vertical movement of beam produces single Horizontal Streak.

screen at a somewhat lower location than when it began its sweep of the first line. This results from the fact that the vertical sweep is moving the beam downward in a vertical direction at the same time the horizontal sweep is moving it back and forth in a horizontal direction.

After the retrace returns the beam to the left side of the screen, after tracing the first

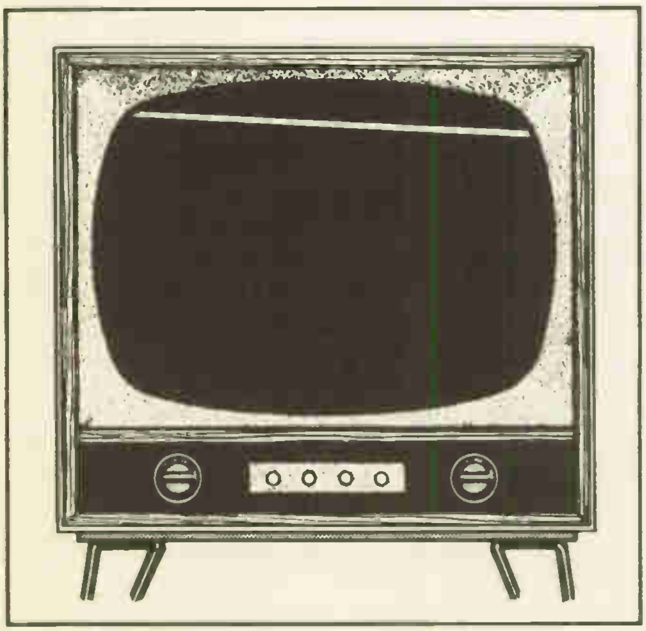

Figure 13. Beam moves from Left to Right under influence of Horizontal Sweep. It moves downward under influence of Vertical Sweep.

line, the beam begins tracing a new line under the influence of the horizontal sweep oscillator. This second line is traced toward the right side of the screen in the same manner the first line was traced. But it is a little lower on the screen.

Fig. 14 provides a good idea of the general manner in which this action occurs. Like the drawing in Fig. 13, this one also is greatly exaggerated. The lines are actually much finer than shown in the illustration, and they are not so far apart. But the illustrations give a good idea of the action which causes the sweep of the beam across the screen.

In the United States the standards call for 525 horizontal lines on a television receiver. During each downward movement of the beam it traces out 262.5 horizontal lines. This means that for each downward movement of the beam there are 262.5 horizontal movements.

During the downward movement of the beam only *half* of the horizontal lines are scanned. After the beam reaches the bottom of the screen it returns quickly to the top to begin a second downward journey. During this second downward trip 262.5 additional horizontal lines are scanned. This second group of lines is interlaced between those scanned during the first downward sweep.

To make this even more clear we should explain that during the first downward sweep of the beam the first line, the third line, the fifth line and all the other odd-numbered lines are scanned. During the second downward sweep of the beam the even-numbered lines are scanned. Technically, this is called "interlaced scanning".

After the beam has made two complete vertical sweeps it has traced out 525 horizontal lines; half of them during the first downward sweep, the other half during the second downward sweep.

It must be kept clearly in mind that the interlacing of the two groups of horizontal lines is no accident. Such things do not "just happen".

The movement of the electron beam is kept under rigid control at all times. That control is exerted through the various combinations of pulses present in the composite video signal.

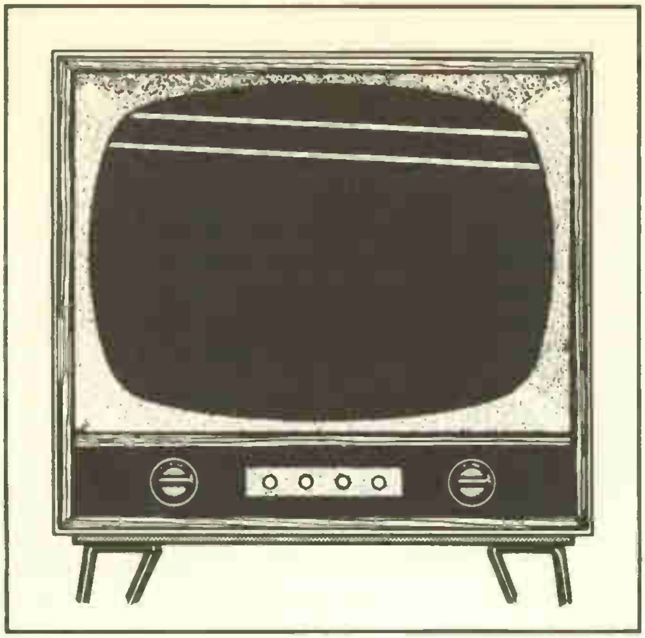

Figure 14. Second Horizontal Line is lower on screen than first.

The beam ends its pattern of line tracing at a definitely indicated location at the bottom of the screen. Likewise, it again begins its pattern of tracing horizontal lines at the top of the screen in a carefully predetermined manner. Each movement is, at all times, under the direct control of the composite video signal.

It is difficult to draw an illustration showing the exact pattern of all the 525 lines on the screen of a television receiver. The pattern of those lines is deliberately designed to blend into each other so they become indistinguishable as lines, and become parts of a complete picture.

The action can be studied more easily, and is more readily understood, by considering the action in a pattern which has only 19 lines instead of one with the 525 lines actually used in television work. The action is similar in each case.

We have drawn a diagram, Figure 15, which represents the manner in which a pattern would be traced by the beam on a screen using only 19 lines.

By studying Fig. 15 carefully we can follow the movement of the beam while it traces out a complete picture. We can follow the movement of the beam while it traces out the horizontal lines during one downward sweep, then continue to follow it when it returns to the top for the second downward sweep which fills in the lines between those traced during the first downward sweep.

We have explained in a previous lesson that each downward sweep of the beam is called a "field". We have also explained that two downward sweeps is called a "frame".

Each frame constitutes one complete picture. Which means that it takes two downward sweeps of the beam to make a complete picture consisting of 525 horizontal lines. While these things were explained in a previous lesson we are repeating them at this time to make certain you have not forgotten them.

Now to return to our consideration of the action described in Fig. 15. The trace of the first line begins at the point designated as *A*. The trace slants toward the right and slightly downward. It is the heavy solid line which ends at the right side just about at the numeral 2.

The beam rapidly retraces from that point to the left side. The retrace is indicated by the light solid line.

The second trace line begins at point 3. While this is the second trace of the first field, it will actually be line No. 3 of the complete frame. That is the reason it is called line No. 3.

The trace of that line can be followed across the diagram to the right. It ends at the right side of the diagram at a location just below the numeral 2.

By following the solid line — heavy for the trace, and light for the retrace — you will find the tracing of the first field ends at the bottom of the screen in the center. That point is designated as point *B*.

When the beam reaches point *B*, after tracing all the odd-numbered lines, it will have completed one field. The beam then returns to the top to begin tracing out the second field to complete the frame.

At the instant the beam reaches point *B* at the end of the first field a *vertical sync pulse* triggers the vertical saw-tooth oscillator. That causes the oscillator to initiate its vertical

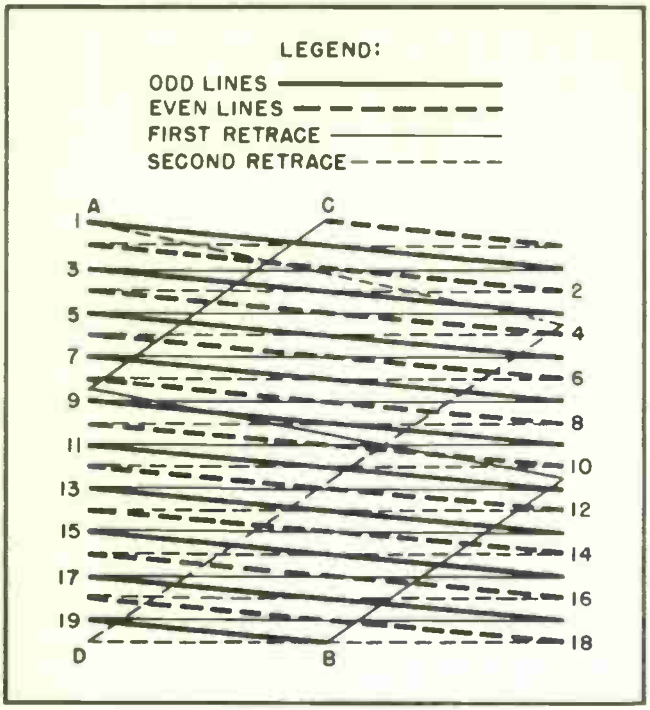

Figure 15. Beam Movement on 19-Line screen.

retrace. The vertical retrace returns the beam to the top of the pattern.

During the vertical retrace, which moves the beam from the bottom of the pattern to the top, there is no interruption of the horizontal movement of the beam. The horizontal deflection voltages keep moving the beam back and forth horizontally in its regular pattern.

Even though the vertical retrace moves the beam upward much more rapidly than the vertical trace moves it downward, it does not move so fast as the horizontal voltages move horizontally. The result is that the beam does not move in a straight line from the bottom to the top.

To see exactly what does happen suppose we return our attention to the action which begins with the start of line 19 in Figure 15. That is the last line traced during the first field.

The horizontal saw-tooth voltage moves the beam in a horizontal direction while tracing out line 19, just as it does with each of the preceding lines. During the first half of the trace the line follows much the same pattern as the other lines.

But halfway through the trace of the line — at the instant the line reaches point *B* — the vertical retrace begins moving the beam upward. Instead of the 19th line continuing toward the right along the same direction it followed before reaching *B*, it suddenly begins moving upward. While moving upward it continues to move toward the right, but instead of slanting *slightly* downward, it suddenly changes direction to slant *sharply* upward.

By the time the beam reaches the right side of the pattern, to finish what started out as line 19, it winds up at a location almost halfway up the screen. In Fig. 15 we see that the line ends at a point near the end of line 10.

At the end of the 19th line — or what started out as the 19th line — the horizontal retrace takes hold in the normal manner. The beam is suddenly returned to the left side of the pattern.

While the horizontal retrace is moving the beam from the right side to the left, the vertical retrace continues to move the beam upward. Therefore, the beam slants upward from the right to the left during this short period of time. Actually, the horizontal retrace moves the beam to the left much more sharply than is indicated by Fig. 15.

Reaching the left side of the pattern again, the horizontal trace voltage takes hold to start the beam on another trip to the right side of the pattern. But the vertical retrace continues to move the beam upward. So, the beam again slants upward from the left side toward the right.

This upward slant ends at the center of the pattern at the top. That is shown in Fig. 15 as point C.

The vertical retrace, which began at the bottom of the pattern at point *B*, now ends at the top of the pattern at point *C*.

The instant the vertical retrace ends, a new downward vertical trace begins. This means that the horizontal line, which began as an upward slant toward the right, finishes as the second half of a normal horizontal line. It traces out a half-line from point *C* to the right side of the pattern.

At the end of the horizontal trace the horizontal retrace voltage takes hold and moves the beam back to the left.

The position of the beam is now such that it is ready to begin the trace of a full new horizontal line. This line is not traced over the same path followed by line 1 of the first field. Neither does it follow that of line 3 of the first field. Instead, it traces out a new path. This new path is halfway between 1 and line 2. It is "interlaced" between them.

The horizontal movement, and the downward vertical movement, of the beam continues. It traces out line after line.

But all the lines traced during this second downward movement are positioned between the lines traced during the first downward movement. They are tracing out the lines of the second field; tracing them out so they are interlaced with the lines of the first field. In Fig. 15 they are shown as heavy dash lines.

The odd-numbered lines are traced out during the first field; the even-numbered lines during the second field.

Line 18 is the last of the second field. Line 18 ends at the right side of the pattern. When it ends, the horizontal retrace rapidly moves the beam from the right to the left side.

Simultaneously, the vertical retrace also begins to affect the beam. The beam does not move upward very far under the influence of the vertical retrace during the horizontal retrace. It ends the retrace at point *D*. But when it reaches the left side at point *D* to begin a new horizontal trace the vertical retrace becomes fully effective, and influential.

When the next horizontal trace begins it coincides in time with the new vertical retrace. The vertical retrace moves the beam upward while the horizontal trace moves it from left to right. The new line slants upward from point *D* toward the right of the screen, where it ends at a location between lines 3 and 4.

The next horizontal retrace, acting in concert with the continuing vertical retrace, moves the beam to point *A*. Arriving at point *A* the beam is ready to begin tracing the first field for the next frame.

The first field of the next frame is traced over the same path followed by the beam during the first field of the first frame. These patterns are traced over and over. Frame following frame at the rate of 30 frames per second.

While the diagram in Fig. 15 outlines the pattern traced by the beam if there were only 19 lines the precise action which occurs in a television receiver is almost exactly the same. The only difference is that there are 525 lines on a television screen whereas there are only 19 lines in the pattern in Fig. 15.

One other difference is in the spacing of the lines. Those in Fig. 15 are spaced rather widely apart. Those on a television picture tube screen are spaced so closely together they literally blend into each other. Such blending forms the complete pattern of the picture.

Section 10. COMPARATIVE TIME ELEMENTS OF THE VERTICAL AND HORIZONTAL MOVEMENTS

The beam is moved horizontally much more rapidly, and more frequently, than it is moved vertically. In Fig. 15, it is moved horizontally 19 times while it is moved vertically twice. In television the beam is moved horizontally 525 times while being moved vertically twice.

The voltages which cause the beam to move, both vertically and horizontally, have a sawtooth wave-form. The only difference between them is their respective frequencies.

The frequency of the two saw-tooth voltages are closely linked together. This means that each goes through successive cycles by following exactly the same pattern.

Fig. 16 is a graph of the saw-tooth voltages of the vertical sweep previously shown in Fig. 15. The vertical sweep voltages are shown on the same graph with those of the horizontal sweep voltages used in the same illustration in Fig. 15.

Two cycles of the vertical sweep make a complete frame; when combined with the horizontal sweep it means the two sets of voltages go through one complete cycle with each frame, or with two cycles of the vertical sweep.

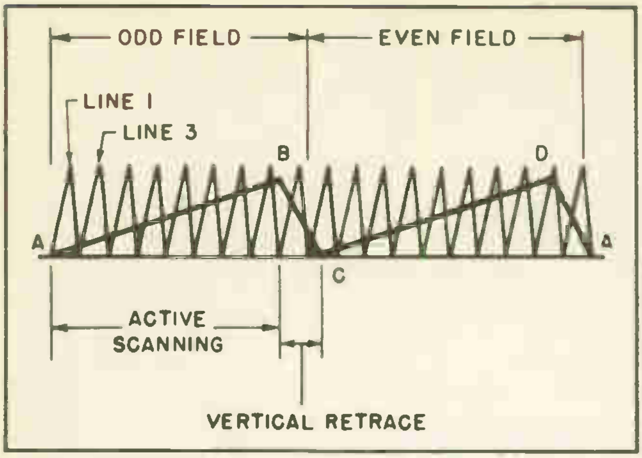

Figure 16. Graph of Vertical Saw-Tooth on same scale with Horizontal Saw-Tooth.

The graph of two vertical sweep voltages is shown on the same scale with 19 of the horizontal sweeps. Their relationships to each other can be studied a little more closely by examining the pair of graphs.

One item concerning the action we have been describing will probably strike you as significant. That is the fact the retrace of one of the vertical fields begins at the center of a horizontal line trace, while the other begins at the end of a horizontal line trace.

What is even more significant — and this is important — at the *end* of one of the vertical retraces the beam is at the *middle of a horizontal line* trace. At the *end* of the other vertical retrace the beam is just ready to start a *new horizontal* line.

The manner in which the vertical retraces *end* is what brings about the interlacing of the two groups of horizontal lines. If they all ended at the same place one field would be superimposed on the other — there would be no interlacing. Proper interlacing tends to reduce the sensation of flicker in the picture, and tends to improve picture detail and sharpness.

All of which means that rigid control must be maintained over the vertical retraces so the beam reaches the right spot at exactly the right instant to do the things it is intended to do. The control is exerted by controlling the exact instant at which the beam *begins* its vertical retrace. Fig. 17 shows the appearance and timing of the pulses at the *end of a field*, just before the vertical sync pulse starts.

Synchronizing pulses to control the start of the vertical retrace are included as a part of the composite video signal. They are a very important part of the signal.

Section 11. SYNC PULSES WHICH CONTROL THE VERTICAL RETRACE.

The manner in which control is maintained over the vertical retrace can be better understood by studying the synchronizing pulses near the end of each field. See Fig. 17. Both the horizontal and the vertical synchronizing pulses, which appear near the end of each field, bear a close relationship to each other — and it is necessary to keep that relationship in mind while studying the action.

Fig. 18 shows the arrangement of the various synchronizing pulses at the end of one field, while Fig. 19 shows the arrangement at the end of the other. In both cases the vertical sync pulses are preceded by a group of six *equalizing pulses.* More will be said of the equalizing pulses a little later.

The arrangement of the sync pulses in Fig. 18 is such that a full interval of *H* exists between the last horizontal sync pulse and the first equalizing pulse. That is the manner in which the various pulses are arranged for one of the fields.

The arrangement of the pulses for the other field is shown in Fig. 19. Note that only one-half the interval of *H* exists between the last horizontal sync pulse and the first equalizing pulse.

The equalizing pulses are used immediately ahead of the vertical sync pulses to equalize the voltage in the several parts of the timing circuits. They do not have any direct effect on the vertical retrace pulse, but they prepare the circuit conditions for the vertical sync pulses.

For this immediate explanation we can think of the equalizing pulses as being a part of the vertical sync pulse, and playing a part in determining the exact time at which the vertical trace is initiated.

Let us review, briefly, the action described in Fig. 15. In that illustration we find line 19 going only halfway across the pattern before it starts moving in a vertical direction. In line

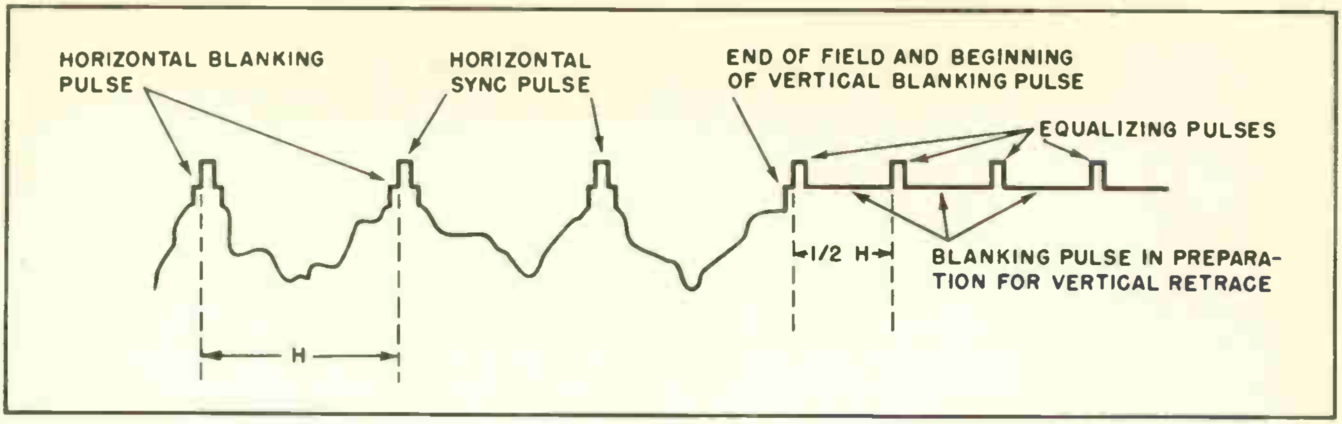

Figure 17. Sync Pulses and Equalizing Pulses at end of Field.

18, however, the horizontal line is completed before the beam starts moving in a vertical direction.

That action is governed by the sync pulses. It is governed by both the horizontal sync pulses and the vertical sync pulses. Those sync pulses are arranged very much as shown in Figs. 18 and 19.

The interval between the beginning of the first equalizing pulse and the triggering pulse which starts the vertical retrace is always the same. It is not important to us at this time to know exactly when the vertical retrace starts; we can even think of it as starting at the instant of the first equalizing pulse. Or, the vertical retrace could start with the beginning of the third equalizing pulse, or the fifth.

It could start with the second vertical sync pulse, or with the third, or with the fourth.

The important thing is that the *interval between the first equalizing pulse and the beginning of the vertical retrace is always the same.*

For this explanation let us think of the vertical retrace as beginning with the first equalizing pulse. If that were true we would find the vertical retrace in Fig. 18 starting at the end of the horizontal line. That would be a condition similar to the one discussed in connection with line 18 in Fig. 15.

In the case of the action illustrated in Fig. 19 the vertical retrace would begin when the last horizontal line was halfway through its trace. That would be a condition similar to that which exists in connection with line 19 in Fig. 15.

The horizontal oscillator never loses synchronism during the vertical retrace. That is guaranteed by the presence of the regular hori-

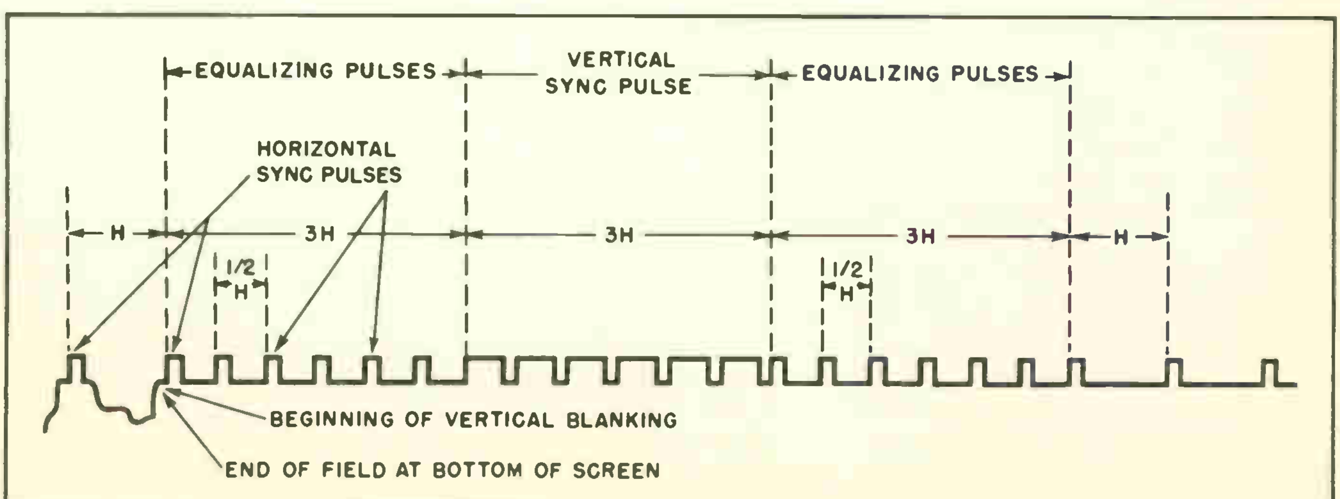

Figure 18. Arrangement of Sync Pulses at End of Field.

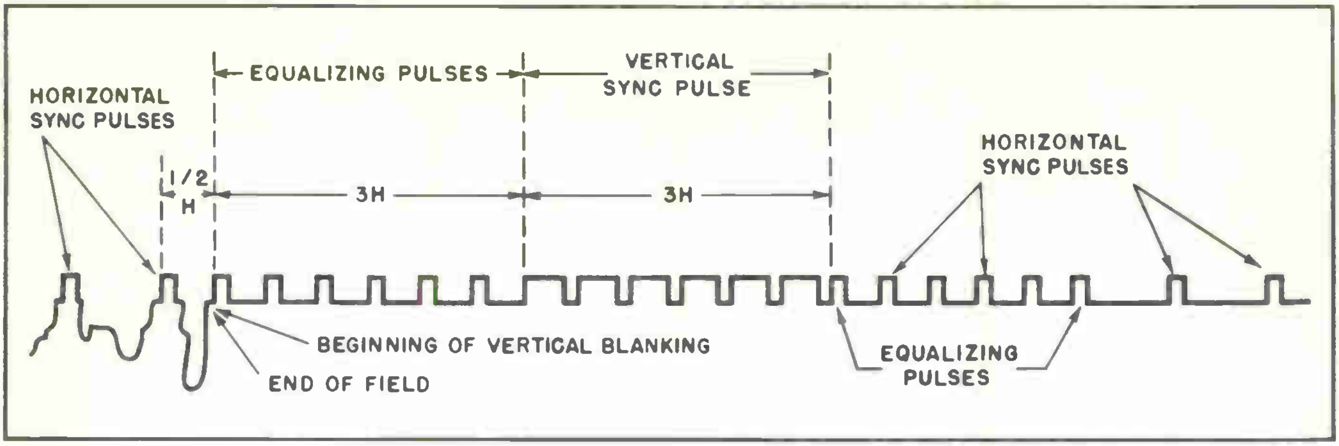

Figure 19. Sync Pulses at End of Field. Field ends differently than in Figure 18.

zontal synchronizing pulses which continue throughout the entire vertical synchronizing interval.

By way of explanation it might be well to mention that the horizontal oscillators are maintained in synchronism by short, sharp voltage pulses. Those pulses are filtered through a special circuit which is sensitive only to that type of voltage pulse.

The vertical oscillator is maintained in synchronism by a group of long pulses. Those long pulses are filtered through a special circuit which is sensitive only to that type of pulse.

Each time there is a sudden, sharp rising voltage — a sudden, sharp voltage pulse — it acts to trigger the horizontal oscillator. You will note, by studying the voltage wave-forms in Figs. 18 and 19, there is a sudden, sharp rise in the voltage at regular intervals. Those sharp voltage pulses continue throughout the vertical retrace interval.

Thus, the horizontal sweep circuits continue to move the beam back and forth horizontally across the face of the screen, even during that interval in which it is also moving from the bottom of the screen to the top. Maintaining synchronism is important; it forces the beam to strike the screen at exactly the location at the top where it should go.

Section 12. WHEN THE VERTICAL RETRACE BEGINS

In the preceding section we acted on the temporary assumption that the vertical retrace started with the first equalizing pulse. While there is a rigidly fixed interval between the first equalizing pulse and the beginning of the retrace, the retrace does *not* begin at the instant the first equalizing pulse appears. It is well we direct some of our attention to just what does take place during that period which immediately precedes the vertical retrace.

The vertical sync pulses are fed to a triggering circuit to start the vertical retrace through a special filtering circuit, just as we mentioned earlier. That special filtering circuit has a name; it is called an *integrating circuit.*

The camera video signal, contained in the composite video signal, and other varying voltages are placed on that special integrating circuit as well as the vertical sync pulses which are used to trigger the retrace action. Therefore, the voltage which might possibly be present on the integrating circuit at the instant the vertical sync pulses reach it may vary from one field to another. That is not desirable.

It is important that the timing of the vertical retrace be rigidly controlled. The vertical retrace must occur at a definite instant of time. Therefore, the manner in which the vertical synchronizing pulses reach the triggering circuit cannot be left to chance.

The action of the integrating circuit through which the vertical sync pulses are filtered is to add the voltages of a succession of long pulses. The integrating circuit is not affected by one or more short voltage pulses, but is affected by an accumulation of voltages. It is affected when several long voltage pulses accumulate on it,

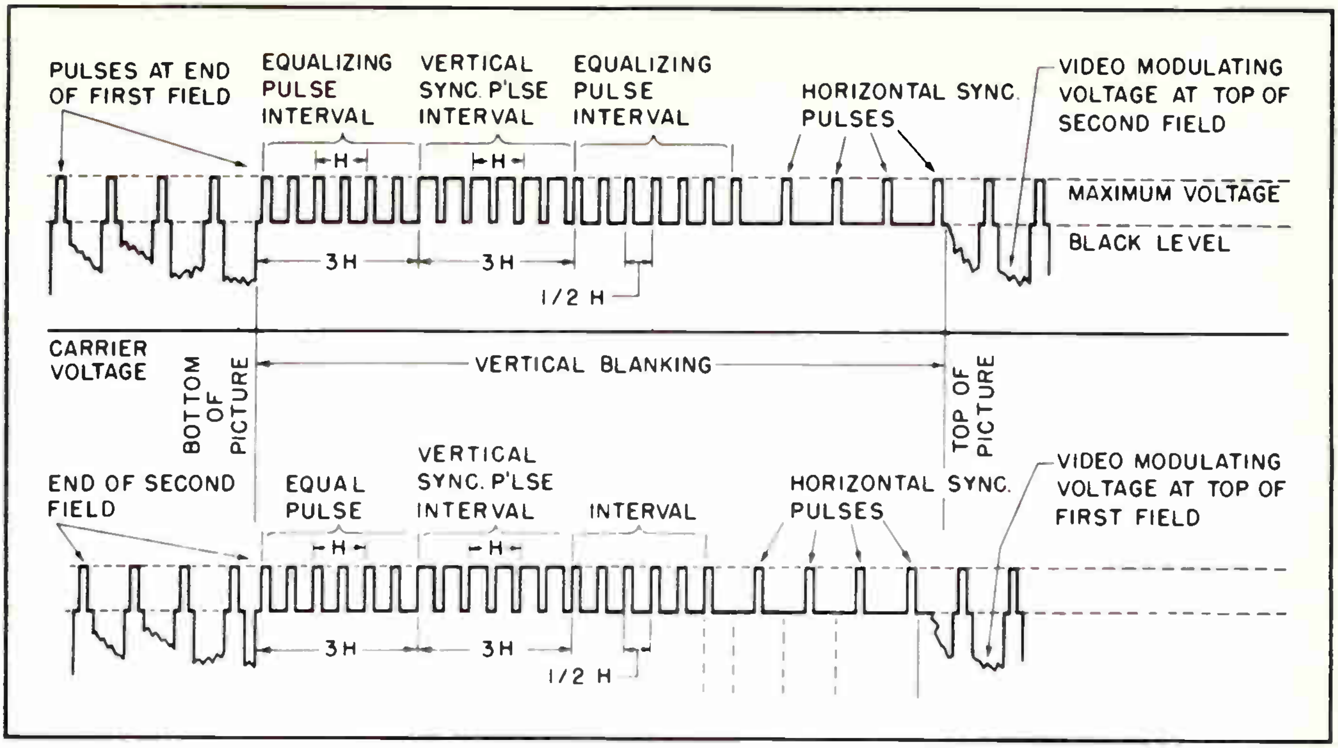

Figure 20. Composite Video Signal at end of First and Second Fields.

and their voltages are added together.

All of which means that it is important for the vertical sync pulses to reach the integrating circuit at a time when the existing voltage on the circuit is exactly the same as it was for the preceding retrace, and the retrace before that, and for all the other retraces which precede and follow.

The equalizing pulses make certain the voltage on the integrating circuit is always the same at the instant the vertical sync pulses reach it. By blanking the camera video signal, then impressing a series of equalizing pulses, all of which are identical with each of the others, on the integrating circuit, the voltage on that circuit is equalized so it is always the same at the instant the vertical sync pulses begin to arrive.

This means that the voltage on the integrating circuit, at the instant the vertical sync pulses arrive, is always the same. It is the same at the end of one field as it was for the preceding field, and for the one that follows. Thus the triggering of the vertical retrace can be precisely controlled. Nothing is left to chance.

You may trace the various pulses through their actions at the end of each field, then compare them with the corresponding pulses at the end of the other field by carefully studying Fig. 20. We have prepared a graph of the equalizing pulses and vertical synchronizing pulses found at the end of each field, and have then arranged them so the time relationships can be compared.

It can be seen that equalizing pulses both precede and follow the vertical sync pulses. Six equalizing pulses follow the vertical sync pulses for one field, while seven such equalizing pulses follow the sync pulses for the other.

More equalizing pulses are necessary at the end of one field than of the other. This is because the equalizing pulses begin at different times, with respect to the horizontal sync pulses, on one line than on the other.

At the end of one field the equalizing pulses begin with the regular interval of the horizontal sync pulses. This is the condition which exists at the top section of the diagram in Fig. 20.

They begin midway between the horizontal sync pulses at the end of the other field. That is the condition which exists in the lower section of the diagram in Fig. 20.

There must be an equalizing pulse to trigger each horizontal sweep of the horizontal oscillator. This is necessary to keep the horizontal sweep locked in synchronism during the vertical retrace period.

Since the equalizing pulses and the vertical sync pulse begin one-half a horizontal cycle earlier at the end of one field than the other, it is necessary to provide one additional equalizing pulse in the series which follows one vertical sync pulse than for the other.

In closing this lesson we want to emphasize one fact very clearly. The purpose of this lesson is to explain the manner in which the composite video signal is created, and the type of technical information it contains.

The composite video signal is created at the transmitting studio. It includes technical information from the camera and from the synchronizing generator. Nothing that you can do to the receiver circuits will change that composite video signal in any manner. You have no control over it whatsoever.

It can be argued that there is no real need for a receiver service technician to know the details of the composite video signal. There would be a lot of logic in such an argument.

Even though you cannot control the make-up of the composite video signal, the fact still remains that you will work with receiver circuits which make use of that signal. The differentiating and integrating circuits separate the various sync pulses, and apply them to the proper synchronizing circuits in the receiver. You will be called upon many times to adjust and service those circuits in television receivers. The more you know about the composite video signal, and the sync pulses it contains, the more intelligently you can work with those circuits.

Furthermore, the video signal from the camera tube comprises a major portion of the composite video signal. It is the electrical signal which transmits the intelligence necessary to reproduce the scene viewed by the camera. That video signal is very complex, especially in color receivers. The more you know about it the better you will be able to handle jobs relating to those circuits.

The fact still remains that you may find some of the information contained in this lesson a little too technical for you at this time. That need not discourage you.

You will be working with an increasing number of circuits which employ this type of information. As you work with these new circuits you will understand more clearly the purpose for the types of signals described in this lesson. You will become increasingly aware that the type of technical information contained in those signals is important in television work.

NOTES FOR REFERENCE

The composite video signal contains all the information needed by a television receiver to reproduce the scene viewed by a television camera.

In addition to the video signal information from the camera, the composite video signal contains the pulses needed to maintain synchronism between the receiver and transmitter.

The composite video signal contains two types of synchronizing pulses. One synchronizes the horizontal sweep of the transmitter. The other synchronizes the vertical sweeps of both.

Horizontal synchronizing circuits in a receiver are affected by a sudden, sharply rising voltage pulse.

Vertical synchronizing circuits in a receiver are affected by a slowly rising voltage which takes a longer time to accumulate sufficiently to affect the sweep circuits.

Horizontal sync pulses are filtered through a special circuit called a *differentiating circuit* before they reach the horizontal sweep circuit. The design of that circuit is such that only short, sharply rising voltages pass through it.

Vertical sync pulses are filtered through a special circuit called an *integrating circuit* before they reach the vertical sweep circuit. That circuit is not affected by short voltage pulses; it passes only those which build up slowly over a relatively long period of time. Actually, it adds together a succession of long pulses to make the *vertical sync pulse*.

The composite video signal carries the necessary information to properly interlace one field with the other so each field covers that portion of the screen intended for it to cover.

The composite video signal includes the horizontal blanking pulses to blot the electron beam during the retrace periods.

Time dimensions of the blanking and sync pulses in a composite video signal must meet the rigid standards imposed by the FCC.

Equalizing pulses are used to equalize the voltage on the integrating circuit before the vertical sync pulses are applied to it. By impressing a series of equalizing pulse voltages to the integrating circuit immediately ahead of the vertical sync pulses the voltage present on that circuit is made identical for all successive vertical retrace pulses.

NOTES

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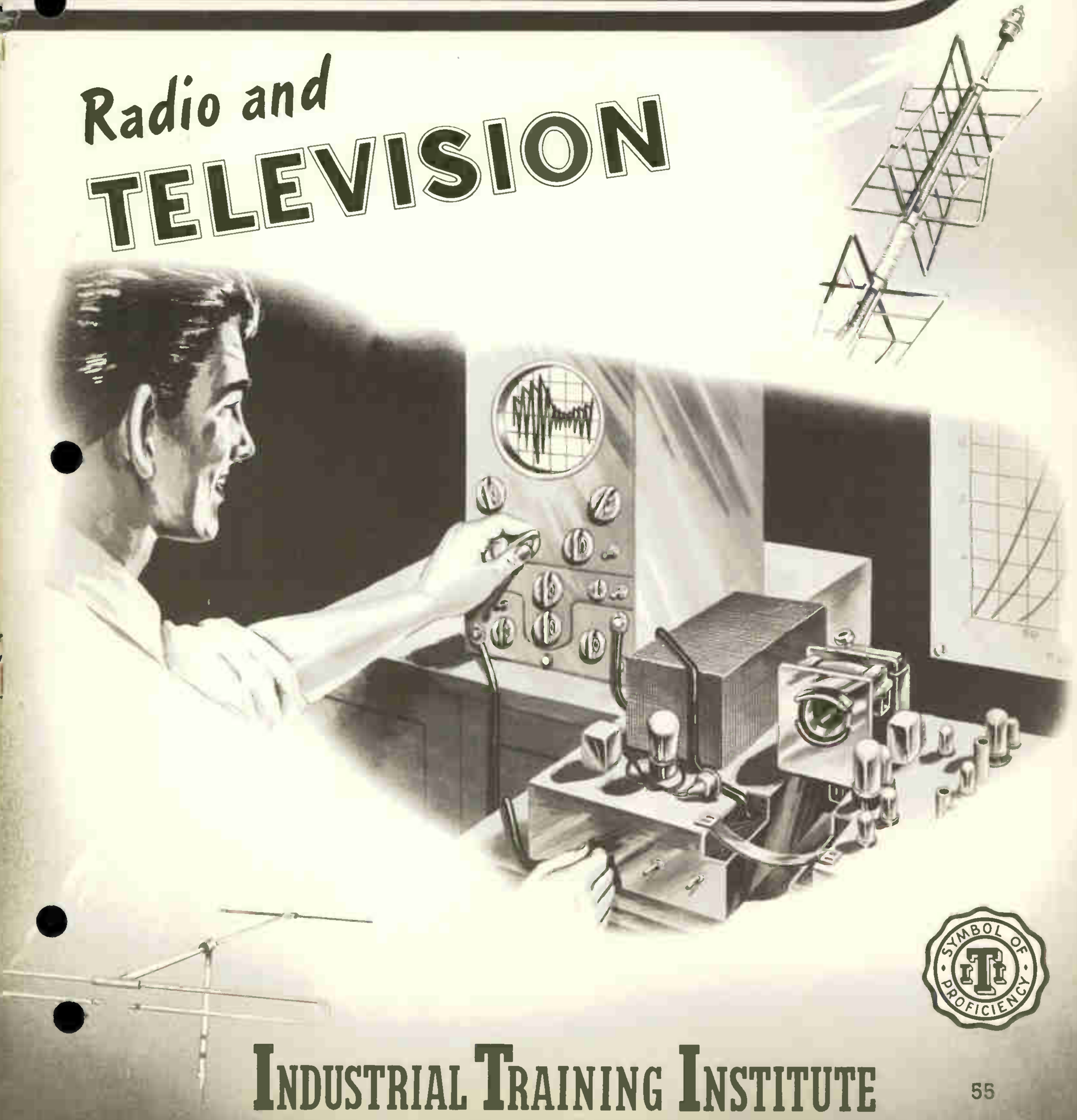

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VIDEO SIGNAL AT THE RECEIVER

Contents: Breaking Down the Picture — Picture Detail in Terms of Video Frequency — White Line on Black Background — Signal Voltage Changes When There Is Greater Picture Content — Picture Information as Related to Video Frequencies — Time Elements Within the Horizontal Sweep — Time Elements in Sync Pulse — Video Frequencies Needed for Fine Picture Detail — Limitations on Picture Detail — Vertical Detail — Utilization Ratio — Practical Limits on Picture Detail Content — Gamma — Notes for Reference.

Section 1. INTRODUCTION

In the preceding lesson we introduced you to the composite video signal. We explained some of the things which go into the composition of that peculiar TV signal. We tried to explain how the composite video signal contains the information necessary for a TV receiver to reproduce a scene viewed by a TV camera, all the necessary information.

We explained how the composite video signal carries within itself — in the form of electrical voltage variations—such information as is needed to lock TV receiver circuits into synchronism with transmitter circuits, so the transmitter and receiver can act together — so they are synchronized together.

Because of the vast amount of information it must carry the composite video signal assumes complex, yet very precise, forms. It embraces within itself an extremely wide range of frequencies. It is with those varying frequencies, and their action in a receiver, that we now concern ourselves.

In Fig. 1, we see an image as it appears on the screen of a TV receiver. That is the picture as it would appear to our human eyes.

That picture, however, does not move from the transmitter to the receiver instantaneously as a complete unit. Far from it.

That picture is broken down into a great many horizontal lines. Those lines are sent from the transmitter to the receiver, one by one. Only *one* line can be sent at one time. In fact, only a small part of any one line is transmitted during any given instant.

The amount of picture information which must be transmitted electrically during the scanning of a single line can be better understood

Figure 1. Picture on screen of TV receiver. (Courtesy Hallicrafters Radio.)

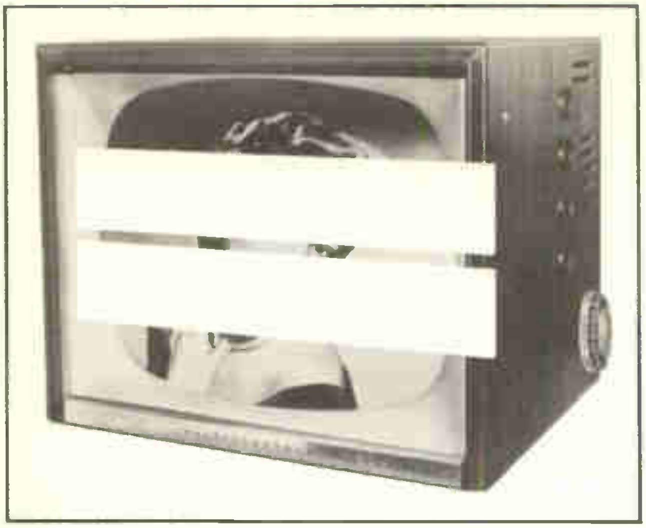

Figure 2. Picture from Fig. 1 partially covered so one horizontal line is exposed.

by studying Fig. 2. In Fig. 2 we have reproduced the essential features of Fig. 1, except much of the picture has been covered by blanking strips of opaque material.

If the two covering strips are moved closely together the space between them can be narrowed to exactly the part of the picture included within one scanning line.

If you examine the picture detail which is visible between those two covering strips it does not make much sense. By itself it does not make any sense.

Yet, that is the way the content of a picture is broken down so the information necessary to reproduce it can be transmitted electrically. The picture, or scene, is broken down into 525 horizontal lines. Not one of the lines, by itself, conveys any more information than that in the area between the covering strips in Fig. 2.

After breaking the picture down into thin horizontal lines it is necessary to break the lines down into short pieces. Each short piece is transmitted as a separate electrical signal element.

Even by breaking down a picture, or scene, into a large number of individual lines, then scanning each of the lines in rotation, the composition of the electrical signal carrying the information necessary to reproduce it remains very complex. It consists of a wide range of frequencies.

We have touched briefly, in other lessons, upon the wide range of frequencies present in a composite video signal, especially in the lesson which precedes this. We now concern ourselves with an investigation carrying us more deeply into the make-up of those frequencies. We will look into the manner in which varying frequencies transmit, in an electrical form, the vital information needed at the receiver to reproduce the scene viewed at the camera.

We will penetrate more deeply into the technical details involved in picture transmission. We will try to explain in ordinary words the technical relationship which exists between high picture fidelity and the wide range of frequencies which are handled in video circuits.

Section 2. BREAKING DOWN THE PICTURE

Suppose the two strips of opaque material in Fig. 2 are moved upward to the top of the picture tube. When so positioned the space between them is just enough to expose the screen area scanned by the first horizontal scanning sweep of the electron beam within the tube.

That beam moves from the left side of the picture tube toward the right. It passes over the light colored areas of the narrow exposed strip, and it passes over the dark areas. As a matter of fact, it passes over all parts of the narrow strip, the light parts, the dark parts, and those of various degrees of shading between.

By varying the intensity of the electron beam in the picture tube it can be caused to reproduce that same scene. If the beam is strong at given areas on the picture tube screen they will be reproduced as light areas. If the beam is weak when passing over other areas they will be black, or very dark areas. Varying intensities of the beam between maximum brilliance and maximum blackness causes various degrees of gray.

All of which means that an electron beam sweeping over a narrow strip of fluorescent screen material, such as that between the two strips in Fig. 2, can cause the screen to become light or dark gray. The screen will be light or dark, or some shade of gray, depending on the intensity of the beam as it touches each individual portion of the strip.

If, after the first line has been scanned, the strips are moved downward to a new position, that would represent the portion of the screen scanned by the electron beam during its second trace sweep.

After the second line has been traced the two strips can be moved downward to still a third position. The third position exposes the amount of screen area swept by the beam during the third scanning; it represents the third line. And so it goes all the way to the bottom of the screen. The beam sweeps across the screen, line by line, until it reaches the bottom of the screen.

By returning to the top of the screen and starting a new group of lines it is possible to duplicate much of the action that goes on inside a picture tube. But keep in mind this is a mechanical duplication. Such a mechanical duplication can never attain the extremely high speed with which an electron beam actually moves.

Going down the face of the screen the second time the spacing between the two strips exposes areas lying *between* those lines scanned during the first downward movement. That is exactly the way in which the lines are scanned within a picture tube. Except, the actual scanning is infinitely faster.

While scanning the screen area exposed between the strips during a single sweep across the screen, the intensity of the electron beam changes for each change in brilliance from light to gray to black. It also changes for every other change in the degree of light intensity.

The changes in light intensity are represented — electrically — by changes in the video signal voltage. The number of times the voltage changes during the scanning of one line provides a good clue to the frequencies required to properly reproduce a scene. Each change in the voltage level of the signal is equivalent to a cycle of the frequency. Frequent changes in the voltage level are equivalent to high frequencies.

If the picture changes gradually from light to dark, then back to light again, during a single sweep of a horizontal line it means the video signal voltage must go through one complete cycle during that sweep.

Since the horizontal line frequency is 15,750 cycles per second, it means the video signal would require a frequency of 15,750 cycles to reproduce a scene consisting of nothing but a gradual change from light-to-dark-to-light during one sweep.

If, instead of one complete cycle of light-dark-light during one horizontal scanning, there are ten changes from light to dark to light during a single sweep the video signal would have a frequency of ten times 15,750, or 157,500 cycles per second.

One hundred changes between light, dark and light means the video signal has a frequency of 1,575,000 cycles per second.

The sharper the changes between light and dark, or between dark and light, while the beam is scanning a horizontal line the quicker the video signal must go through a cycle. In making a sharp change from extreme light to extreme dark, or vice versa, the video signal may go through a single cycle very rapidly. Or through part of a cycle.

The video signal may never actually go through 1,000,000 complete cycles within the span of a single second. But during the interval of ¼th of a microsecond it may go through a complete cycle; which means that during that very short interval of time the video signal is actually going through voltage changes at the *rate* of 4,000,000 cycles per second.

We can expand this explanation a little further by saying that during the span of a single second the video signal may go through some voltage changes at the *rate* of several *million per second*, and others at the *rate* of a relatively few *thousand per second*. In between those extremes it may go through many other changes at other rates.

The ability of the video circuits to handle rapid changes in the signal voltage level determines how sharply the horizontal picture details are reproduced. Discrimination against the passage of any important signal frequencies causes fuzziness and blurring in the picture.

Section 3. PICTURE DETAIL IN TERMS OF VIDEO FREQUENCY

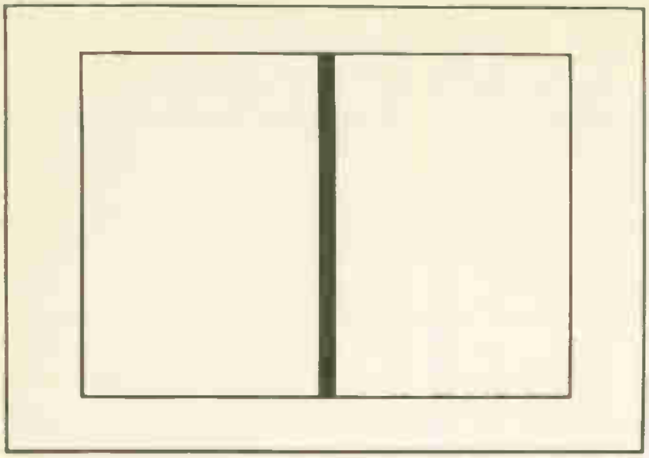

Figure 3. Single black vertical line on screen.

In order to obtain a better understanding of the preceding section suppose we consider the action which occurs when a very simple scene is viewed by a TV camera.

In Fig. 3 we have just about as simple a scene on a TV screen as is possible. The scene does not represent anything in particular. It is merely a black vertical strip through the center of the screen.

However, the composition of that scene presents a clear contrast between the blackness of a single vertical line and the whiteness of the background.

If a video camera were called upon to view a scene which consisted solely of a black vertical line on a white background the signal voltage from the camera would assume a very definite wave-form. It would be characteristic of that particular scene.

In scanning the scene the beam would move horizontally. It would scan an unvarying white background as it moved over the first part of each sweep.

Suddenly it would strike the black vertical line.

Because the line is relatively narrow the beam does not need much time to cross it. As soon as it crosses the narrow black line the beam again strikes the white area.

Perhaps we can follow the action more easily by studying the scene in conjunction with the video voltage which represents electrically the picture content during the scanning of the scene. That can be done by studying Fig. 4.

We have reproduced the scene from Fig. 3 once again in Fig. 4. Added to the scene is a graph of the video signal voltage which is present during the scanning of a single horizontal line. The video voltage graph appears below the scene being scanned, and is drawn to the same horizontal scale.

At the left end of the voltage graph is a blanking pulse, with a synchronizing pulse mounted on it. Next is the end of the blanking pulse.

When the blanking pulse voltage is removed the video voltage is that which represents the camera signal. Since the camera sees an area of white, it generates a video signal equivalent to that of a "white level."

The "white level" signal, following the blanking pulse is merely a horizontal line. It represents a low level signal because a white video signal is always a low level signal.

As the scanning beam moves to the right

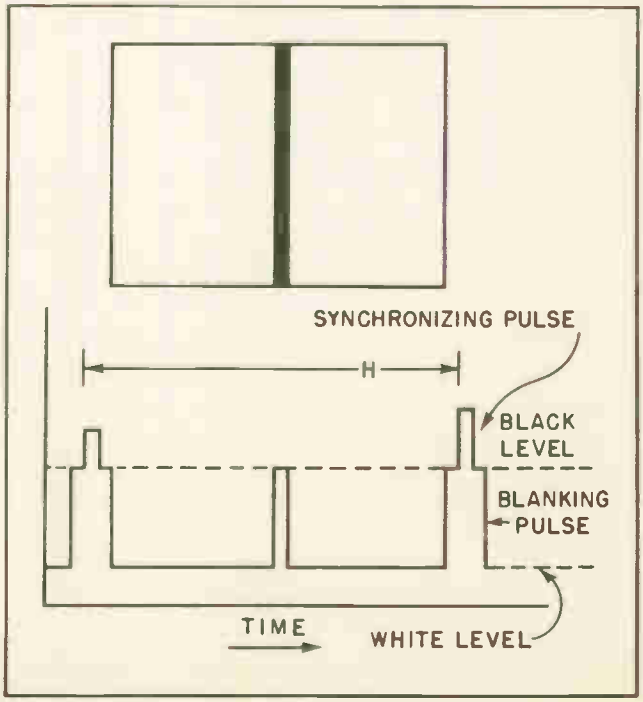

Figure 4. Graph of Video Signal Voltage produced during single horizontal scanning of scene in Fig. 3.

across the scene it eventually comes to the vertical black line. A black object in a televised scene always produces a strong video signal from the camera.

In this case there is a sharp rise in the video signal voltage as the scanning beam strikes the vertical black line. The signal voltage remains at the high level until the scanning beam has passed the black vertical line.

The sharp rise in the signal voltage is clearly shown in the graph of the video signal voltage. You will see the sharp rise in the video signal graph directly below the point where the black vertical line is present in the scene being scanned. The rise in the video voltage graph corresponds exactly to the black line, with the line of the graph again dropping to the white level when the scanning beam moves on into the other white area.

At the end of the active scanning area another blanking pulse comes along. Then a sync pulse signals the return to the left side for another scanning trace.

In terms of video frequency we can recognize the fact that it must be extremely low during the period between the end of the first blanking pulse and the scanning of the black vertical line. During that period the video voltage is going through virtually no change. We can say its frequency is close to zero.

Actually, for practical purposes, reasonably good minimum frequency response in the vicinity of 60 cycles per second is entirely adequate.

But the sharpness of the voltage rise during the transition from white to black, when the beam first touches the black line, represents a very rapid change. The rise in the voltage is probably in the vicinity of one-quarter of a microsecond; which, in terms of frequency, is equivalent to approximately 4,000,000 cycles—or, 4 megacycles.

The change from the black level to the white level is equally abrupt. It is also on the order of 4 megacycles. The *rate* of change is on the order of a frequency of four megacycles despite the fact that the voltage *change* occupies only a part of one cycle.

The higher the frequency response of the video circuits — both in the camera circuits and those in the receiver — the sharper are the outlines in a picture. The sharper the picture can be made to "focus."

Section 4. WHITE LINE ON BLACK BACKGROUND

Fig. 4 provides a good idea of the type of electrical information contained in the composite video signal. It represents the information in the signal during the sweep of one horizontal line when the object being viewed consists of a single vertical black line across a white background. Perhaps you would be interested in learning the type of electrical signal which represents the scanning of a black background on which appears a single vertical white line. That is just the reverse of the condition found in Fig. 4.

In Fig. 5 we have a single white line vertically across a black background. Immediately under the drawing of the scene is a graph of the voltage in the video signal resulting from a single horizontal sweep across the scene.

The scanning beam moves across the scene

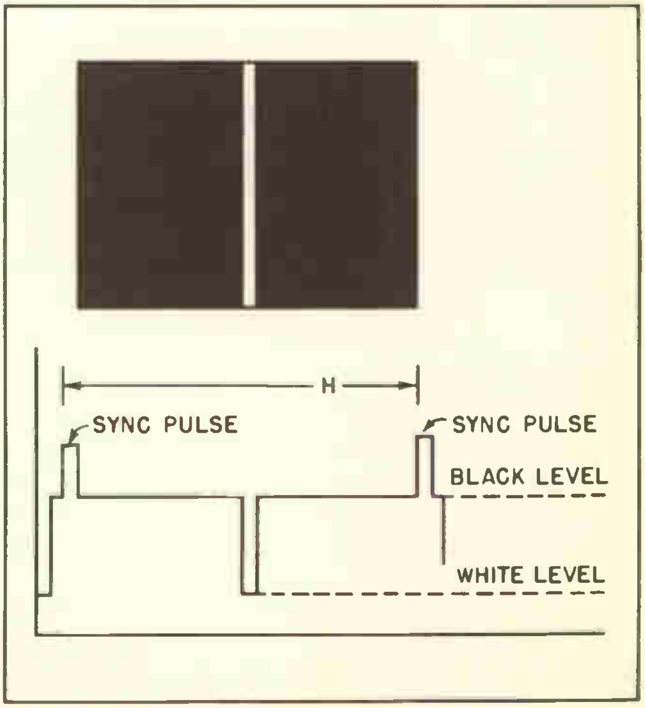

Figure 5. Graph of Video Voltage produced during one scanning of white vertical line on black background.

in much the same manner as in Fig. 4. But an examination of the signal voltage graph reveals a difference between them.

Since the picture content of the scene in Fig. 5 is the reverse of that in Fig. 4 it would seem only natural that the video signal voltage for the scene in Fig. 5 would be exactly the reverse of that in Fig. 4. At first glance it almost seems the two voltage graphs are alike, except for being reversed. Closer examination reveals other details of difference.

The blanking pulses in both video signal graphs are the same, and are positioned alike. The sync pulses are also similar.

Thus, in those two respects the two video signal graphs are alike. But the camera signal voltage representing the picture content is different in the two graphs.

The principal portion of the video signal voltage in the graph in Fig. 5 is on the same level with the voltage of the blanking pulse. This is true because of the black background of the scene. But in Fig. 4 only that portion of the video signal voltage representing the black line has an amplitude equal to the level of the blanking pulse.

Considering the picture content alone one is entitled to ask just how high a frequency would be necessary to reproduce the scene in Fig. 5. Considering the picture content alone, entirely aside from the blanking and sync pulses, one might guess that a frequency band-pass of approximately 15,750 cycles might be adequate.

There would be good basis for such belief, yet it would not be entirely accurate.

The picture content alone, in Fig. 5, consists merely of a single white line running vertically through the center of a black background. Thus, during a single horizontal scanning sweep there is a change from black to white, then back to black.

That would seem to be a voltage change consisting merely of one voltage cycle per horizontal sweep, or a frequency of 15,750 cycles per second.

So far, so good. Up to this point such reasoning would be reasonably accurate. But there is more to be considered than appears at first glance.

There is only one voltage change occurring during the change from black to white, and only one more during the interval when the change is from white to black. But those changes occur during a *very short time interval* within the horizontal sweep. While the major portion of 1/15,750th of a second is available during the horizontal sweep, only a very small portion of that time passes during the *change* from black to white, and an equally short period of time passes during the *change* from white to black.

In determining the frequency response of a circuit it is the shortness of the time intervals during a signal voltage *change* which is the controlling factor. This is merely another way of saying that the shortness of such intervals determines the broadness of the frequency band-pass.

Section 5. SIGNAL VOLTAGE CHANGES WHEN THERE IS GREATER PICTURE CONTENT

An understanding of the relationship of video frequency response to picture content and detail

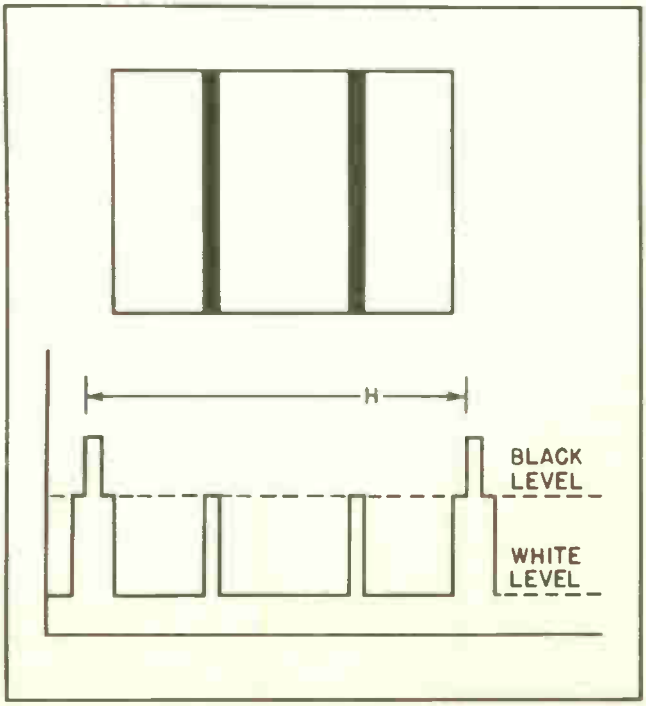

Figure 6. Graph of Video Voltage of two vertical black lines against white background.

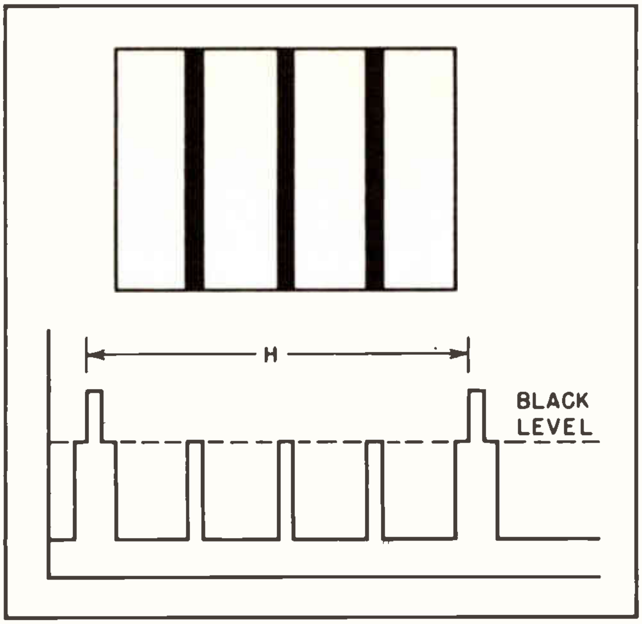

Figure 7. Graph of Video Voltage for three vertical black lines against white background.

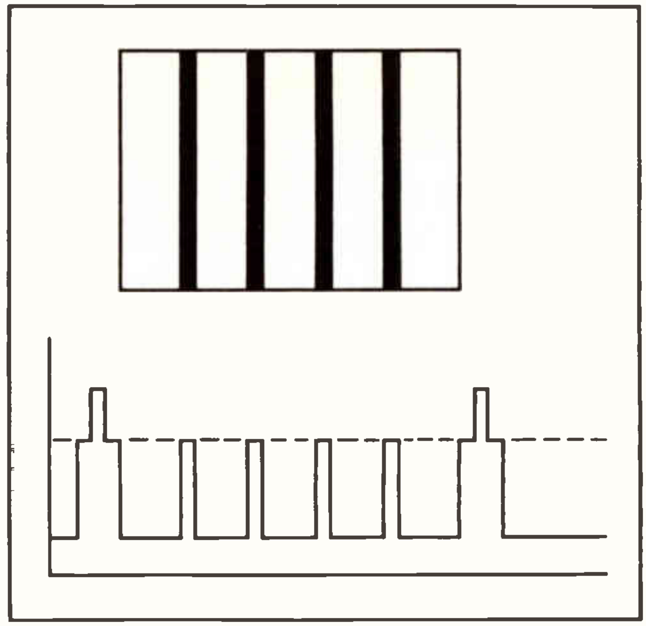

Figure 8. Graph of Video Voltage of four vertical black lines against white background.

can also be approached from a different angle. In the two preceding sections we have been dealing with scenes where there is only one major picture element involved. That single picture element has been against a solid background of a contrasting light level.

Sometimes it is easier to understand the necessity for a wider frequency range when we introduce more than one picture element into the scene. That has been done in Fig. 6.

In Figs. 4 and 5 we had a single vertical line against a contrasting background. In each of those cases we had only one cyclic change in the video signal voltage during each horizontal sweep.

In Fig. 6 we have two black vertical lines against a white background. This is twice as many cycles of change during a single horizontal sweep as in Figs. 4 and 5. Thus, on the mere face of it, the circuits handling the video signals must be capable of passing more frequencies in Fig. 6 than in the other two.

Within limits this is true. Therefore, this manner of reasoning can be carried still further.

Fig. 7 shows the graph of the video signal voltage for a scene in which three black vertical lines are scanned during one horizontal sweep of the scanning beam. Note that the video signal voltage goes through three times as many cycles as in Figs. 4 and 5.

In Fig. 8 the video signal voltage goes through four times as many cycles to reproduce the scanned line as in Figs. 4 and 5.

This reasoning can be carried further. By adding more and more vertical lines we would eventually approach a situation of reality where the scanning beam passes over very small picture elements, and passes over them very quickly. Where the picture elements are very small it is possible to include a very great number of them within the limits of a single horizontal scanning line.

We have a situation approaching that condition in Fig. 9. In that illustration we have three vertical black lines, each of which has considerable breadth. The widths of these lines are of much the same order as those with which we have been dealing in the preceding illustrations.

But included in Fig. 9 are some very thin lines. They have so little breadth that the scanning beam passes over them very rapidly.

All of which means that the voltage of the video signal, which results from the scanning beam passing over the thin lines, will rise very

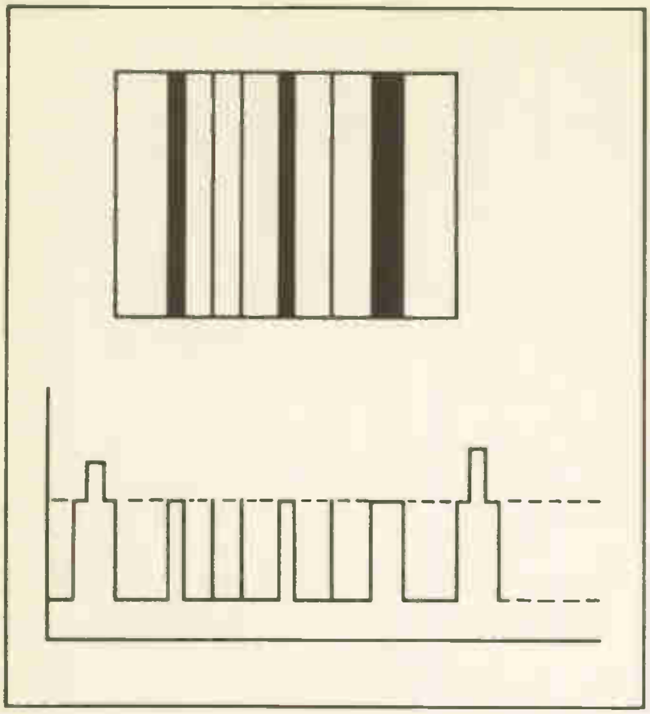

Figure 9. Video Voltage graph where vertical lines have varying widths.

sharply and very quickly. It will also drop equally fast. Nor will the voltage be present for more than a fraction of a microsecond.

Since the signal voltage rises and falls very rapidly during the short time-interval the beam is crossing one of the thin lines, it means during that cycle the signal has a very high frequency.

During that short period of time it is *changing* at the *rate* of many thousand cycles per second. Probably at the rate of several megacycles per second.

If there are several thin vertical lines close together, as shown in Fig. 10, the beam passes over them one after the other. The voltage of the beam rises for each black area of a thin line, then falls when passing over the white area between them. In a situation of this kind the signal voltage goes through several cycles of high frequency during the scanning of those lines in quick succession.

If there should be 100 such thin vertical lines across the face of the screen the video signal voltage would go through 100 cycles while the beam moves from the left side of the screen to the right. Which means the video signal would go through 100 cycles during that period.

If the beam moves from the left side of the screen in 1/15,750th of a second it means the video signal voltage goes through 100 cycles during 1/15,750th of a second. That would be at the rate of 100 times 15,750 cycles per second, or 1,575,000 cycles per second.

Actually the frequency of the video signal would be at an even higher rate. The beam moves from the left side of the screen to the right in less than 1/15,750th of a second, since it goes through a complete cycle during that period of time. Part of each cycle is devoted to the retrace.

The sharper the detail in a picture the less blurring which can be permitted. This is merely another way of saying the greater the detail the better the picture. More blurring can be permitted when picture details are large than when they are small.

Even 100 variations of detail during one horizontal scanning line is not adequate to provide the fine detail usually considered essential in television work. To have a really acceptable picture it must contain much more detail than that.

Every person who has watched a television

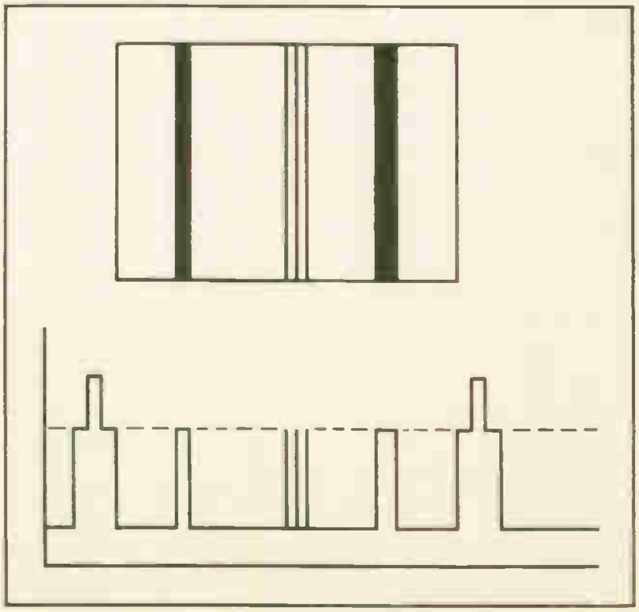

Figure 10. When beam passes over several thin lines in quick succession Video Signal goes through several cycles of high-frequency.

picture is aware of the fact that many elements of picture detail are present. There may be many large areas where there is no change in the shading of the picture detail, but there are also many areas of small detail, such as small pattern details in men's suits and clothing, and details of facial lines and hair during close-ups of TV personalities.

Reproduction of those small details requires that the circuits which handle the video signal be capable of passing high frequencies; in fact, must pass both high frequencies and low frequencies. There is a direct relationship between high video frequencies and the reproduction of fine detail in a picture.

Section 6. PICTURE INFORMATION RELATED TO VIDEO FREQUENCIES

By starting with a picture which presents a pattern similar to that shown in Fig. 11 we can again approach the relationship between picture detail and video frequencies. In Fig. 11 we have a picture pattern which is essentially a checkerboard. The electron beam scans a succession of dark and light areas during a single horizontal sweep.

The checkerboard pattern in Fig. 11 would probably be a small part of a larger picture, but for our purposes we can confine our thinking to the areas shown. For the moment we will confine our attention still further. We will concentrate on the upper row of squares in Fig. 11.

During the scanning of a single horizontal line the electron beam passes over the alternate dark and light squares in succession. A graph of the voltage in the video signal would be like that shown at the bottom of the illustration.

One cycle of the video voltage would consist of that period between the beginning of one square and the beginning of the next which has the same picture content. This means one cycle consists of the signal voltage between the beginning of one dark and the beginning of the next dark square. The area scanned during one cycle is indicated in the illustration; it consists of the scanning of one dark square and one light one.

The video signal, which carries the picture information needed to reproduce one horizontal line cutting across the upper row of squares in Fig. 11, would have to go through 15 cycles during each horizontal sweep. This is because there are 15 dark squares followed by 15 light squares.

Since the time duration of one horizontal line cycle is slightly less than 1/15,750th of a second it follows that the time duration of each video cycle would be slightly less than 1/236,250th of a second. This is because each video cycle of a pattern which goes through 15 video cycles during each horizontal line cycle would be only 1/15th as long as the time duration of the line cycle.

If the time duration of each video cycle in the video signal, resulting from a scanning of the

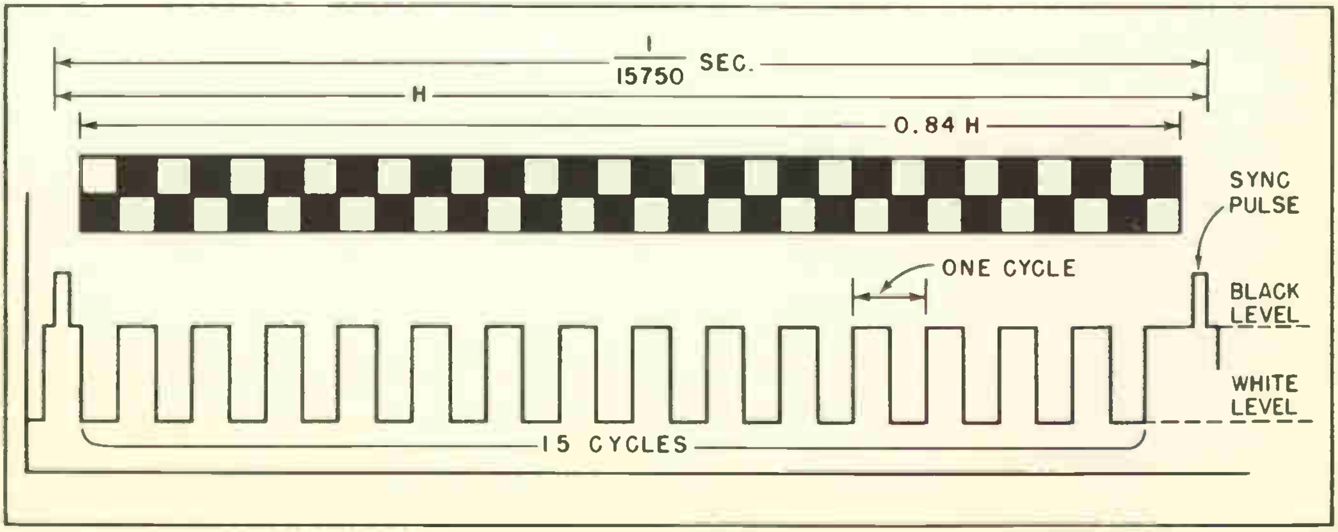

Figure 11. Video Signal Voltage resulting from checkerboard pattern.

pattern in Fig. 11, is slightly less than 1/236,250th of a second, it means the video frequency required to transmit that picture information is 236,250 cycles per second.

By this time it should be increasingly clear to you that the more picture detail which is present in a picture the higher is the video signal frequency needed to carry that picture information. There is a direct relationship between the frequency of the video signal and the quantity of detail in a picture.

It should also be kept in mind that in most cases the picture content sent from the camera to the receiver is much more complex than that presented by the example in Fig. 11. Instead of the relatively large areas of pattern found there, and the sharply defined squares, most pictures consist of a multitude of light changes during a single sweep of the electron beam across it.

All of which means that the frequency needed to transmit fine details in a picture scene must be much higher than the 236,250 cycles required in Fig. 11.

As a matter of record, it should be kept in mind that far higher frequencies are actually needed to transmit a pattern as sharp as that shown in Fig. 11. That is because the signal voltage goes through a change during the transition from light to dark, or vice versa, at a very high rate. During the instant in which the signal voltage goes through the change needed to switch from light to dark, or from dark to light, the frequency rate during that half-cycle is well up in the megacycle range.

Were that not true the outline between the light and dark areas would be blurred rather than sharp. We will touch on these things again later in this lesson.

FCC standards provide a maximum video frequency of 4 megacycles within the 6-megacycle channels assigned to television service. This is reasonably adequate for most black-and-white picture transmission.

Frequency limitations tend to create some visible blurring on the screens of the larger picture tubes if one attempts to view those receivers from a close-up position. When one moves back to a proper viewing distance the blurring is less noticeable.

At one time the 4-megacycle limitation on the video signal appeared to present insurmountable obstacles to the transmission of color pictures. It was then believed a frequency band-spread of not less than 13 megacycles was necessary to transmit the picture information in the three primary colors. Continued research now makes possible the transmission of three-color television within the 4-megacycle frequency limitation.

Section 7. TIME ELEMENTS WITHIN THE HORIZONTAL SWEEP

Some of the things we are telling you in this lesson may seem repetitious. Yet, most of the points we are trying to make are important in television work. The more we repeat them while fixing other, and newer, ideas in your mind the easier it will be for you to remember them.

We have mentioned the number 15,750 many times in this lesson, and those which have preceded this. That is the horizontal line frequency, and has a definite relationship to the number of lines in a TV picture, and the number of frames per second.

Such a frequency was not chosen haphazardly, nor by chance. It was arrived at after long and careful consideration of the many things which figured in its choice.

The number of lines in a picture eventually became fixed at 525. The number of lines which were decided upon had a direct bearing on the horizontal frequency.

Even the final selection of the number of horizontal lines was not made without much thought and research. Many years were spent in research and experimentation before the present number was finally fixed.

The final decision on the number of lines in a TV picture was the subject of long controversy among experimenters within the industry. During the early 1930s it was generally believed half that number, or even less, would be satisfactory. Fewer than 250 lines were used by many experimenters.

Other experimenters reported much better results — better pictures — by using somewhat more than 350 lines. Some experimenters fixed on 443 lines as the proper number.

When experimentation with interlaced scanning proved successful it became evident that a fewer number of frames with a large number of lines would provide greater detail. Eventually, most of the scientists and engineers decided upon 525 lines as being capable of providing the best results without creating too many resultant frequency problems.

It may prove interesting to learn that other countries use standards different from those we use. Mexico and Canada, as well as most of the Latin-American Countries, have followed the lead established here. Most of them use the same standards we use, although Venezuela uses 625 lines at 25 frames each. Their horizontal line frequency is 15,625, a little lower than ours. But such is not true in Europe.

Some European Countries use standards which call for a smaller number of horizontal lines, while others use a higher number. Some countries use close to 650 horizontal lines. Some use interlaced scanning, just as we do. Others do not.

England uses 405 lines at 25 frames, and a maximum video frequency of 2.7 megacycles.

All of which means that television receivers built for use in the United States cannot be used in many European Countries, nor can TV receivers built in those countries be used here without modification.

Some European countries use 20 frames per second, some use 30, others use 60. Some of those which use more lines than we do have fewer frames per second, but use interlaced scanning. Others use a higher rate of frames per second, but without interlaced scanning.

Since the FCC has standardized television transmission at 525 lines in this country, and the number of frames at 30 per second, we have 15,750 cycles per second in the horizontal sweep. This frequency is arrived at by multiplying the number of lines by the number of frames per second. We have 15,750 cycles per second in the horizontal sweep by multiplying the number of lines — 525 — by the number of frames — 30.

When the horizontal sweep frequency is standardized at 15,750 cycles per second it provides us with another time interval — another interval which has also become a standard. That is the time it takes for the horizontal sweep to go through one cycle.

Since the time intervals involved in these matters are always small fractional parts of a second it is easier to discuss them in terms of microseconds than in fractional parts of a second. A microsecond, as you already know, is equivalent to one-millionth of a second. Which also means that it takes one million microseconds to equal one second. The use of microseconds makes it possible to avoid unnecessary use of fractions.

Dividing 15,750 cycles into 1,000,000 microseconds gives us the time interval of one horizontal sweep cycle. Working out the arithmetic we find that each horizontal cycle is equivalent to 63.5 microseconds. This should not be new to you because we have discussed it several times before.

In the previous lesson we learned that each horizontal sweep cycle is referred to in technical circles as *H*. *H* is also equivalent to 63.5 microseconds.

Fig. 11 shows the length of the active trace of the sweep cycle as being 0.84H. This is the same as 84% of *H*.

Working out the arithmetic involved we learn the length of each *active* horizontal trace is approximately 53.34 microseconds. For purposes of convenience in radio and television work that value is usually shortened to 53.3 microseconds.

The actual time of each horizontal trace may vary slightly above or slightly below 53.3 microseconds, but such variation is very small. For practical purposes we are justified in accepting 53.3 microseconds as a reasonably rigid standard.

The graph in Fig. 11 shows the relationship of the active trace interval to the full value of *H* somewhat more vividly than words alone can describe it.

Section 8. TIME ELEMENTS IN SYNC PULSE

The preceding section gives you a pretty good idea of the time intervals which must be considered during each horizontal sweep cycle. It also gives you a pretty good preparation for a closer study of the time elements which enter into the structure of the sync pulse.

You will recall from the lesson which preceded this that fairly rigid standards govern the formation of the sync pulses in a composite video signal. The necessity for those rigid standards are founded in the fact the shape of the sync pulse determines the starting time of each horizontal trace as well as the retrace. Should there be any material variation in the beginning of successive traces it would result in uneven alignment of vertical elements in a picture.

The voltage of the sync pulse must rise from the level of the blanking pulse pedestal to the maximum of the sync pulse in not more than 0.004H. This means the front edge of the sync pulse must rise so rapidly that not more than 0.004H, in terms of time, shall elapse from the beginning of the pulse until it reaches its maximum.

In terms of microseconds 0.004H figures out to 0.4% of *H*, which is the same as saying 0.4% of 63.5. In terms of microseconds, it figures out to 0.254 microseconds.

That is a trifle more than one-quarter of a microsecond.

A signal going through its cycles at such a rate would have a frequency of approximately 4 megacycles. This is, as you already know, the highest permitted frequency of the video signal.

Section 9. VIDEO FREQUENCIES NEEDED FOR FINE PICTURE DETAIL

If the pictures and scenes to be scanned by a camera tube, and transmitted to the receiver in the form of a composite video signal, consisted solely of large picture areas it would be possible to transmit that information with relatively low video frequencies. Unfortunately, the TV viewing public would never be satisfied with such quality of transmission.

Viewers demand fine details in the scene being viewed, and want those fine details transmitted and reproduced. They want to see the pattern of the cloth in the actor's clothing, the scratches on the sponsor's used automobile being offered for sale, and the wrinkles in the aging actress' neck and face. They also want to be able to read printed items which come within the range of the camera so the individual letters can be seen, not merely a blur.

To reproduce such fine details of picture content it is necessary to convert changes of light intensity into changes in the video signal voltage level. When scanning fine details the beam passes over them very rapidly, which means the video voltage levels change very, very fast.

If those fine details are to be observed, and preserved for reproduction at the receiver, it is necessary to provide circuits capable of handling high-frequency video signals without introducing changes in the voltage structure. If the video circuits which amplify and pass the video frequencies affect them in such a way that some of the higher video frequencies are lost, the result will be loss of detail in the picture reproduced on the screen of the picture tube.

Figure 12. Fine detail in picture like this requires careful handling of higher video frequencies. (Courtesy Zenith Radio.)

From a strictly practical point of view such loss is undesirable. It is almost certain the owner of the television receiver will be unhappy with it.

Figs. 12 and 13 provide two illustrations of how it is possible to transmit fine picture detail by means of high video frequencies, and reproduce it on the screen of a large picture tube. In one picture you can see the details of the venetian blind in the background, as well as details of the child's hair and clothing. In the other the details of the model's dress stand out sharp and clear.

If picture details are not sharp and clear the fault usually, although not always, lies in the handling of the video signal within the circuits of the receiver. Loss of fine details nearly always results from failure of the receiver circuits to pass the higher video frequencies. Failure to pass the higher frequencies results in blurring, and loss of detail. The appearance of the picture then resembles a photograph which has been taken when the lens is out of focus.

The condition and quality of the picture depends on the fidelity with which the higher video frequencies are handled. The more carefully the higher video frequencies are handled, the sharper the picture will be on the screen of the picture tube.

Section 10. LIMITATIONS ON PICTURE DETAIL

In photography it is usually the aim of the photographer to obtain as much "detail" as possible. Except in portrait work, the photographer strives for all the detail his camera is capable of capturing.

The term "detail" in photography refers to the fine, sharp lines between adjacent picture elements. When the detail is sharp there is a clear distinction between each of the elements and its neighbors so each stands out in a manner clearly visible to the human eye. Blades of grass are distinguishable as picture elements, not a blurred mass; tree leaves are distinct items, not a blended whole; bricks in a distant building stand out clear and distinct.

When the detail is not so sharp there is a tendency for one element to blur into adjacent ones. This reduces the clear distinction between them, and causes them to blend together into an indistinct whole. In such cases the larger objects remain distinct, provided the loss of detail is not too severe. But the finer detail is lost.

Figure 13. High Video Frequencies are responsible for presence of fine Picture Details. (Courtesy Zenith Radio.)

Efforts are made to attain the same ends in television. There are certain limitations which have prevented television detail reaching the same high degree of perfection achieved in photography.

The worst limitation which handicaps television is that placed on the higher video frequencies. The FCC limits the highest video frequency to 4 megacycles. Despite that limitation, the quality of television pictures is generally acceptable to most viewers.

When picture elements are large, such as those in Figs. 5, 6, 7, and 8, they can be almost perfectly reproduced. Where the transition in light content from one picture element to another is gradual the picture can also be reproduced almost perfectly.

Where the change from one level of light intensity to another is quite sharp it may not be possible for the receiver circuits to handle the signal voltage changes without introducing some degree of distortion. When that happens there may be some degree of blurring. However, if the circuits are properly adjusted the picture should be sharp enough to be satisfactory.

Let us turn back to Fig. 11, and the checkerboard. There are only 15 cycles of video voltage change per horizontal line while scanning that scene. This means the *average* frequency of the video signal during the scanning of one line is relatively low.

But, while the *average* video frequency for the entire line is relatively low, the video frequency during the signal voltage changes from one picture element to another is quite high. During the short time interval in which each of those changes take place the video voltage changes very rapidly.

If the video circuits which handle the video signal are not capable of handling the higher video frequencies there is a tendency to distort them, and stretch them over a longer period of time. Instead of the change from one area of the checkerboard to another being sharp and clear, as in Fig. 11, the lines between them are blurred. The change from one to another will blend into each other more gradually, somewhat like that shown at *B* in Fig. 14.

The number of picture elements which can be accommodated in the video signal per horizontal line without blurring can be determined with reasonable accuracy. We start with the fact that 4 megacycles is the top video frequency.

At 4 megacycles each cycle is one-quarter microsecond in duration. This also figures out to 4 cycles per microsecond.

It takes two picture elements to make one video cycle. A dark element and a light element. Which means that in one microsecond we can accommodate four video cycles of 2 picture elements each; or, eight picture elements in each microsecond.

We have already worked it out that there are 53.3 microseconds in each horizontal trace. Since we can have eight picture elements during each microsecond it means we can have 426 picture elements in each horizontal line, (53.3 x 8).

This means it is possible to scan and reproduce 426 picture elements during one sweep of the electron beam without exceeding the 4-megacycle limitation on the video frequency. To put this in terms of a practical demonstration it would be possible to have a checkerboard of 426 squares similar to that in Figs. 11 and 14, and to reproduce those squares on the screen of the picture tube. All this could be done without exceeding the 4-megacycle limitation on the video signal frequency.

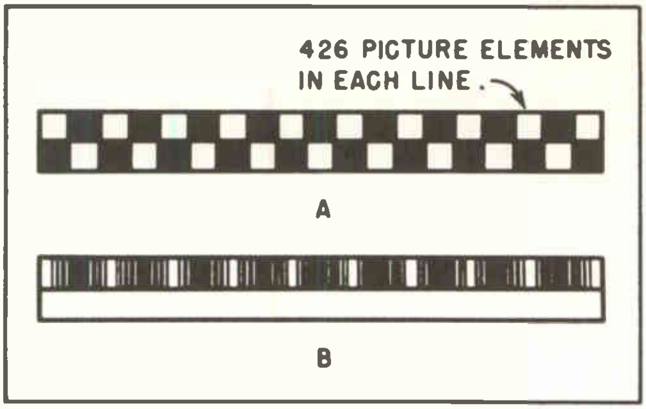

Figure 14. If too many picture elements there will be blurring between elements.

Keep clearly in mind that such reproduction of detail has nothing to do with the size of the picture tube screen. No more detail can be reproduced on a large screen than on a small one. The reason lies in the fact that reproduction of detail has nothing to do with the size of the picture tube screen; it is entirely a function of the frequency-handling ability of the video circuits.

If the video circuits in the receiver are unable to handle the higher video frequencies fine detail cannot be reproduced on the screen regardless of its size.

One of the objections some people have to large-screen television receivers is that the detail often seems less clear than on the smaller screens. The reason for this is that while the larger screen shows the same *number* of picture details in a scene, the *size of each* is greater on the large screen than on the smaller one. When the large screen is viewed from a close-up position the detail often appears too coarse to be acceptable.

The only remedy for such condition, of course, is to move farther away from the screen.

If there is any attenuation of the frequency-handling ability of the video circuits, so the higher frequencies are lost, some degree of blurring occurs between adjacent horizontal picture elements. Fig. 14 makes that clear.

To reproduce a sharp, clear-cut picture like that at *A* in Fig. 14 it is necessary for the video circuits to handle the higher video frequencies without distortion or attenuation. Loss of high video frequencies results in blurring, such as that shown at *B* in Fig. 14.

The greater the number of picture elements in a horizontal line, and the greater the degree of change from one light level to another, the greater is the tendency for blurring to occur.

Should the electron beam actually be required to scan 426 picture elements, with as wide a range of light-level change as in Fig. 14, some blurring would be unavoidable.

In most television scenes the number of picture elements in each horizontal line is considerably less than 426, and usually the change from one light level to the other is much less abrupt. All of which makes it easier for the television circuits to reproduce the original scene with truer fidelity.

The present television system, as we know it in the United States, is capable of reproducing a reasonably clear picture containing an acceptable amount of detail. It is able to do a reasonably satisfactory job despite the many limitations placed upon it.

Failure of a television receiver to provide a picture which is acceptable can usually be traced to failure of one or more circuits to do the job. Instead of the video circuits in a receiver being adjusted to handle the full 4 megacycles of frequency spread, which is necessary to good reception, we have found many receivers incapable of handling a frequency spread of more than 2 megacycles, or two and one-half megacycles. The result is that the picture on the screen is blurred, and not fully satisfactory.

With the trend toward larger picture tubes it has become increasingly important for the video circuits to accept and handle extreme ranges of the video signal. Loss of detail is much more noticeable on the larger picture tubes than on the small ones.

Adjusting video circuits for wide-range frequency response has drawbacks as well as advantages. The wider the frequency response of a tuned circuit the lower the gain which can be achieved from the amplifier circuit. Some manufacturers, especially of smaller screen receivers, have deliberately reduced the frequency response of the tuned video circuits to attain greater gain. That practice was acceptable so long as small-screen tubes were used.

With the increasing trend toward larger picture tubes greater fidelity in detail structure is needed, which means wider range frequency response in the video circuits. But since the wider frequency response reduces the gain per stage it has been necessary in some cases to increase the number of stages, or use higher-gain tubes.

Some manufacturers have attained good frequency response, and retained good gain characteristics, by using a higher I-F frequency and better components in the circuits. During recent years there has been a growing tendency to use I-F frequencies above 41 megacycles.

Section 11. VERTICAL DETAIL

The *vertical* detail it is possible to achieve in television is directly dependent on the number of scanning lines. This is not difficult to understand.

Just to make certain you do understand why this is true we will examine the vertical composition of a picture.

The scanning beam is focused, both in the camera and the picture tube. It is focused so it is little more than a tiny dot at the point where it strikes the sensitive screen.

When scanning the horizontal lines the beam follows a very narrow path; a path no wider than the diameter of the dot made by the electron beam.

The location — in a vertical direction — of a picture element with respect to the width of the scanning beam is a matter of importance in

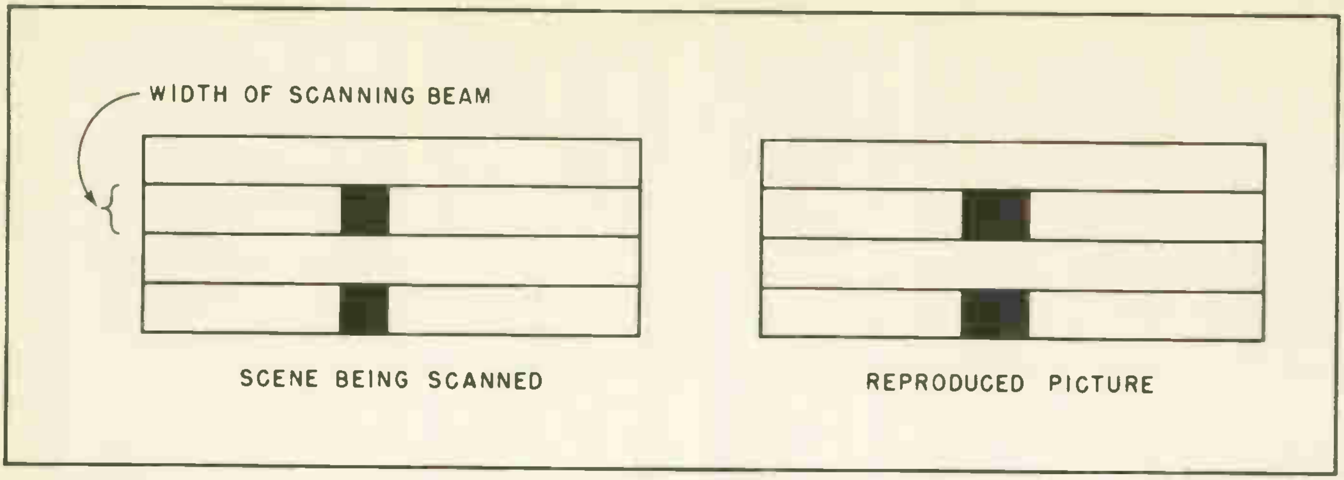

Figure 15. Reproducing Picture Element same width of Scanning Beam, and fully covered by it.

reproducing that picture element. A few examples will explain what we mean.

In Fig. 15 we have some picture elements. The picture elements are small, exactly the same size as the width of the scanning beam where it passes over them.

When the picture elements are the same size as the width of the scanning beam they are reproduced in exactly the same form as exists at the original scene being scanned. Compare the illustration at the right with the one at the left.

But suppose the picture elements are positioned a little differently. Suppose they are so positioned that one scanning beam touches them, but does not entirely cover them, and it takes two passes of the electron beam to sweep the full body of the picture element. Such a situation is portrayed in exaggerated form in Fig. 16.

In a case of that kind the scanning beam hits only a part of the picture element. A portion of the beam touches a dark picture element, while part of it rests on a light picture element.

The electrical video signal which leaves the camera is neither black nor white; it is some degree of gray between those extremes. When that picture element is reproduced at the receiver it is gray instead of black, and affects two lines instead of one.

More than that, the other part of the dark picture element will be scanned by a following sweep of the beam. That, too, will reproduce a gray picture element. Thus the effect on two lines instead of one.

The result is that instead of the original black spot being reproduced as a black spot it will be wider vertically, and will be gray instead of black. The result is similar to that shown at the right side of Fig. 16.

A condition, such as that described in Fig. 16, will exist *only* when the picture element is *very small* in a vertical direction, yet is so positioned that it requires two passes of the beam to cover it, and neither pass of the beam covers it entirely. Since this condition exists only when the picture element is very small it is not especially troublesome because it is not noticeable on most receivers. Yet, it is a condition you should know.

The seriousness of this condition has been reduced by using 525 horizontal lines. If the picture had fewer lines the condition would be more serious. Use of 525 lines causes each sweep of the beam to cover only a very narrow portion of the screen. This means a picture element would have to be very small to create the situation shown in Fig. 16. Nevertheless, it could become important in large-screen television.

To better understand this situation, and the relationship between the number of lines and vertical detail, suppose we consider an example where the vertical picture element extends across several horizontal sweeps of the electron beam. We have illustrated that condition in Fig. 17.

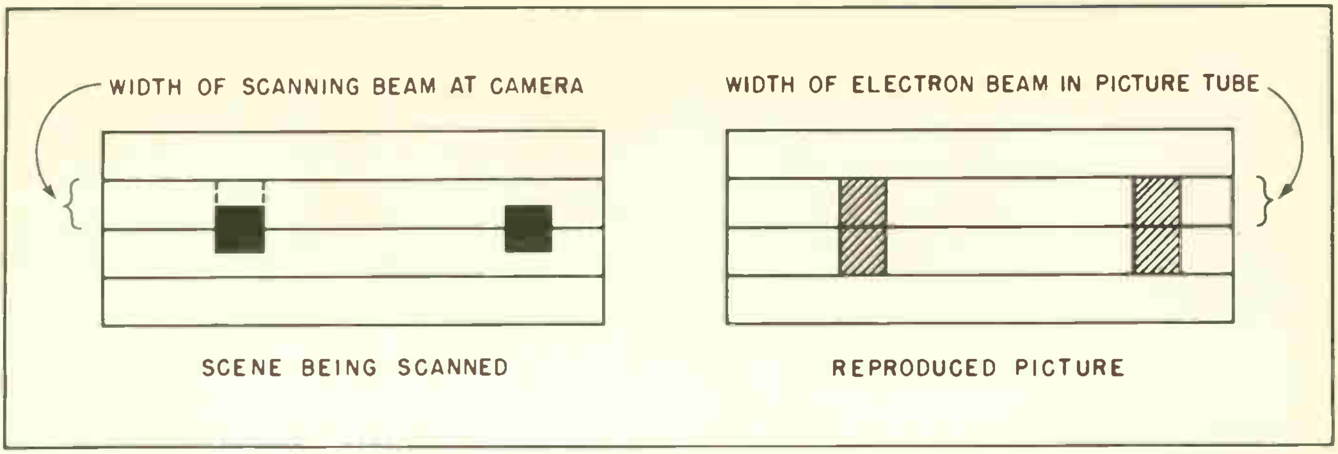

Figure 16. Scanning Picture Element so positioned that two passes of beam needed to cover but neither covers completely.

The illustration at the left side of Fig. 17 shows a vertical picture element spanning completely across three horizontal lines, and halfway across the fourth. In the other illustration at the right we see how such a vertical picture element is reproduced at the receiver. The three lines which were completely spanned by vertical picture elements are reproduced with true fidelity. But the upper end of the picture element, which extended only part way into the path of the fourth horizontal line, is only incompletely reproduced. The upper end of the reproduced picture element is gray instead of black. The upper end is blurred instead of sharply defined.

The second vertical picture in Fig. 17 represents a slightly different situation. That line completely spans four horizontal scanning lines, without partially extending into another at either end. That vertical picture element is reproduced virtually as it appeared at the original scene.

The third picture element represents a condition similar to the first one. The reproduced picture element is slightly longer than the original, and the upper end is gray instead of black. It is similar to the first picture element, except it is not quite so long.

It should be kept in mind that the conditions we are illustrating are exaggerations. But they must be exaggerated if we are to make them clear to you.

Instead of each horizontal sweep of the electron beam covering the vertical expanse we have suggested in the illustrations, they actually cover far less.

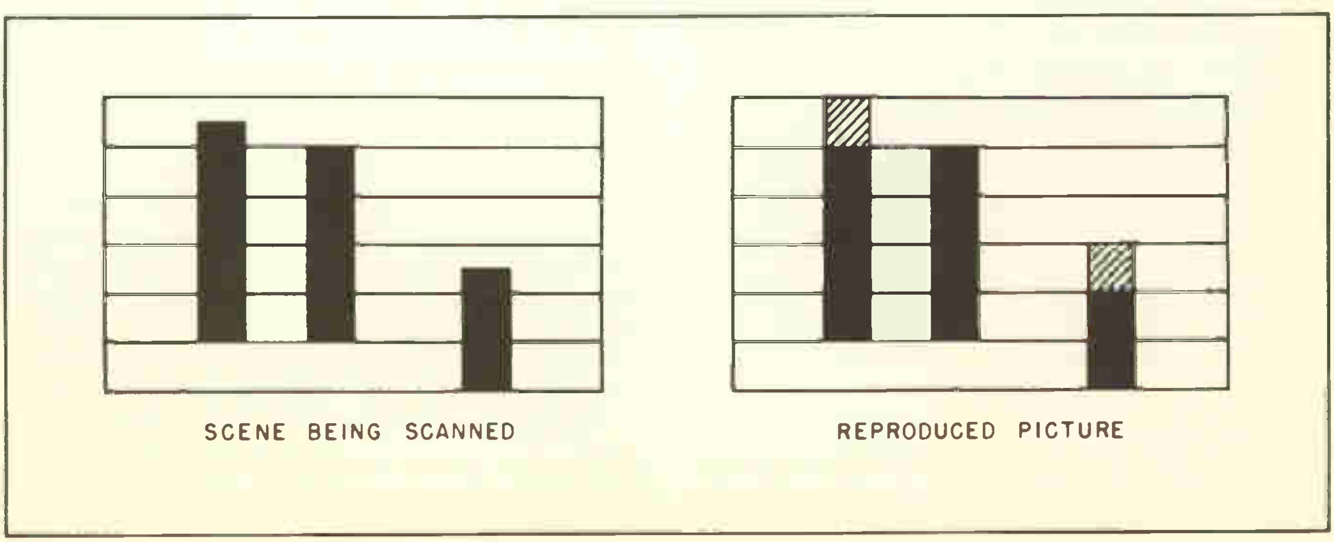

Figure 17. When Vertical Picture Elements extend across several Horizontal Lines.

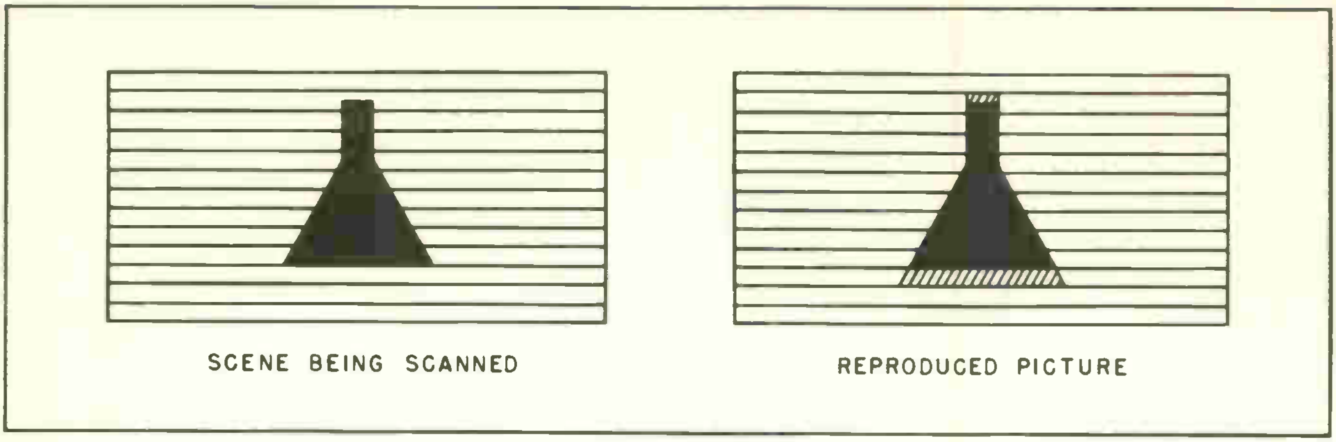

Figure 18. Vertical reproduction of Irregular Object.

We can get a little better idea of how vertical picture elements are reproduced by studying Fig. 18. Through a study of that illustration the idea is impressed on us that many horizontal sweeps are required to cover the full vertical area of a picture object.

The major portion of the vertical elements of the object are reproduced in much the same manner as they actually appear. If the upper edge of the object does not precisely coincide with the horizontal sweep of a line some blurring will result. This is indicated in the reproduced picture at the right. The same is true of the bottom edge.

All of which means that most of the object will be reproduced with true fidelity, but some small amount of blurring may occur at the top and the bottom.

As the number of lines are increased, and the physical size of the object being viewed is increased, the reproduction becomes more true. Since there are 525 horizontal lines, and most objects are spanned by a considerable number of lines, the vertical fidelity of picture elements is usually quite good. Unless the size of the object is very small, its vertical detail should be reproduced with true faithfulness.

Section 12. UTILIZATION RATIO

In connection with the ability of a television system to reproduce vertical detail in a picture we become involved with a technical property which goes under the mouth-filling name *utilization ratio.* Despite this formidable term, this factor is not especially difficult to understand.

Each television system has just so many horizontal lines. In the United States this is 525 lines. But the fact we have that number of horizontal lines does not mean we can reproduce a separate vertical detail for each of those lines. A number of factors enter.

The actual number of scanning lines which are useful in representing vertical detail are compared with the total active scanning lines to arrive at the *utilization ratio.* The utilization ratio is actually the ratio of *useful* scanning lines to *active* scanning lines.

Many tests and experiments have shown the utilization ratio varies from about 60% to about 90%, although the latter degree is seldom attained. The average utilization ratio is nearer 75%.

Fortunately, a clear knowledge of utilization ratio, and how to determine it, is not exactly a matter for service technicians to worry about. Nevertheless, it is a subject which keeps popping up in technical magazines; therefore, it is just as well you have some idea what the discussion is about.

The utilization ratio has a direct bearing on the amount of picture detail which can be included in a televised picture. The utilization ratio, together with the number of active scanning lines, are the determining factors.

Vertical picture detail is just as important as horizontal picture detail when determining the sharpness and clarity of the picture reproduced on a television receiver screen. Unless the vertical detail is approximately as sharp and clear as that reproduced in a horizontal direction, the picture will not be as satisfying as is generally desirable.

Broadly speaking, utilization ratio includes those factors and actions we explained in connection with Figs. 16, 17, and 18. But it goes a little further than that. It includes the other determining factors which affect the quality of vertical picture detail production.

To arrive at some idea of the total amount of picture detail which can be reproduced in a vertical direction suppose we consider the relationship of the utilization ratio to the actual number of horizontal lines which are visible on the screen of the picture tube.

To begin, we must remember that all horizontal lines are not actually visible. A few lines are blanked by the vertical blanking pulse before the vertical retrace begins. Others are blanked during the vertical retrace. Still others are blanked after the retrace has ended and a new trace movement has started.

The exact number of horizontal lines which are actually blanked during each field, or during each frame, is not the same in all cases. The timing of the sync generator is the more immediate governing factor.

However, the variation from one occasion to another is not great. For purely practical purposes we can usually estimate the number of blanked lines as approximately 8% of the total. This means 8% of the 525 lines, or 42 lines per frame.

Some of these lines are blanked at the top of the picture, some at the bottom. The important fact to keep in mind is that these lines are not active insofar as the job of conveying picture information is involved.

Eliminating the 42 inactive lines leaves 483 lines which are actively used for the purpose of conveying picture information.

To learn the amount of vertical picture detail which can be transmitted by a television system it is necessary to multiply the number of active lines by the utilization ratio. If we accept the average utilization ratio figure of 75% as being reasonably normal we would multiply the number of active lines by that figure. Multiplying 483 active lines by 75% gives us approximately 360.

This means that approximately 360 vertical details is the maximum number which can be included in the average television picture.

It will be quickly recognized that few, if any, actual pictures possess so many vertical details. Nevertheless, possessing the ability to reproduce them makes it possible to sharply mark the bottom and top edges of picture areas which change sharply from one light intensity to another.

The picture content in Fig. 19 goes a step farther in making this point clear.

In the matter of actual numbers there are not many vertical details in this picture. But some of the picture details lie in a horizontal plane, with sharp demarcations above and below them. The top of the actor's shoulders, and the top of his hat are good examples. If the receiver circuits were unable to provide sharp vertical detail the shoulders and the hat would be blurred.

Much the same is true of the hat brim. The hat brim extends horizontally, with a slight upward tilt at one side. By providing good

Figure 19. Good reproduction of Vertical Detail makes it possible to sharply outline edges of actor's hat. (Courtesy Stewart-Warner.)

vertical picture detail the television system is able to recreate those items in sharp outline, rather than permitting them to be blurred.

In your own mind you may feel that such close attention to detail is not a matter of great importance. But a customer who has paid his money for a television receiver usually wants the best, and the sharpest, reception he can obtain. It is up to you to understand the factors which control that ability to reproduce sharp detail, so you can do your part to keep the customer happy. At least keep him as happy as customers are ever kept.

It is not always easy to check picture detail while viewing an average broadcast. Filmed broadcasts are notably lacking in detail, and it is impossible to tell by watching such a broadcast whether the circuits are capable of handling fine detail or not.

Many live broadcasts are lacking in detail, especially some that are sent long distances over co-axial cables. Quite often some of the details are lost during such transmissions.

A broadcast which is picked up "live" from the local studio of the station making the broadcast is the best method of checking picture detail; even so, some of these do not provide sufficient fine detail for you to be absolutely certain.

If you are able to discern details of the eyelashes during close-ups, or the thread pattern in men's clothing, or fine wrinkles in women's clothing or cloth, you can be reasonably certain the fine detail is good. Ability to pick out wrinkles in the actors' and actresses' faces and necks and hands is one good way to check for fine detail, especially when so many Hollywood characters are making their comebacks in television.

However, such methods of checking are not always reliable because the art of "make-up" is often adequate to cover up tell-tale signs of age. It is better to supplement your checking procedures by studying other picture details.

There is no better way to check the detail on the screen of a picture tube than to study a test pattern broadcast by a TV station. Fig. 20 shows such a test pattern.

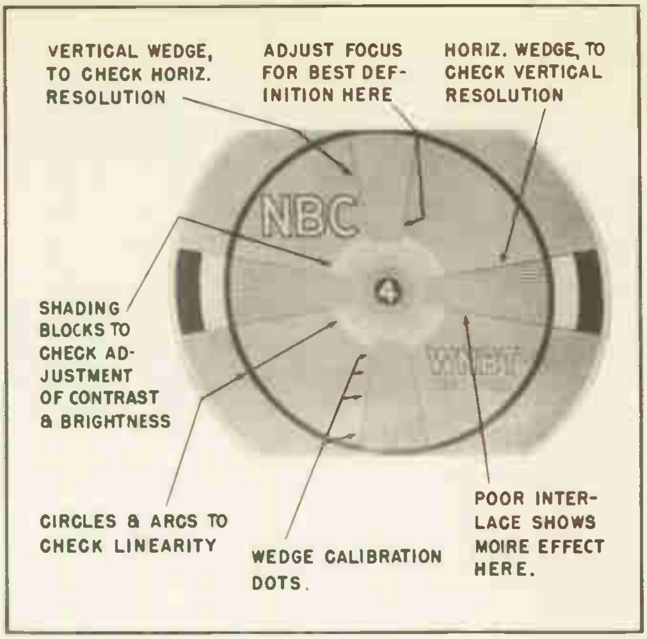

Figure 20. Test Pattern used to check content of Picture Detail.

A test pattern of that kind has been scientifically prepared so it discloses many types of trouble in television circuits. One of the most important is its ability to reveal content of picture detail.

The parallel lines in the horizontal and vertical wedges provide an excellent means of checking for picture detail. The vertical wedges make it possible to check the horizontal detail, more commonly known as "horizontal resolution." The horizontal wedges enable the experienced technician to check the vertical detail. More will be said about the use of test patterns for checking television troubles in other lessons.

One drawback to using test patterns for checking detail — or for other purposes — is that such test patterns are no longer broadcast so regularly as they were during the early days of television. When television stations were still a novelty it was a regular practice for them to broadcast test patterns for many hours each day.

Broadcast time is now far too valuable to waste it on test patterns, except during the late night hours and very early morning hours when no other programs are scheduled. That is the reason it is necessary to study other details in regularly broadcast television programs in order to determine whether or not the production of detail is as good as it should be.

Section 13. PRACTICAL LIMITS ON PICTURE DETAIL CONTENT

It is theoretically possible to transmit as many as 200,000 individual picture elements in each frame of a television picture. Practical considerations limit that number to a considerable degree.

The first limiting factor is the blanking time. That reduces the actual number of picture elements because both the horizontal and vertical blanking time intervals help reduce the number of individual picture elements which can be handled.

The most accurate method to determine the number of picture elements which can be transmitted during one frame is to multiply the number of vertical picture elements by the number of picture elements in each horizontal line. Using the figures we have already mentioned that becomes a relatively simple matter.

We have explained that 360 is about the maximum number of vertical picture elements which can be handled. We have previously mentioned that approximately 426 picture elements can be handled in each horizontal line.

By multiplying 360 by 426 we come out with a little more than 150,000. For practical purposes it is generally estimated that 150,000 picture elements is just about the maximum number a television system can be expected to handle. Many receivers are not able to handle that many.

For purposes of comparison let us see how this stacks up against the picture detail content in motion pictures.

Commercial motion pictures, such as those produced in Hollywood for showing in theaters, use 35-mm film. Each frame of such pictures is capable of handling approximately 500,000 picture details. That is far greater picture detail than can be handled by any existing television system.

All of which would make it seem at first glance that television reproduction is vastly inferior to motion picture reproduction.

But it must be kept in mind that 35 millimeter motion picture film is produced specifically for projection on large screen where it is necessary to provide a large amount of detail. A better comparison between television and motion pictures would be with 16-mm film.

Serious amateur photographers use 16-mm film. So do commercial firms which use motion pictures to portray special features. That size of film is widely used throughout the country for advertising purposes. In fact, many Hollywood features originally put on 35-mm film are often reprinted on 16-mm film for use in schools, churches, youth organizations and other groups.

In comparison with 35-mm film, the picture detail content of 16-mm film is only 125,000 picture elements per frame. This is roughly one-fourth that of the larger commercial film, and less than that of television.

There is some degree of error in making a comparison in this manner. Despite the fact television appears able to reproduce slightly more detail than 16-mm film, such is not entirely true on a practical basis.

The picture detail content in a 16-mm film is slightly better than most television systems are able to handle. But there is a close comparison between the picture content of 16-mm film and that of a properly adjusted television system.

Section 14. GAMMA

The matter of *gamma* in connection with the transmission of pictures through the medium of television sometimes crops up in technical journals, and is sometimes a bit of a mystery to servicemen who are not acquainted with the term.

The truth is that few servicemen have any real need for a technical knowledge of gamma, but we think it wise to mention the subject so you will be aware of it.

Gamma represents the extent to which light is emphasized, or de-emphasized, in television systems. The matter of gamma enters in the engineering of both transmitting equipment and receiving equipment, but is not a matter of direct concern to servicemen since they cannot do anything about it in any event.

The term *gamma* has been borrowed from photography. Its name is derived from the Greek letter gamma which has long been used in mathematical equations for computing graphical curves which show the response of the human eye to changes in light intensity.

Both the human ear and the human eye respond in their respective fields along what is called a *logarithmic curve*. By this is meant that they respond to slight changes in intensities at low volume, but respond only to large changes in intensities at high volume.

You are probably well aware of this fact if you stop to think about it, although you may never have given much thought to it.

Probably the best example of this peculiarity of the human eyes is in the way they see the stars in the sky. It is no secret that the stars are present in the sky at all times, but we see them only at night.

At night the stars show up brilliantly; in the daytime we cannot see them.

The reason lies in the manner in which our eyes respond to changes of light intensity. The stars shine just as brilliantly during the day as at night, but they are able to add so little additional light to the light of day the human eye cannot perceive the slight degree of light change they cause. Thus, we do not see stars during the day.

It has been said that the human eye can observe the striking of a match for many miles if the night is dark enough. But the same amount of light from a similar match can be seen only a short distance during the day.

All of which means that the human eye can detect a very low level of light if the light level on all sides is also very low.

For all practical purposes this term *gamma,* when used in connection with television work, refers to changes in light intensity which can be distinguished by a pair of normal eyes. In some ways the term *gamma* bears much the same relationship to light that the term *decibel* bears to sound.

(In this connection we should explain that we devote an entire lesson to decibels later in the course. If that term is hazy to you at this time you should be patient.)

NOTES FOR REFERENCE

A picture detail is the smallest element in a picture which can be seen by the human eye, or is the smallest element which possesses a separate light intensity.

Where the light intensity changes from one position to another on a picture tube screen it represents a change from one picture detail, or picture element, to another.

Detail which can be handled in a television system is closely related to the allowed frequency.

Present regulations of the FCC allow 4 megacycles as the top limit of the video signal frequency.

There are 525 lines in a standard television frame. Approximately 42 of these are blanked out during vertical retraces, which leaves 483 active horizontal lines.

The number of picture elements which can pass through the video circuits of a television system during the scanning of one line is limited by the 4-megacycle limitation. It is about 426 picture elements per line.

Canada, Mexico and most Latin-American Countries use the same frame and sweep standards as the United States.

Venezuela has standards based on 50-cycle power frequencies which amounts to 625 lines in 25 frames.

England uses 405 lines at 25 frames.

The duration of each horizontal sweep cycle is determined by the number of horizontal cycles per second. It figures out to about 63.5 microseconds per cycle.

The *active* time of the trace amounts to 84% of the full horizontal cycle, or approximately 53.3 microseconds.

The time during which a video signal changes from one extreme light condition to another determines the rate at which the signal voltage changes during that time interval. If the time interval is very short the rate-of-change is very high. During that short interval of time the voltage change is equivalent to a high signal frequency.

If the high-frequency response in a video circuit is not good the signal voltage is unable to undergo rapid changes without distortion being introduced. This results in blurring of the picture.

Good high-frequency response in the video circuits is necessary to provide good detail — or good resolution — in the horizontal plane of the picture.

Vertical detail in a television picture is dependent on the number of lines.

The *utilization ratio* is a figure of merit showing how well the individual horizontal lines can be utilized to outline vertical detail.

Picture detail content in a television picture is roughly equivalent to that contained in a 16-mm motion picture film.

The ability of video circuits to handle high frequencies determines the speed with which the sync pulse voltage can rise. The sharper the rise of that sync pulse the closer the individual horizontal lines can be locked together.

Gamma is a technical term which relates to the ability of the human eye to distinguish between different levels of light intensity.

NOTES

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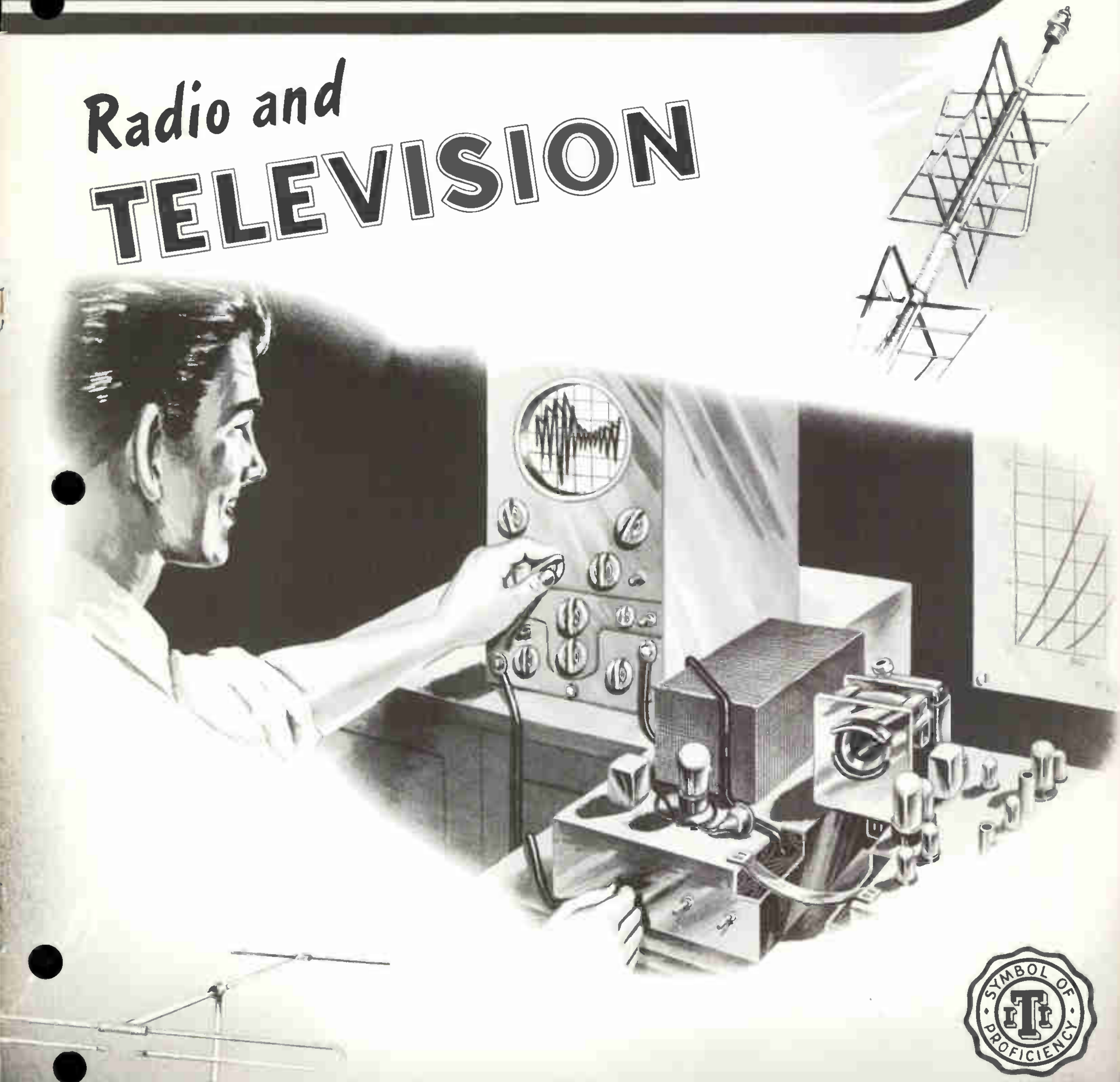

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RADIO TELEVISION

WHAT THE TEST PATTERN SHOWS

Contents: Introduction — Typical Test Pattern — Purpose for Which Test Patterns Are Used — Basic Test Pattern Construction — Checking Aspect Ratio — Generating Saw-Tooth Wave-Form — Linearity of Saw-Tooth Sweep Voltage — Brightness — Contrast — Focusing — Picture Resolution — Measuring Vertical Resolution — Calculating Vertical Resolution — Measuring Horizontal Resolution — Other Faults Disclosed By Observation of the Screen.

Section 1. INTRODUCTION

The composite video signal embodies within itself all the information a television receiver needs to reproduce a scene viewed by a TV camera. Thus, it naturally follows that any distortion introduced into the composite signal is noticeable on the picture tube screen.

A full understanding of these facts makes TV servicing easier.

The composite video signal is a complex mixture of high frequencies, and low ones. If the original scene is to be correctly reproduced all those many frequencies must be passed by the amplifier circuits which handle them, and they must be so handled that the wave-form of the video signal is not changed or distorted.

Should any of the video amplifier circuits which handle the composite signal be unable to pass the higher video frequencies a certain amount of blurring is certain to appear in the reproduced picture. Vertical lines, or vertical patterns, in the picture will not be sharp and distinct.

There is usually some degree of blurring in the reproduction of any picture. The exact amount depends on the degree to which the higher video frequencies are attenuated. If the high-frequency response is good the degree of blurring is reduced to the point where it is not noticeable.

Failure of the two fields of each frame to interlace properly shows up in the picture; such improper interlace shows up in a characteristic manner.

Poor focus shows up in another way which is characteristic of that particular defect.

The point we are trying to make is that failure of any circuit, through which the composite signal passes, to function properly always shows up in the picture on the screen of the picture tube. Each defect shows up in a manner which points directly to the source of the trouble.

Failure of the vertical circuits to function properly shows up on the screen of the picture tube. This fact was explained in a previous lesson, and will be discussed in other lessons which are to follow. What we are trying to impress on you at this time is that such failure can be diagnosed by watching the pattern on the screen of the receiver.

Malfunctioning of the circuits in the horizontal deflection system also shows up on the screen of the picture tube. Various types of defects in the horizontal deflection circuits show up in different ways.

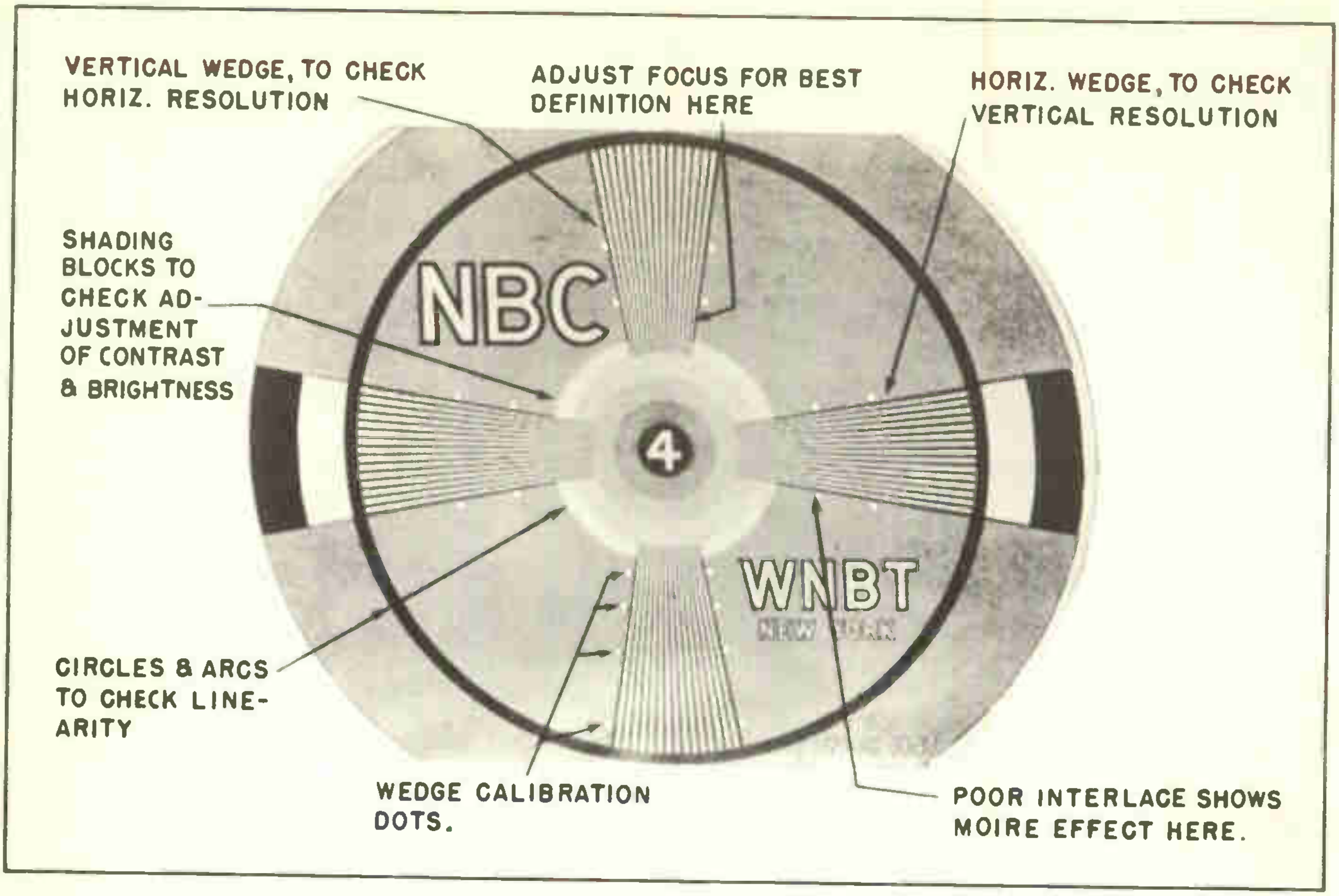

Figure 1. Type of Test Pattern widely used by NBC stations.

By studying the pattern of the picture on the screen an expert TV service technician is usually able to go directly to the cause of the trouble. The pattern on the screen often reveals the source of the trouble so clearly the technician is able to correct it in a matter of minutes.

Section 2. TYPICAL TEST PATTERN

Very early in the age of television it became evident that a scientifically designed test pattern would aid service technicians to diagnose circuit troubles. Such test patterns came into widespread use.

Fig. 1. is a picture of a test pattern designed by NBC, and used by many of the stations controlled by that network. The pattern is altered by the individual stations to the extent that the call letters differ from that shown in Fig. 1.

The test patterns are broadcast before the beginning of the regularly scheduled shows, and after the programs have gone off the air.

During the first few years after the second World War it was a regular practice of TV broadcast stations to transmit a test pattern for several hours in the morning, and again for several hours at night. That made it possible for TV technicians to test-check and adjust television receivers on their test benches.

The spectacular growth of television has made broadcast time very valuable. Many of the larger TV stations are now reluctant to devote much time to the transmission of test patterns. Some stations have almost completely discontinued the practice.

When new TV stations go on the air, especially in new TV territory, they usually broadcast a test pattern for several hours each day for several months. This practice enables service technicians to check tuned circuits of receivers so they can receive the station.

Many of the smaller TV broadcast stations continue to transmit a test pattern for several hours each day at definitely scheduled intervals.

Smaller TV broadcast stations seem more ready to provide this convenient service than the larger, and more powerful, metropolitan stations.

To some a test pattern has little significance. To others it seems little more than a device TV stations use during slack hours to avoid the expense of a "live" show.

There is much more to most test patterns than that.

Not all test patterns conform to the one illustrated in Fig. 1. But most are scientifically designed to provide a generous amount of test information to receiver technicians who are trying to get receivers aligned, and back into operation.

While the pattern shown in Fig. 1 is typical of those used by the NBC network stations, another pattern is also used widely throughout the industry. That is the one shown in Fig. 2.

The pattern shown in Fig. 2 was designed by the engineering division of the Radio Manufacturer's Association, an organization which has since changed its name to Radio and Television Manufacturer's Association.

TV stations affiliated with other networks, or unaffiliated with any network, sometimes use some other type of pattern they have designed themselves.

Section 3. PURPOSE FOR WHICH TEST PATTERNS ARE USED

In a previous lesson we mentioned that a skilled television technician could often detect the source of trouble in a television receiver by studying the form of the pattern on the screen. The reason that is true is most kinds of defects in TV receiver circuits make themselves known by some change-from-normal in the appearance of the picture. Test patterns are deliberately constructed to emphasize those things technicians usually look for.

When a technician is aligning the various circuits in a TV receiver one of the things he tries to observe is that proper ratio is maintained between the width and height of the picture. Technically, this is referred to as the "aspect ratio".

The pattern in Fig. 1 is so designed that it is easy for the service technician to check the aspect ratio. That is done by observing the appearance of the two large circles in the pattern.

You can see there is a large black circle which just touches the top and bottom of the picture. Outside of that is a white circle. The white circle touches the right and left side of the pattern, but extends beyond the top and bottom of the picture.

When the circuits are so adjusted that both of these are actually *round* circles, and not ellipses, the aspect ratio is properly proportioned. The black circle should touch the top and bottom edges of the picture, while the white circle should just touch the right and left sides.

Thus, the presence of those two circles in the pattern provide service technicians with a reference against which they can check the condition of the receiver circuits.

As was mentioned at the beginning of this lesson, TV broadcast stations no longer transmit test patterns for such long periods as formerly. They insist they can no longer afford to do it.

All of which means that service technicians must often improvise other means for checking alignment of the picture.

There are special instruments on the market which feed a modulated signal into the front end of a television receiver. The modulation on the signal can be changed and varied so a technician can check any circuit in a receiver. Some technicians use these instruments.

One drawback to such instruments is the fact they represent a very heavy money investment. Many men entering the TV servicing field simply do not have that kind of money to spend.

Fortunately, a reasonably accurate job can be done without such instruments if the serviceman is able to exercise some degree of ingenuity.

Many service technicians check the linearity of their picture by observing the appearance of the CBS "eye" which is flashed on the screen at the beginning and end of all programs carried by CBS stations. That "eye" is round, or nearly so, and by adjusting the circuits so the "eye" is round on the receiver screen the technician can be reasonably certain the circuits are pretty well adjusted.

The four wedges shown in the test pattern in Fig. 1 are not merely doodles that some artist thought up. The gradually expanding lines (there is a wedge expanding in each of four directions) serve a definitely useful purpose.

The reason these wedges are designed the way they are, and the purpose behind their use, will be explained in greater detail later in this lesson.

The solid block of black at the outer ends of the horizontal wedges serve a definite purpose. So does the block of solid white.

The several concentric circles at the center of the pattern, with their varying shades of gray, serve to convey definite technical information to an experienced serviceman.

Section 4. BASIC TEST PATTERN CONSTRUCTION

Despite the fact that test patterns often vary from one TV station to another, they all seek to convey certain basic technical information. Perhaps it would be better to say that all seek to provide a basic reference background against which the technical circuits of a receiver can be checked.

The patterns shown in Figs. 1 and 2 are by no means the only ones used in various parts of the country; nevertheless, they serve as an illustration of the type of background information technicians have found desirable for testing purposes. Much of our attention will be devoted to a discussion of the pattern in Fig. 1, since that is probably used more widely than any other; but you will find that much of what we tell you applies in equal degree to the pattern in Fig. 2.

If a station in your area transmits a different type of test pattern you should get in touch with them and find out exactly how the pattern is to be used.

The black areas and the white areas in the test pattern are about equal. The background of gray is about midway in shading between black and white.

Such arrangement duplicates rather closely the conditions under which most television scenes are televised. Since this is true we can be reasonably sure that a television receiver adjusted to reproduce the test pattern in Fig. 1 should be reasonably capable of reproducing most television scenes.

The large black areas and the large white areas at the outer edges of the horizontal wedges are worth a little comment. The sharp contrast between the large area of white and the large area of black permits the technician to study the manner in which the receiver circuits handle the sudden, sharp swing in the camera video voltage from one extreme to the other.

The ability with which the receiver circuits handle the camera video signal under those conditions provides a good indication of how they would handle similar sharp swings in the signal voltage when receiving an actual picture. If the line of separation between the white and black areas is sharp and clear it can be assumed similar sharp changes in the signal voltage during normal reception will be handled equally well.

On the other hand, if there is a blur where the white blends into the black a technician can be reasonably certain similar blurring will occur during normal picture reception. It is not our purpose at this time to explain what abnormalities in the TV circuitry cause such blurring, but we do call your attention to the manner in which the test pattern makes it possible for a technician to check them.

Since, as mentioned, TV broadcast stations do not transmit patterns for such long periods as they formerly did technicians resort to other methods for checking. Oddly enough, they are coming to depend more and more on commercial advertisements for that purpose.

Fortunately, advertising commercials tend to become more frequent, and more regular, simultaneously with the decline in test pattern transmissions.

Commercial advertisements tend to be repetitious and regular. Technicians become familiar with their appearance, and often select certain of them for testing purposes. Sometimes one commercial is selected for the purpose of check-

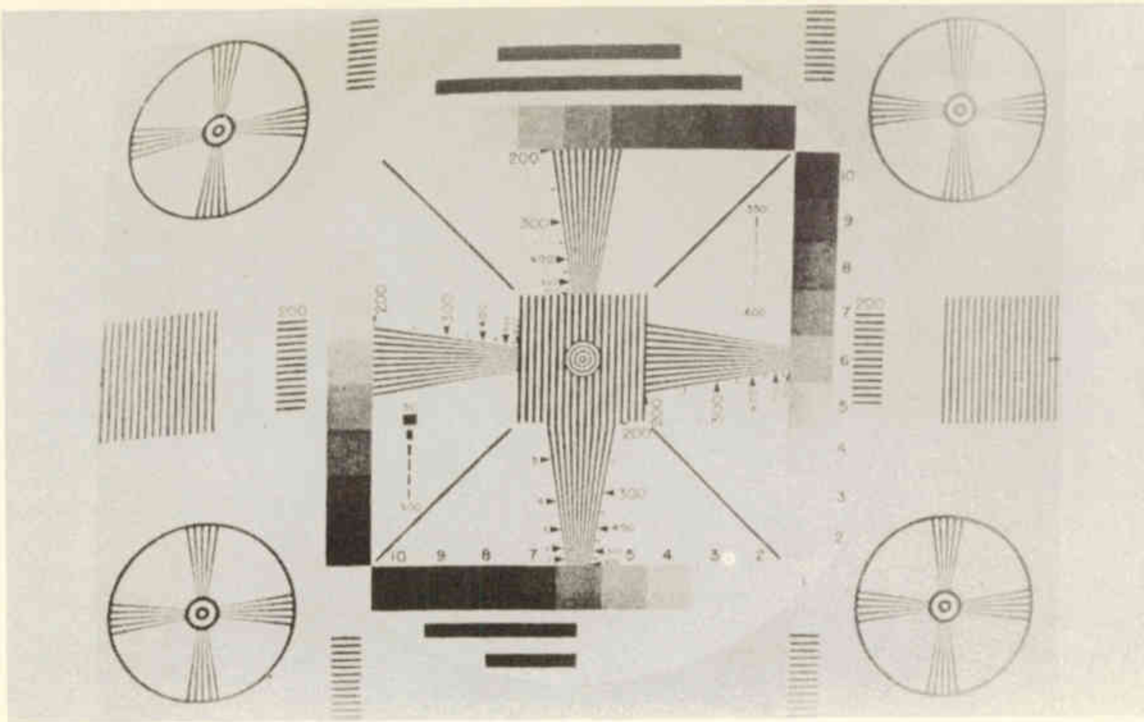

Figure 2. Test Pattern designed by RMA.

ing one type of picture condition, while others are selected for other purposes.

Section 5. CHECKING THE ASPECT RATIO

We have already explained how the aspect ratio of a picture can be checked by using a test pattern. When using the test pattern shown in Fig. 1, or one similar to it, the aspect ratio can be assumed to be good when either or both of the circles can be clearly seen to be true circles.

When using a test pattern similar to that in Fig. 2 the aspect ratio is checked in a slightly different manner. The RMA test pattern has a small circle in each of the four corners. When each of those circles is perfectly round, and each is the same distance from the nearest edges of the pattern, a technician knows the aspect ratio is correct.

Two of the circles in the test pattern in Fig. 2 are perfectly round, but one is deliberately distorted so it assumes the shape of an ellipse. The fourth circle is not perfectly round, but neither is it seriously distorted.

Were all four circles perfectly round it would mean the aspect ratio of the receiver is good. When distortion is present it means some of the receiver circuits are not perfectly adjusted. It is not our purpose to explain at this time the circuits involved, we are merely explaining how test patterns can be used for checking receiver conditions.

Where neither of these types of test patterns is available to a service technician it becomes necessary for him to depend more heavily on his ingenuity. We have already mentioned the CBS "eye" which is regularly flashed on the screens by CBS stations. Many technicians use that "eye" for testing purposes, and are able to do a good job of adjusting the aspect ratio by using it.

In other communities, where CBS stations cannot be received, it is necessary to use other

Figure 3. Circular Objects in a picture can be used to check the Aspect Ratio. (Courtesy Zenith.)

patterns for testing. The circular "DeSoto-Plymouth" commercial on one of the TV shows has been a favorite for several years among technicians for testing purposes. One drawback to that is the fact the show appears only once a week, and the pattern is on the screen for only a short period of time.

The circular "Lucky Strike" emblem is probably used by more technicians for testing purposes than any other single commercial. One advantage is the regularity with which it appears on so many stations. There are few localities where the Lucky Strike circle cannot be seen one or more times each day on one or more stations.

Almost any commercial which employs a large circle can be used for testing the aspect ratio of the television picture. If the circle is reproduced on the screen in the form of a true circle the circuits can be assumed to be properly adjusted. If they are egg-shaped something is out of adjustment.

Other commercials which can be used for checking the aspect ratio include some of those featuring automatic washing machines. Some such machines have a large circular window in the front. The appearance of the circular window is used by skilled TV technicians to check the adjustment of TV receiver circuits.

Circular patterns of various kinds can usually be counted upon to appear more regularly in commercials than in the programs. But that is not always true.

In "Super Circus" it is a regular custom for one or more large drums to be shown. Quite often they are in the orchestra or band, but other times they are props for the clowns as in Fig. 3. The circular drums can be used to check the aspect ratio.

In other regular programs it frequently happens that some circular object is a regular part of the show. Some panel shows feature a circular pattern as a background for the sponsor's commercial.

Section 6. GENERATING A SAW-TOOTH WAVE-FORM

In earlier lessons we explained how a saw-tooth voltage is often generated. At this time we will not review all the information in those lessons, but a brief refresher seems well worthwhile.

Saw-tooth voltages play an important part in television. They are responsible for the forces which move the electron beam across the screen of the picture tube so the beam touches all parts of the screen surface.

In most cases a saw-tooth wave-form is generated by slowly charging a capacitor, then suddenly discharging it. Or, by suddenly charging a capacitor, then slowly discharging it.

An elementary type of saw-tooth oscillator is shown in diagrammatic form in Fig. 4. It is, as you undoubtedly recognize it to be, a multivibrator.

One tube conducts while the other is cut off. Then conditions reverse, so the second tube conducts while the first is cut off.

But due to the varied values of the capacitors

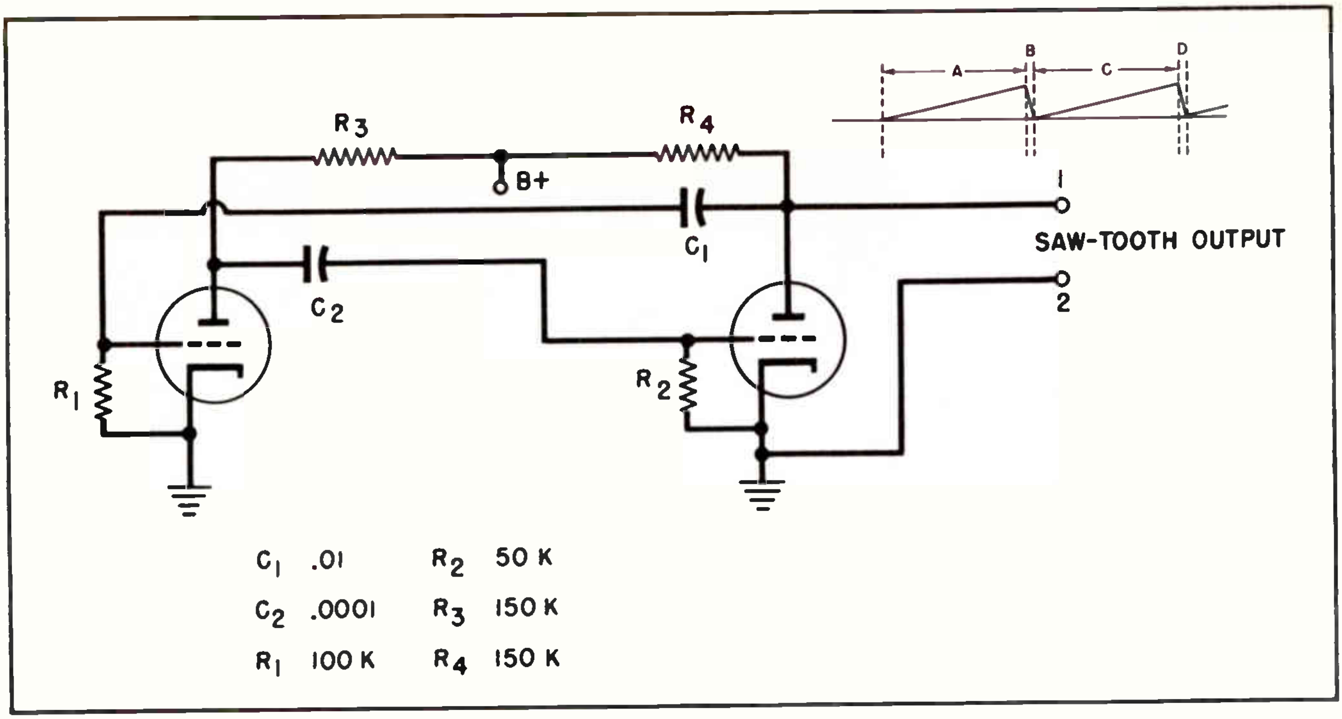

Figure 4. Multivibrator Oscillator used to generate Saw-Tooth wave-form.

and resistors in the separate grid circuits, the two tubes do not conduct for equal lengths of time. One conducts several times as long as the other.

Capacitor C_1 is charged by the action of anode current of the second tube. It is discharged through resistor R_1.

Capacitor C_2 is charged by the action of the current in the anode circuit of the first tube. It is discharged through resistor R_2.

The time-constant of C_1 and R_1 is longer than that of C_2 and R_2. This results from the fact the capacity of C_1 is greater than that of C_2, whereas the resistance of R_1 is greater than R_2.

The output voltage from the multivibrator is tapped off at the right. It has a saw-tooth wave-form, as indicated at the upper right of the illustration.

The voltage in a saw-tooth wave-form, such as that shown in Fig. 4, rises at a relatively slow rate. That is the interval indicated by the letter A in the graph wave-form. But it falls quite rapidly. That is shown by the intervals B and D.

In short, the voltage rises slowly, then falls rapidly.

In this case, as in the case of all multivibrators and other relaxation oscillators, a capacitor is slowly charged, then rapidly discharged.

Section 7. LINEARITY OF SAW-TOOTH SWEEP VOLTAGE

The charging voltage as it is applied to a capacitor can be plotted against time in the form of a graph.

Fig. 5 is a diagram of a very simple electrical circuit which shows a charging voltage being applied to a capacitor. Below the diagram is a graph of the rising voltage.

When a charging voltage is applied to a capacitor in the manner shown in Fig. 5 the voltage across the capacitor rises in a non-linear manner. It rises in the form of a curve rather than in a straight line.

The voltage — and its graphic curve — tends to rise rather steeply at first. Then, as the inrushing current tends to build up an opposing voltage inside the capacitor, the voltage rises somewhat more slowly. As the voltage across the

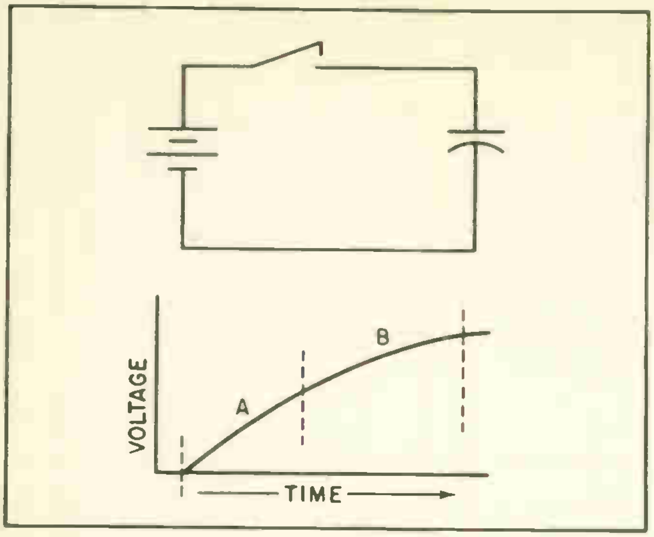

Figure 5. Graph of Charging Voltage applied to capacitor.

capacitor continues to rise, the rise becomes progressively slower.

If we direct our attention to the manner in which the voltage in the capacitor rises during the early part of its rise we find it increases at that time in a fairly linear (straight line) manner. To put this in other words we can say that despite the fact the over-all rise of the voltage in a capacitor is definitely not linear, the fact still remains that during the early period of the rise the voltage does rise in a linear manner.

This fact can be seen somewhat more clearly by studying the graph of the voltage rise in Fig. 5. That portion of the curve indicated by the letter *A* is almost straight — almost linear.

But the latter part of the graphic curve — that portion indicated by the letter *B* — is definitely a curve; it is non-linear.

Engineers who design saw-tooth oscillator circuits strive to use circuit components which will cause the circuit to utilize only that portion of the voltage where it rises in a linear manner. When properly designed, a saw-tooth oscillator circuit generates a wave-form of such nature that the voltage rises in a linear manner.

The more nearly successful the engineer is in these aims the more smoothly and evenly the electron beam is caused to move across the screen of a picture tube. If the beam moves too swiftly over the first part of the screen, and too slowly over the second part, the first part of the picture is stretched unduly while the second part is compressed.

On the other hand, if the beam moves too slowly over the first part of the screen, and too swiftly over the second part, the picture is also distorted. In that case the first part of the picture is compressed while the second part is stretched.

Linearity of the scanning motions can be judged by observing the appearance of the test pattern on the screen of the picture tube. If a test pattern, similar to that shown in Fig. 1, is on the screen, the linearity is determined by studying the shape of the large circles.

If the circles are perfectly round the scanning circuits can be considered to be properly adjusted. On the other hand, if the circles are oval-shaped, or egg-shaped, it is equally evident the scanning circuits need adjustment.

If it is not possible to study a test pattern, such as those illustrated in Figs. 1 and 2, the linearity of the scanning circuits must be determined in another manner. One of the commercial patterns we have already mentioned should then be studied, if one is available.

If none of the circular patterns we have mentioned can be picked up in any of the programs available to you it will be necessary to work out something else. The important thing is to study some type of circular pattern as it is picked up by the receiver from a transmitter.

In this connection you must be careful not to fool yourself. Be absolutely certain the "circular pattern" you are observing is truly circular. Usually you can determine this from the nature of the broadcast, and the content of the picture.

It is not difficult to understand the results if you adjust your circuits so you pick up a pattern on the screen in the form of a circle which was originally broadcast in the form of an oval, or ellipse. By rounding out an ellipse into a circle you have created a circle in that particular instance, but all your other pictures will be distorted.

Bunching of the picture on the right side of the screen is one of the most common types of distortion. This is caused when the saw-tooth wave-form is non-linear.

The saw-tooth wave-form begins in the normal manner; the first part of each cycle is linear. But the upper part of the rising voltage tends to flatten out.

When the upper part of the voltage flattens out, and the saw-tooth voltage no longer rises linearly, the beam is not moved over the right side of the screen as swiftly as over the left side. The graph of a saw-tooth wave-form when such a condition is present is shown in Fig. 6. Note the distortion between *A* and *B*, and again between *C* and *D*, and also between *E* and *F*.

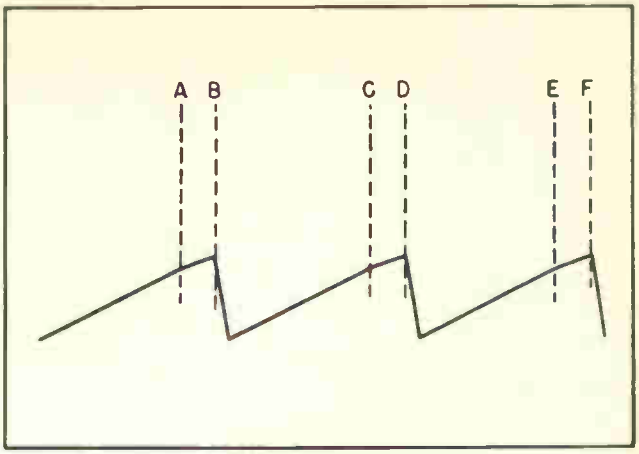

Figure 6. Distortion of a Saw-Tooth wave-form.

The non-linearity in the voltage wave-form in Fig. 6 is caused by permitting the capacitor to charge beyond the point at which its charging rate becomes non-linear. The voltage is permitted to rise into the non-linear portion of the changing curve.

One cause of a condition of that kind would be a capacitor of the wrong size. If anything should cause the capacitor used in that particular circuit to lose part of its capacity it would create the condition described.

Another cause would be a resistor which has changed value. Loss of resistance would permit the capacitor to reach a full charge more quickly, thus reaching the non-linear portion of the charging curve more quickly.

Linearity of the scanning circuits can also be checked by studying the inner concentric circles in the test pattern, or by observing the condition of the wedges in the pattern.

The two vertical wedges are the same length. If one is longer than the other it is a sign the scanning in that direction does not follow a linear pattern. Thus, if the top wedge is longer than the lower one it is a sign the pattern is either stretched at the top, or compressed at the bottom.

The same is true of the horizontal wedges. If the one at the right is longer or shorter than the one at the left it indicates the horizontal scanning circuit is not linear.

It is difficult to name all the types of picture patterns which can be used for checking purposes. Experience is the only true guide. But in the long run it is largely a matter of good judgment.

The picture content in Fig. 7 is a fair example of what a TV technician looks for when checking the linearity of scanning circuits. In the background of the picture are the square tiles on the bathroom wall. Common sense tells us those tiles are square; at least they are regular.

Should there be any lack of regularity in their size from one side of the picture to the other, or should there be any discrepancy in their size from top to bottom, it would indicate lack of linearity in the scanning circuits. An experienced technician would then know what to do to correct the condition.

Keep in mind that we are merely pointing out the manner in which the appearance of the picture conveys technical information to the mind of a skilled technician. At this time we are not discussing the technicalities of the circuits involved. We do not expect you to understand those circuits until they are explained to you. That comes later.

Section 8. BRIGHTNESS

Most people who have ever used a television receiver are familiar with the "Brightness Control" and with the "Contrast Control." Usually those controls are positioned on the front panel of the television receiver, but occasionally one or both are on the back panel.

Figure 7. The regular pattern of the square tile can be used to check Scanning Linearity.

We have no intention of going into a technical discussion of how those two controls perform their functions. At least, not at this time. We will go into the details of the circuits associated with them later in the course.

The important point at this time is that you are probably familiar, at least to some extent, with the term "brightness" as it applies to television receivers. In a sense the term can be associated with the ability of a receiver to reproduce *whiteness* in a picture. The greater the degree of brightness in a picture the whiter the white elements can be made.

On the other hand, it is not desirable to have too much brightness. If the brightness level is too high the white elements are over-accentuated, while the elements which should be black are actually gray. Furthermore, the varying shades of gray picture elements are lighter than they should be.

It is usually desirable to fix the normal *brightness* level so there is a full range of contrasts from deep black to pure white. The correct shades can be reproduced only when brightness control is correctly adjusted.

The test pattern in Figs. 1 and 2 provide a good guide for adjusting the brightness control. The concentric circles at the center of the pattern in Fig. 1 provide a means for gaging the brightness. The outer circle is pure white; the inner one is solid black. The correct adjustment is obtained when there is a definite contrast between the inner black circle and the adjacent one which is a lighter shade of gray.

There should also be a definite contrast between the outer white ring and the next inner one. The circle immediately inside the white one should have a definite shade of gray, although a lighter shade than those further inside.

There should be a definite, though regular, gradation from white at the outer ring, through various shades of gray of the three inner rings, to solid black at the center. When the brightness control is properly adjusted that condition is obtained.

Section 9. CONTRAST

While the *brightness* control acts to provide a general level of brightness for all shadings of the picture elements, the *contrast* control accentuates the degree of difference between the various shadings of black and gray. Actually, the contrast control acts to regulate the degree to which the video signal is amplified.

The brightness control and contrast control must usually be adjusted at the same time. Whenever one is adjusted it is usually necessary to make a slight adjustment on the other to maintain the proper condition of picture reception.

The contrast between the various levels of light intensity among the picture elements can be judged by observing the appearance of the concentric rings at the center of the test pattern. Unless the contrast control is properly adjusted the black in the picture will not be so intense as it should be; or will be too black.

In a sense, the brightness control can be thought of as controlling the degree of whiteness in a picture, while the contrast control acts upon the blacks. That manner of describing the action tends to over-simplify the situation to some degree, but it is not far from being correct.

Where test patterns are not available it is necessary for the technician to check picture content in other ways. Experienced technicians usually have pet ways of their own for adjusting the brightness and contrast control. Each usually has some pet program which he feels is best suited for making that adjustment.

The individual taste of the customer must also be given some consideration. Most technicians try to set the controls to suit the taste of the customer, rather than trying to adjust the controls to their own individual tastes.

In any event, the controls should always be adjusted so the range of shades on the screen will cover the full sweep from full white to full black. When that is done the adjustments are usually such as to satisfy most persons. If a test pattern is available it makes the job of adjusting those two controls somewhat easier; but they can always be adjusted to a reasonable degree of satisfaction regardless of whether such a pattern is available or not.

Section 10. FOCUSING

Anyone who has ever focused the lens on a camera or binoculars, or adjusted a pair of eyeglasses, knows what is meant by focusing. The matter of focusing the electron beam in a picture tube is not materially different.

The electron beam in a picture tube is focused by adjusting the controls so the individual electrons in the beam strike the fluorescent screen within the smallest possible area. When properly focused the beam forms a very tiny dot on the screen where it strikes.

It is usually desirable to focus the electron beam as sharply as possible. It is just as desirable to sharpen the focus of the beam in a TV picture tube as it is to sharpen a pencil to its smallest point when making a drawing.

The sharper the point on the pencil the easier it is to show fine details in a drawing. For the same reason, the sharper the focus of the electron beam in a picture tube the easier it is for the tube to reproduce fine details in the picture.

Another comparison can be made between the appearance of a picture on a TV picture tube and a photograph taken with a camera. If a camera is not properly focused the picture is blurred, and the fine details are missing. In a similar manner, lack of proper focusing in a picture tube causes blurring and loss of detail.

Fig. 8 shows how proper and improper focusing affects the quality of the picture. In the upper part of the illustration, in part *A*, all the electrons in the beam are so focused they strike the screen at the same point. By thus concentrating them it is possible to make that one spot much more sharp and distinct.

In the lower part of the illustration, in part *B*, the electron beam is not so sharply focused. The electrons are permitted to strike a larger area than *A*. If the condition is sufficiently serious there is certain to be some overlapping between adjacent lines. Change of light intensity, as the beam moves in a horizontal direction, is not so sudden or sharp as when the beam is more sharply focused.

The result of permitting a condition like that shown at *B* in Fig. 8 is for the picture to be blurred and lacking in detail. The appearance of the picture is not so pleasant as when the details are sharp and clear.

Most test patterns are specifically designed to provide quick and easy checking of the condition of the focus. The wedges in Figs. 1 and 2 are useful for this purpose.

The wedges in both test patterns are composed of a group of converging lines. The vertical wedges are wider at the outer ends, narrowing toward the center of the pattern. The horizontal wedges are also wider at the extreme outer ends, and also narrow toward the center of the pattern.

If the focus of the electron beam is poor the lines of the wedges tend to blur together where the lines are close together. Even when the inner ends of the wedges are blurred so badly the lines are indistinguishable from each other it is usually possible to distinguish the lines at the outer ends where they are farther apart.

The sharper the focus of the beam the more length of the lines in the wedges can be distinguished. If the focus is excellent, and the other adjustments on the receiver are good, it is possible to distinguish all the lines for their entire length.

In the matter of focusing another problem is often present. That is the one of obtaining good

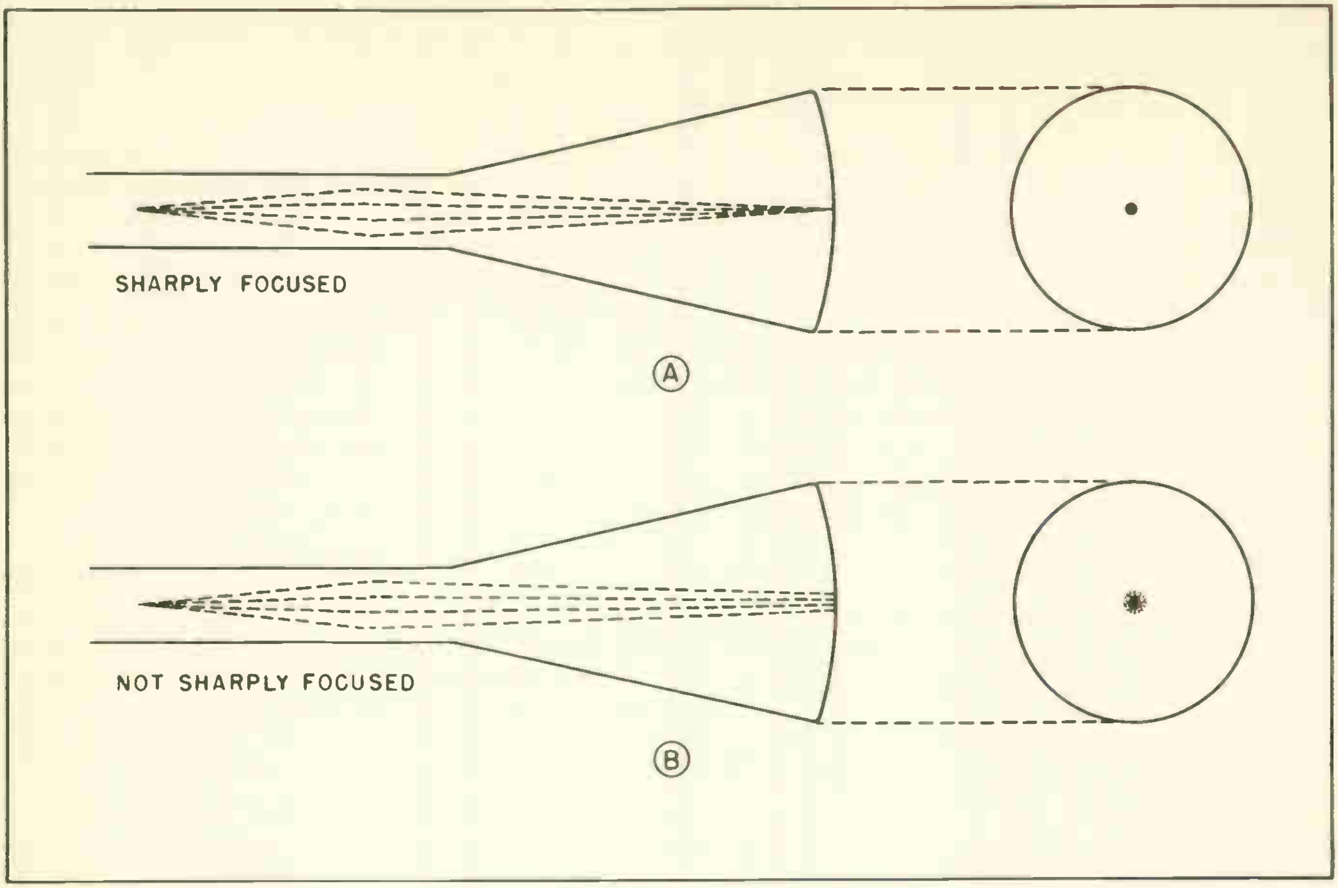

Figure 8. Effect of Focusing.

focus over the entire area of the picture tube screen.

Because of the many factors involved it often happens that the beam is focused sharply on one part of the screen, but less sharply on other parts. In many tubes the electrons in the beam travel farther to reach the outer edges of the screen than to reach the center of it. If the focusing adjustment is such that the focus is sharp at the center it may be somewhat less sharp at the outer edges.

If it is difficult, or impossible, to obtain sharp focus over all areas of the screen it is usually desirable to have the focus sharp at the center while permitting the outer edges to be slightly out of focus.

Much research has gone into the physical construction of picture tubes during recent years. The contour of the screen in many picture tubes is now such that the beam can be focused on all parts of it. Nevertheless, that is a problem which can exist, and it is well for the service technicians to be aware of it.

Section 11. PICTURE RESOLUTION

Picture *resolution* is a technical term which refers to the detail which is present in a picture. Since abundance of detail in a picture creates a better picture it is possible to say that the greater the detail the better the resolution.

Resolution in a TV picture is measured in terms of lines. The more lines, the better the resolution.

The use of lines for the purpose of measuring resolution must not be confused with the number of horizontal sweep lines used in TV transmission. This is different.

In using lines to measure picture resolution we merely use them for purposes of determining the number of picture elements which are present in either a vertical or horizontal direction. If the horizontal resolution is good enough to reproduce 200 vertical parallel lines we can then describe the horizontal resolution as being equal to 200 lines.

The same terms can be used to describe the vertical resolution. If the vertical resolution is good enough to reproduce 150 parallel horizontal lines we can then describe the vertical resolution as being 150 lines.

If the horizontal resolution can be described as 250 lines it means the video circuits are more carefully adjusted, and the general quality of video amplification is better, than when the resolution is 200 lines. Following the same reasoning, vertical resolution of 175 lines or 200 lines is better than 150 lines.

When we speak of 150 lines we mean 75 white lines and 75 black ones. By 200 lines we mean 100 white lines and 100 black ones.

One interesting aspect of this matter of determining picture resolution by reference to the number of lines which can be reproduced is that of comparing vertical resolution with horizontal resolution. This is not a particularly important matter for a service technician, yet it is an interesting bit of information.

Assuming the vertical resolution to be good, say on the order of 300 lines, it naturally follows that in a given inch of screen area a given number of lines could be distinguished. If the horizontal resolution is comparable to that of the vertical it would seem to mean that in a given square inch of screen area so many vertical lines could be distinguished, and so many horizontal lines.

In that case it would be natural to be able to distinguish the same number of lines in both the vertical and the horizontal planes.

And such would, indeed, be true.

If the area is enlarged the same conditions would hold true. The number of lines distinguishable in a horizontal plane would be the same as could be distinguishable in a vertical plane. That should not be surprising.

Now suppose we enlarge the area until the height of the square is equal to the height of the raster. Would the same reasoning hold true?

The answer is yes.

However, we would still have some horizontal surface area unaccounted for. One-fourth of the surface area, in fact.

Actually, the number of lines which figure in the calculation of the vertical resolution is what governs.

To explain — if 150 distinguishable lines give us a vertical resolution of 150 lines it will take 4/3 times that many actual lines to give us a horizontal resolution equal to 150 lines.

This may seem a little confusing, but it is the way picture resolution is figured. Fortunately, it is not a matter of great concern to most service technicians, despite the fact most of them find use for the information.

Section 12. MEASURING VERTICAL RESOLUTION

It may come as some surprise to you to learn that a test pattern similar to that in Fig. 1 makes it possible for you to determine the vertical resolution of a television receiver without using any other equipment. Not only measure the vertical resolution, but do so with surprising accuracy.

The surprise will be all the greater if you are already familiar with such a test pattern through seeing it broadcast by your local TV station, and never before realized the technical information it was capable of conveying.

The lines in the horizontal wedges in the test pattern measure the vertical resolution. By studying them carefully — and by knowing what to study — you can readily measure the vertical resolution of any TV receiver.

In plain words, by using the test pattern as a guide you can measure the quality of reproduction on the screen of any TV receiver, and do so without any equipment other than the test pattern alone. The lines in the horizontal wedges are also a good guide to the adequacy of interlacing. If the interlacing is not occurring properly and regularly the appearance of the horizontal lines in the wedge will show it up.

The distance between the lines in the wedges is greatest at the larger ends. That is the outer ends of the wedges.

If the individual lines are clearly distinguishable at the outer ends — close to the large black circle — the picture has a vertical resolution of 150 lines.

The lines of the wedges come closer together near the center of the pattern. This means that ability to distinguish individual lines in the wedge at points nearer the center of the screen points to a higher picture quality — a resolution of more lines.

If you examine one of those NBC test patterns quite closely it will be possible to see tiny white dots alongside the outer edges of the wedges. The dots do not always show up plainly on the test pattern, nor are they always clearly visible on photographs of the patterns. But the position of the dots is indicated in the drawing in Fig. 9.

About halfway between the inside of the large black circle and the outer edge of the smaller white circle near the center of the test pattern is a small white dot. The dot can be seen if Fig. 1 is studied carefully.

If the individual lines in the wedges can be distinguished at a point opposite that dot the receiver has a vertical resolution of 200 lines.

About halfway between that dot and the outer edge of the white ring is another dot. If the lines in the horizontal wedge can be distinguished at a point opposite that dot the picture has a vertical resolution of 250 lines.

If the lines in the wedge can be seen at the point where the wedge pierces the white ring the picture has a vertical resolution of 300 lines. And if the lines can be distinguished at the inner edge of the white ring the picture has a vertical resolution of 325 lines.

Section 13. CALCULATING VERTICAL RESOLUTION

It must be kept clearly in mind that test patterns cannot be conveniently viewed in all parts of the country, therefore are not always available to technicians for checking purposes. When that is true it is usually necessary to resort to other means to check resolution. Often the only way is to use a test instrument which has been specially designed for that purpose.

But while we are discussing test patterns we will describe some of the other types of information which can be derived from them through careful study.

You may be willing to accept our statement that you can check the vertical resolution by following the procedure we have described here. On the other hand, if you have a sufficiently inquisitive mind you will probably want to know how the test pattern is capable of providing that type of information.

A key to the reasoning behind the use of the test pattern can be obtained by studying Fig. 10.

If you care to count the lines in the wedge shown in Fig. 10 you will find there are 31 of them. There are 16 black lines and 15 white ones.

For purposes of example suppose you have a condition where the resolution is such that you can distinguish, or resolve, the individual lines at the extreme outer ends of the wedge, at the point where the wedge is widest. To emphasize this point, suppose the resolution is such that you can just distinguish the individual lines at that point, but at no other point closer to the smaller end.

In a case of that kind the resolution would be such that you could distinguish those 31 lines from each other. That means that within that vertical area you would have a vertical resolution of 31 lines.

But the outer end of the wedge has a width equal to just one-fifth of the full height of the raster. Which means that an ability to distinguish the 31 individual lines at the end of the wedge would be equivalent to a vertical resolution of five times 31 lines, or 155 lines.

For practical purposes we would say the vertical resolution under those conditions would be 150 lines.

As the wedge approaches the smaller end — which is the center of the test pattern — it becomes narrower. More lines are crowded within a given vertical distance. Or, to be more exact,

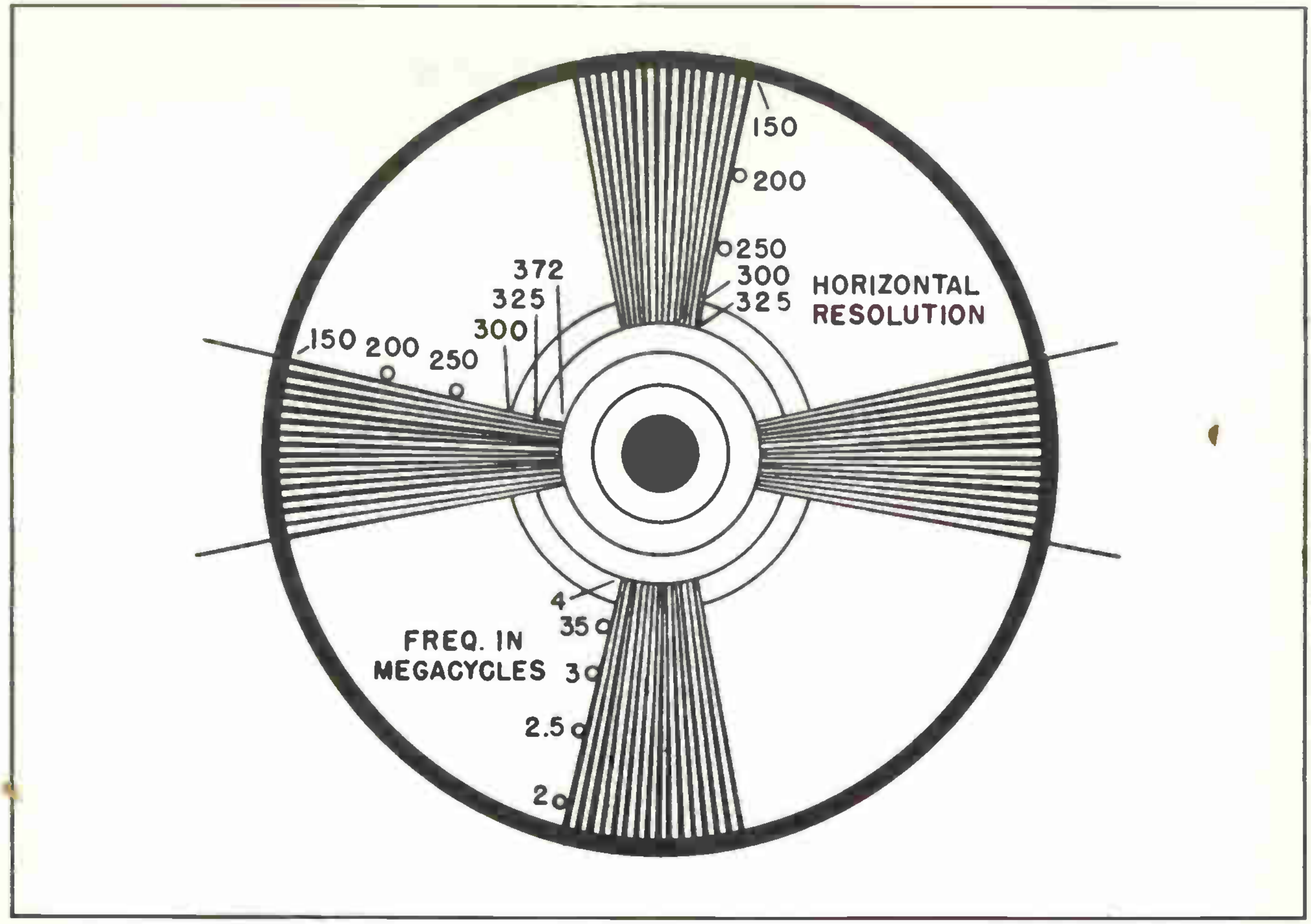

Figure 9. How Vertical and Horizontal Resolution in terms of lines can be determined. Horizontal Resolution in terms of Video Frequency in megacycles can also be approximated.

the *same number of lines are compressed into less vertical distance.*

To be able to distinguish the individual lines where they are packed closer together requires better vertical resolution.

At a point about halfway between the large end of the wedge in Fig. 10 and the outer one of the several concentric rings at the other end the wedge is narrower. If it were measured and compared with the total height of the raster it would be found to be approximately 1/6.45 of the height of the raster.

To be able to distinguish the individual lines of the wedge at that point the vertical resolution would have to be 6.45 times 31 lines, or approximately 200 lines.

All of which should give you a pretty good idea of how vertical resolution can be checked by observing test patterns prepared for that purpose.

In those localities where TV stations do not transmit test patterns for sufficient periods, or do not transmit them at all, it is necessary to substitute the other means of testing. Fortunately, the newer models of television receivers are vastly improved over the earlier ones. Methods of adjusting the focus and the tuned circuits are much better.

Since vertical resolution is largely a matter of securing the proper sharpness of focus most technicians are able to make such adjustments by observing normal picture patterns on the screen. If a "live" broadcast can be tuned in on the receiver the matter of adjusting the focus is usually a relatively simple matter.

This is especially true if the TV signal is reasonably strong so as to provide sufficient contrast to bring in a good picture. In fringe areas, or where the signal is weak, such adjustments are not so easy to make.

If a "live" broadcast can be picked up from a station whose signal is sufficiently strong to provide good contrast the vertical resolution can be checked by observing the content of the picture. The focus control should be adjusted until the smallest amount of vertical detail can be distinguished in the picture.

In remote fringe areas where all signals are weak it may be necessary to resort to special types of test signal generators to make the proper adjustments.

Section 14. MEASURING HORIZONTAL RESOLUTION

The most convenient way to measure horizontal resolution in a television receiver is to observe the appearance of the vertical lines in the vertical wedges of a test pattern. It must be kept in mind that the quality of the horizontal resolution is a function of the frequency response of the video amplifiers.

All of which means that the vertical wedges provide a good check on both the horizontal resolution and the frequency response of the tuned circuits in the receiver.

The important check points to observe in a test pattern are indicated in Fig. 9. The location of the dots along the outer edges of the wedges indicate the check points. They correspond to calculated points of interest.

In Fig. 9 the dots along the edge of the upper wedge are indicated in terms of lines of resolution. Those along the lower wedge are indicated in terms of frequency in megacycles.

In those localities where a test pattern is available for viewing on a receiver under test it is a very simple matter to check the frequency response of the tuned circuits, or the horizontal resolution. Noting the position at which the individual lines of the vertical wedges become indistinguishable provides a clue to the specific information wanted. The position should be checked with reference to the small dots adjacent to the wedges in the pattern.

When the individual lines of the upper wedge can be distinguished only at the extreme top, where they are far apart, the resolution is relatively poor. The resolution is down to approximately 150 lines.

If the individual lines of the wedge can be distinguished at a point opposite the upper dot at the side of the upper wedge the resolution is better. It is equivalent to 200 lines.

If the lines can be distinguished at a position opposite the lower dot alongside the upper wedge the horizontal resolution is still better. It is then 250 lines.

Ability to resolve the lines when they come still closer together can be checked at two additional points. One is where the wedge penetrates concentric circles near the center of the pattern; the other is at the extreme lower end of the wedge.

It must be kept in mind that horizontal resolution has nothing to do with the size of the screen. It is a matter of frequency response in the tuned circuits, and sharpness of the focusing.

The resolution can be just as good on a 10-inch screen as on a 30-inch screen. As a matter of fact the picture may be even better on the smaller tube, despite the fact the resolution is the same on both receivers. The reason is that poor horizontal resolution shows up more distinctly on the larger screen.

All of which is merely another way of saying that the resolution *must* be better on a large screen than on a small one if the picture is to be equally clear. Imperfections which may not be noticeable on a small screen become clearly evident on a large one.

The dots alongside the lower vertical wedge are used to measure frequency response.

It is understandable that only an ability to handle high video frequencies makes it possible to distinguish individual lines at the small end of the lower wedge. From which we can deduce the fact that when the lines of the wedge are clearly visible as distinct lines at the small end of the wedge the tuned circuits in the receiver are passing a wide band of video frequencies.

In this case, the fact the lines are clearly visible, and distinct from each other at the small end of the wedge indicates the tuned circuits are passing signals with frequencies up to 4 megacycles.

If the lines are clearly distinct opposite the upper dot alongside the lower wedge, but are fuzzy and indistinct above there, the tuned circuits are passing video frequencies up to 3.5 megacycles.

If the lines are fuzzy above a point opposite the next lower dot, but distinct below there, the tuned circuits are passing video frequencies up to 3 megacycles, but not handling those higher than that.

And so it goes. If the tuned circuits cannot handle video frequencies higher than 2 megacycles it is clearly indicated by the wedge. The lines become fuzzy above a position opposite the indicated dot shown in Fig. 8.

The same is true for frequencies around 2.5 megacycles.

Section 15. OTHER FAULTS DISCLOSED BY OBSERVATION OF THE SCREEN

It would be convenient for service technicians if it were always possible to tune in a test pattern on a television receiver, then proceed to adjust the circuits of the receiver for best reception. Servicing would then be a much simpler job than it actually is.

Unfortunately, test patterns are not so plentiful as they once were, and they are not available for many hours of the day. All of which means that a service technician must exercise his own ingenuity to arrange substitutes for them.

While we are on the subject of test patterns it is well that we mention something else which is rather closely related to them. That is the other types of technical information which can be obtained about the working condition of receiver circuits by observing the appearance of the pattern on the screen.

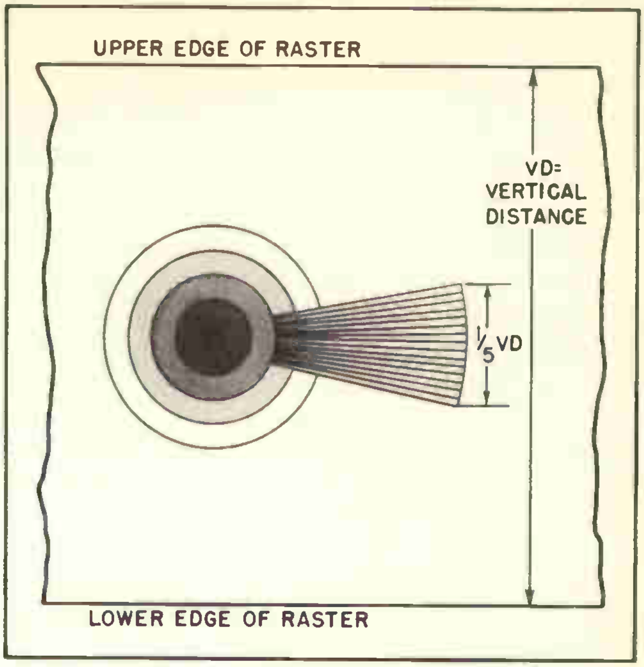

Figure 10. Key to use of Horizontal Wedge to check Vertical Resolution.

Fortunately it is not necessary to have a regular test pattern on the screen of a television receiver in order for the appearance of the screen to convey an enormous amount of information. A skilled technician can learn many things about conditions of receiver circuits merely by observing the pattern on the screen.

In many large service organizations service calls are accepted by girls at telephone desks. They are trained to ask certain questions of the customer, and to note that information on the service tag before it is given to the technician who makes the call.

If the girl who talks with the customer is skillful in the questions she asks she is often able to put enough information on the service tag so the service technician actually knows the trouble he will find before he even sees the TV receiver in the customer's home.

In another lesson we have illustrated how a bright horizontal line across the screen points to trouble in the vertical deflection circuits. If the serviceman knows the make and model number of the receiver he can look up the schematic diagram of that particular receiver and see what type of vertical deflection circuit is used. He will then take replacement parts for that deflection circuit with him when he calls at the customer's home. If it is a matter of changing a tube he can often complete the service call within a matter of minutes, then be on his way to another customer.

It is not too early to mention some other things you should always keep clearly in mind. That is the importance of getting as much information about the receiver you are to check as is possible, before you go to the customer's home to look at it.

Two items of information you must obtain as quickly as possible. These are the brand name of the receiver, and the model number.

Without that information available to him before he left the office the technician might have to make one trip to learn the cause of the trouble, then a trip back to the shop for the parts to make the repair.

If the customer reports a group of heavy diagonal lines across the face of the screen it points to another type of trouble. The skilled technician automatically associates that type of trouble with a defect in the horizontal deflection circuits.

In that case he makes the call prepared to repair the horizontal circuits, and thus does not have to make return calls to the shop for additional parts.

We mentioned at the beginning of this lesson that almost every defect in a television receiver betrays itself through some characteristic clue which appears in the pattern on the screen. Skilled technicians search for those clues, and by following them make their work much easier.

It is far too early to discuss those tell-tale clues at this time. They will be described in detail as you progress with your studies. The underlying troubles which cause them will be explained, together with the methods which are used to correct them.

With this information at hand you can obtain a technical manual covering that particular receiver, and thus be able to check the details of the circuits you suspect of being involved in the trouble. Without a technical manual covering that particular model you will be working largely in the dark.

Few skilled servicemen waste time working on television receivers without having access to a technical manual covering that specific model.

Technical manuals are available to franchised servicemen from the manufacturer. Servicemen who are not franchised to service a specific brand secure their technical manuals from one of the publishers who specialize in that kind of information. The two largest publishers of such technical information are Howard W. Sams, Indianapolis, and John F. Rider, New York.

The technical manuals published by these two companies are available at nearly all radio and television supply houses throughout the United States. Often it is possible to obtain information covering a specific model without purchasing a full volume of the technical information. Many servicemen purchase such technical manuals as they need them. And buy only such manuals as they do need.

While we are on this subject it is just as well we mention something else which may be useful to you. If you ever have occasion to write us for advice concerning a television receiver be very certain you include the brand and model number. Without that information we are often helpless to aid you; and are delayed in helping you until we can write you for the information. If you send that information when you first write it nearly always saves time.

If you can draw a sketch of the appearance of the pattern on the screen when you write it will also be a tremendous help. Often a single illustration of that kind tells us far more than several pages of written description in a letter. If necessary, draw several sketches. They all help.

The point you should never forget is that the appearance of the screen in a television receiver does more to point to the cause of trouble than almost anything else. Unless there are serious faults or serious breakdowns of components in the receiver, a study of the pattern on the screen often points to the source of trouble more accurately than a group of test instruments.

NOTES FOR REFERENCE

Appearance of the test pattern is a good guide to the condition of the circuits in a television receiver.

Aspect ratio of the pattern on a television screen can often be corrected by using a circular pattern in an advertisement broadcast by a TV station.

Both vertical and horizontal linearity can be checked by observing a circular pattern on the screen.

Frequency response of the tuned circuits in a television receiver can be checked by studying the appearance of the pattern on the screen.

When a calibrated test pattern is available for observation the frequency response of television tuned circuits can be checked with amazing accuracy without additional instruments.

Accuracy of the focusing adjustment is readily disclosed by studying the condition of the pattern on the screen.

Defects in the horizontal deflection system show up in the pattern on the screen.

Horizontal resolution can be readily measured by observing the condition of the vertical wedges in a calibrated test pattern.

Troubles in the vertical deflection system are disclosed by typical clues in the pattern on the screen.

An accurate description of television trouble often enables a technician to know the cause before he even sees the receiver.

Technical manuals covering the receiver being checked are an important part of television servicing.

When writing us for technical advice concerning a television receiver you should give us the brand name and model number, and include a sketch of the pattern on the screen. That gives us a tremendous amount of information.

NOTES

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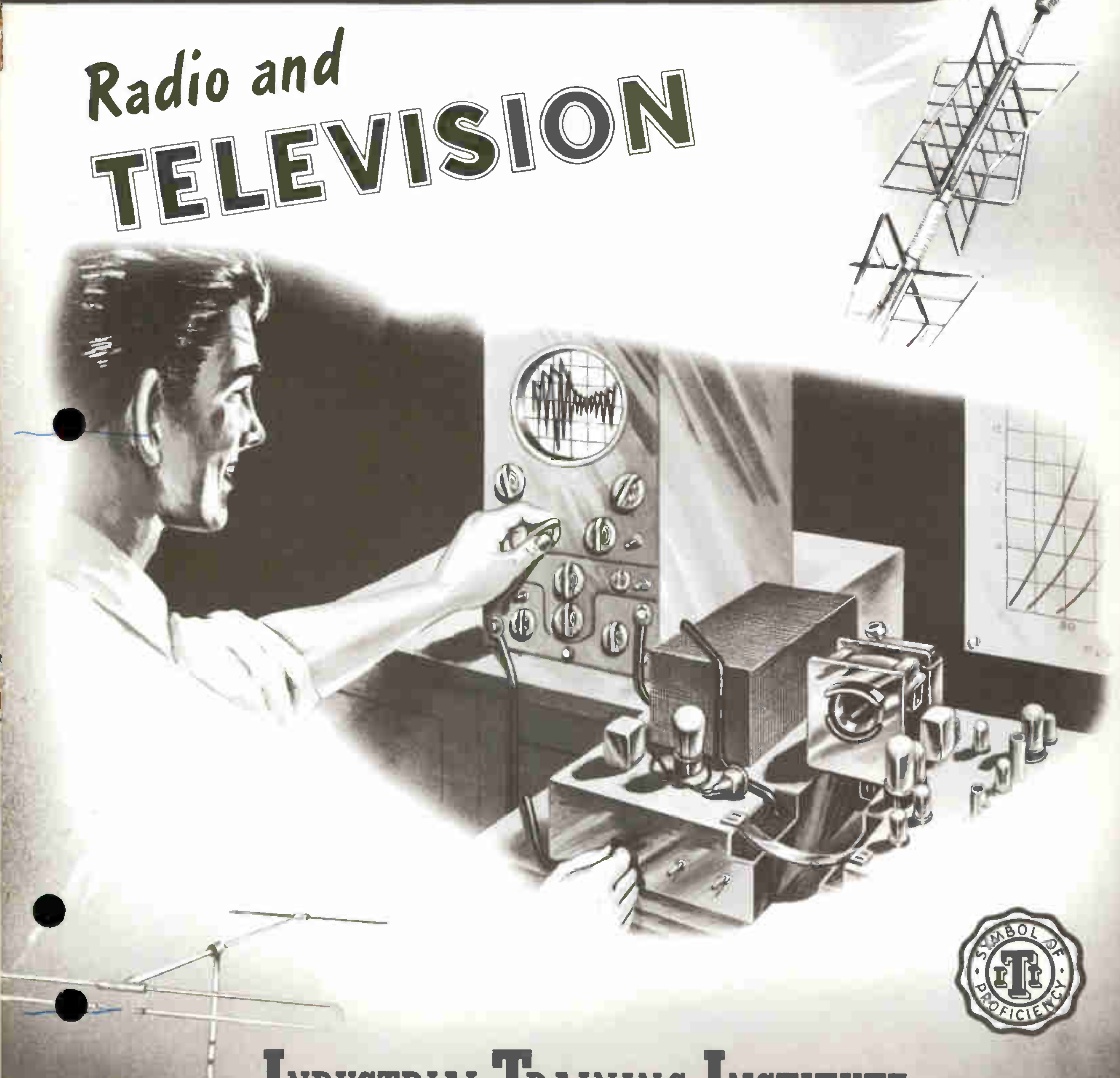

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INDUSTRIAL TRAINING INSTITUTE

RECEIVING THE TV SIGNAL

Contents: Relationship of Receiver Circuits to TV Signals — Separator Circuits — Deflection Circuits — Controlling Movement of the Beam — Image on the Picture Tube — Antenna Signal — Handling Antenna Signal in the Tuner — I-F Amplifier and Detector Action — TV Power Supplies — Care Handling Picture Tubes — Projection Picture Tubes — Notes for Reference.

Section 1. INTRODUCTION

We have discussed many circuits which are common to all types of electronic devices. Power supply circuits, for example, are all much the same despite the fact some are used in radios, others are used in industrial electronic equipment, and still others in television work.

Much the same is true of amplifier circuits. Those used in television work are not much different from those used in radio and other kinds of electronic devices except they are designed to handle higher frequencies, or wider bands of frequencies.

In addition to the circuits commonly used in all kinds of electronic equipment certain special types of circuits have been developed to receive the television signal. Some have not previously been used in other kinds of electronic equipment; others have been modified to receive the TV signal although in their basic form they have long been used in other electronic equipment.

It is our purpose at this time to examine the principal circuits used to receive the TV signal, and see just how they differ from those we have previously studied. Most of the circuits to which you are introduced in this lesson will be examined more closely in later lessons. Whole lessons will be devoted to each of the circuits to explain the part each plays in the reception of the TV signal.

If you feel some of these circuits are not entirely clear to you it is not an occasion for concern. They will be explained in greater detail later in the course.

We will try to point out how these circuits work together, and show their relationships to each other. By introducing them to you at this time, so you can become acquainted with them, it will be easier for you to understand them

Figure 1. Table model receiver with rectangular tube. (Courtesy Sentinel.)

when we later take up the study of each individually.

We have previously hinted that I-F circuits in a TV receiver are essentially the same as those found in radio receivers. Basically, that is true. But there are special characteristics about television I-F circuits which set them aside from those used in radio work. The matter of frequency is one such characteristic. The increasing tendency among TV manufacturers to handle both the video I-F signal and the sound I-F signal in the same I-F amplifying circuits is a matter worth close study. How that is done will be explained in detail later.

The video amplifier is another type of amplifying circuit deserving special consideration. A video amplifier is one which handles the video signal in a receiver after the I-F signal has been demodulated. It is the special wide-band amplifier used to amplify the composite video signal.

Video amplifiers do not occupy the important place in receiver design and construction they once did. There is a growing tendency to handle the video signal as little as possible after it passes through the detector stage. Nevertheless, it is a subject to which it is well worth paying close attention. This is especially true if you take up the study of color receivers.

Another type of circuit which plays an important part in television receivers, yet is not known in ordinary radio receivers is the synchronizing circuit. The "sync" circuits tie the receiver deflection circuits into tight synchronization with the sweep circuits in the transmitter. It is hard to over-estimate their importance.

The special sync separator circuit, which separates the synchronizing pulses from the camera signal in the composite video signal, is another television circuit not known in ordinary radio work.

Deflection circuits — which act to move the electron beam around to the various parts of the picture tube screen — are not necessarily peculiar to television work. They are found in oscilloscopes and radar equipment. But they are new to those whose electronic experience has been confined to radio receivers.

We will devote entire lessons to the details and actions of these special television circuits. Our purpose at this time is to introduce you to them, so you are aware of their existence. Then, when you later begin studying them in detail, you will be in better position to understand how they fit together, and work together, to make an operating television receiver.

Section 2. RELATIONSHIP OF RECEIVER CIRCUITS TO TV SIGNAL

When becoming first acquainted with the various circuits in a television receiver it is probably a good idea to examine the manner in which each is affected by the signals picked up by the antenna. Then by following the path of those signals, as they pass through the receiver circuits, it is easier to recognize the job each of the circuits plays in the proper functioning of the receiver.

The principal circuits found in one type of television receiver are laid out in block diagram form in Fig. 2. No attempt has been made to show the exact composition of any of those circuits, but the manner in which the signals pass through them becomes somewhat more clear. Their relationship to each other and to the TV signal, becomes a little more understandable.

In the television receiver outlined in Fig. 2 the video carrier signal and the sound carrier signal are both picked up by the antenna. It is interesting to note, and remember, that the sound carrier and the video carrier operate on different frequencies. Those carriers are separated from each other by 4.5 megacycles.

Both carrier signals — one amplitude modulated, the other frequency modulated — are amplified in the RF amplifier circuit, then converted to lower frequencies in the mixer circuits.

It will be noted that in most respects the action is very similar to that which occurs in the front end of an ordinary radio receiver. The principal difference is that the frequencies involved in a television receiver are much higher than those used in radio work.

One other difference is that the tuner section of a television receiver must be capable of hand-

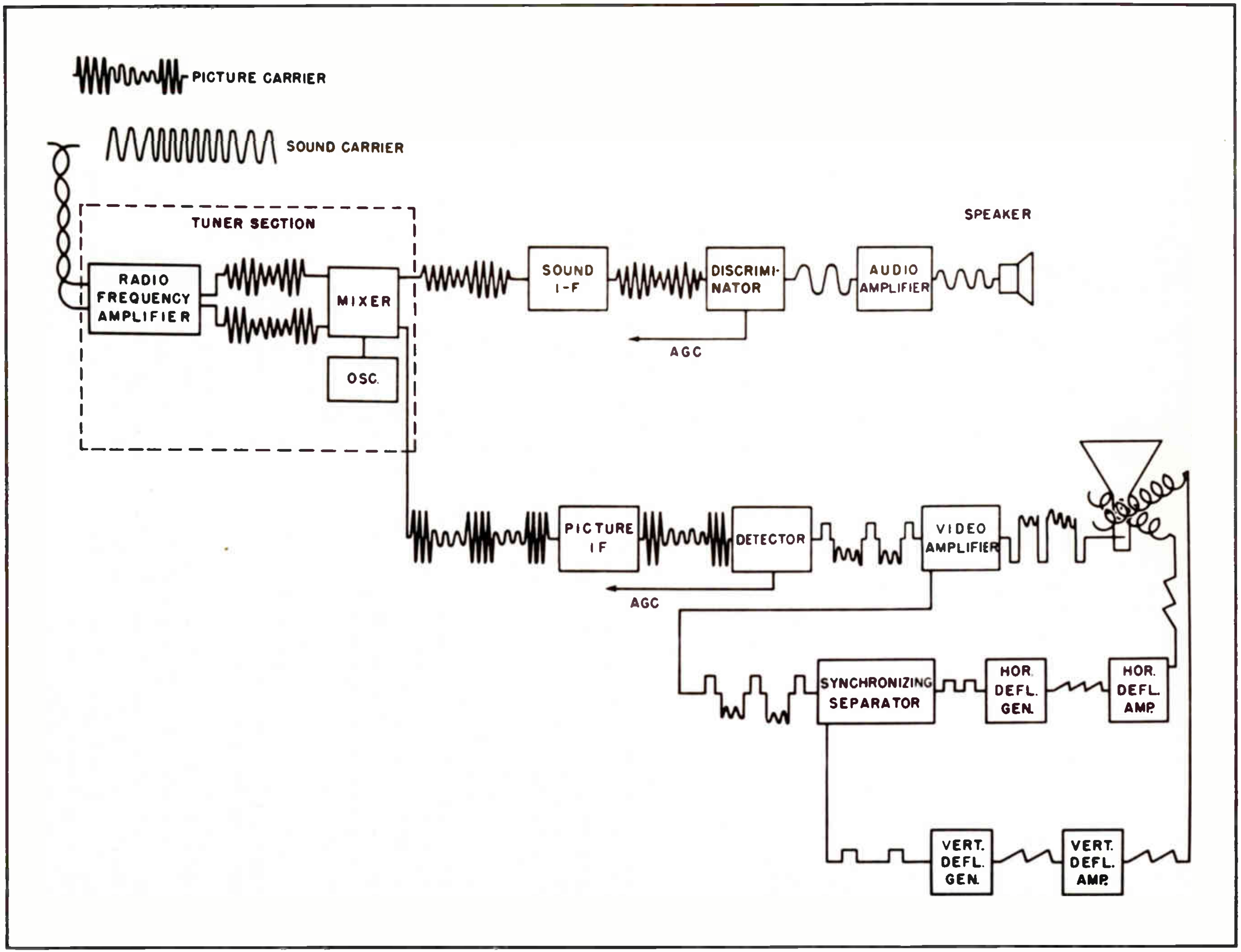

Figure 2. Block Diagram of TV receiver.

ling *two* carrier signals instead of one, as in the case of a radio receiver. The TV receiver *must* pick up both the sound carrier and the video carrier.

Following the mixer stage the sound I-F carrier is fed into a tuned circuit consisting of an I-F amplifier adjusted to the frequency of the I-F sound carrier. The sound I-F carrier is then amplified in much the same manner as that followed in any FM radio receiver.

The sound I-F carrier — being frequency modulated — is then fed to a discriminator circuit, or to a ratio detector circuit, where it is demodulated. Following demodulation, the audio signal is amplified in the normal manner, and finally fed into the loudspeaker.

In the meantime the video I-F carrier signal is fed into another tuned I-F amplifier circuit. That circuit is tuned to the frequency of the video I-F carrier, which is 4.5 megacycles *higher* than the sound I-F carrier.

The video I-F signal passes through three or four stages of I-F amplification. Then it is fed into a detector circuit. That detector circuit is not materially different from those found in most radio receivers, although it does have some special refinements which improve its use in video work.

The video I-F carrier signal is demodulated in the detector circuit, from whence the demodulated signal is fed into the video amplifier. The video amplifier is a special type of wide-band amplifier which is capable of handling the wide range of frequencies included within the composite video signal.

The video signal is then fed to the picture tube, where it is used to modulate the beam of electrons within the picture tube.

In the earlier days of television it was the universal practice to feed the video signal to the control grid of the picture tube. The more recent trend is to feed the video signal to the cathode of the picture tube, while the grid of the tube is tied directly to B minus or ground. More will be said about these practices as we go on.

The block layout of the television receiver circuit shown in Fig. 2 shows how the signals are handled when there are separate channels provided for the amplification of the video I-F signal. That is the practice followed almost universally during the early days of television. It is still followed to some extent in the more expensive types of television recievers.

A somewhat different method of handling the amplification of the I-F signals is shown in Fig. 3. The block diagram of the arrangement of the circuits shows the sound I-F signal and the video I-F signal both being amplified by the same I-F amplifier circuit, and passing through the same detector circuit.

The arrangement of the amplifier circuits shown in Fig. 3 is known as "intercarrier" amplification. The method of amplification is rather ingenious, and will be explained in careful detail in a later lesson. Briefly, however, the I-F circuits are so designed that they pass both the sound I-F and the video I-F signals, despite the fact the two I-F carriers are separated by 4.5 megacycles. This is accomplished by making the frequency response of the I-F circuits somewhat broader than that formerly used.

At the detector the video signal is fed to the video amplifier in the normal manner. A trap circuit is then arranged to prevent any of the 4.5-mc difference signal getting into the video amplifier circuits.

That 4.5-mc signal represents the difference between the two carriers, and results from a mixing of the two I-F carriers in the I-F amplifying circuits.

The 4.5 megacyle difference signal carries both amplitude modulation and frequency modulation — amplitude for the video signal, frequency modulation for the sound.

The special trap circuit prevents the 4.5-megacycle signal reaching the video amplifier circuits, but permits it to reach the sound discriminator, or ratio detector. The sound discriminator circuit is not sensitive to amplitude modulations, but is sensitive to frequency modulations. Since the sound signal is carried in the form of frequency modulations the frequency discriminator acts to demodulate the sound, then pass it on to an audio amplifier. From there it reaches the loudspeaker.

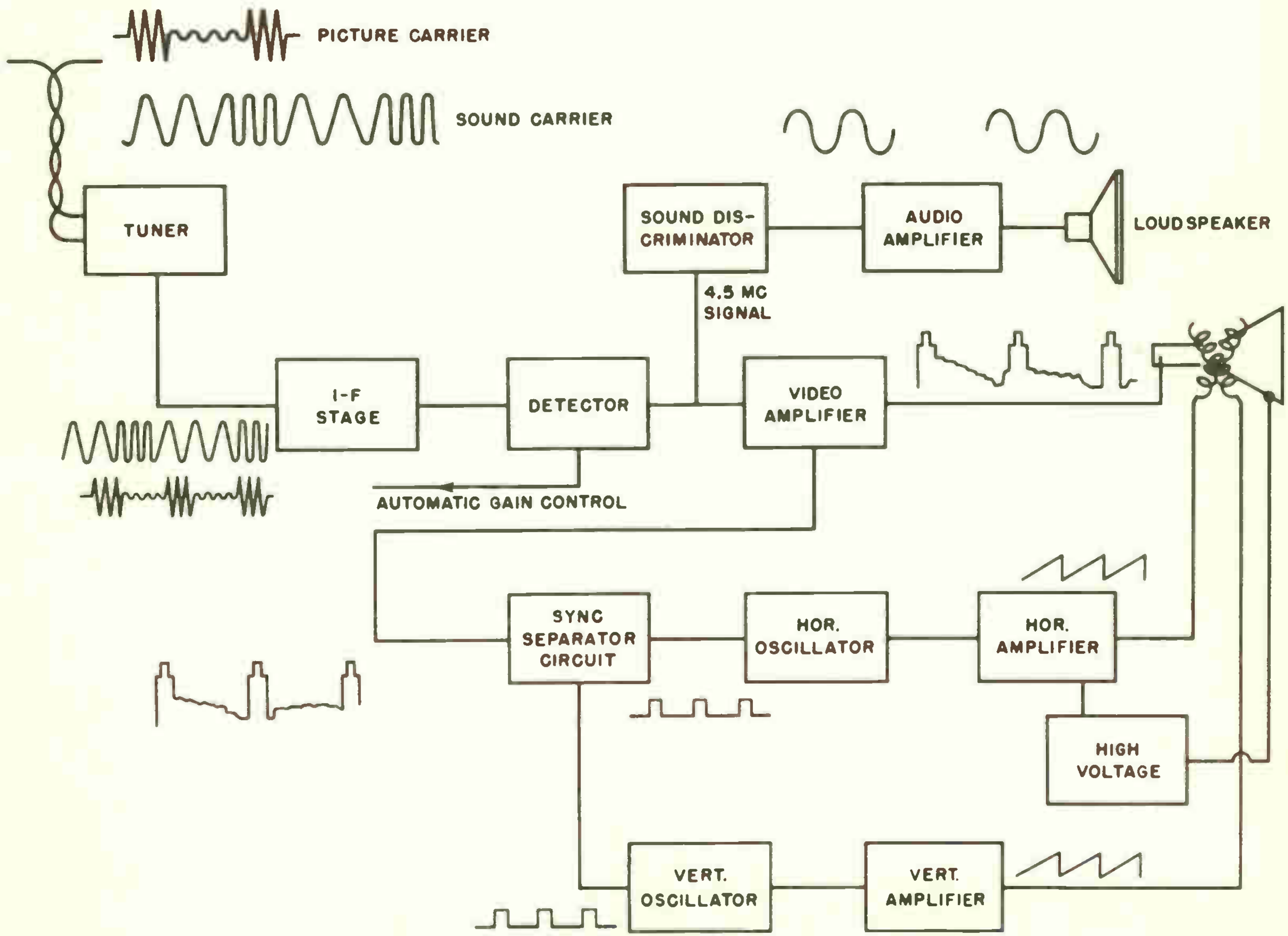

Figure 3. Block Diagram of TV receiver with Inter-carrier Amplification of I-F Signals.

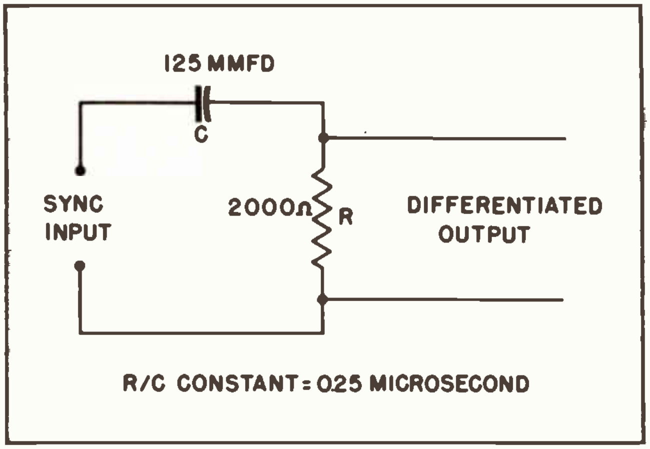

Figure 4. Differentiating Circuit used to separate Horizontal Sync pulses from Composite Video Signal.

Intercarrier I-F amplifying circuits have come into wide use. When they were first introduced they were restricted to the less expensive receivers, but as the circuits became more refined and improved they have come into greater use in all kinds of television receivers.

One big advantage of intercarrier amplification is that first cost of construction is materially lower. Fewer tubes are needed in the receiver circuits. It is easier to keep the circuits in alignment, and they require less service.

These circuits, and the way they handle the TV signal, will be explained in much greater detail at the proper time.

Section 3. SEPARATOR CIRCUITS

Here is a type of circuit which is important to the proper operation of a television receiver, yet has no counterpart in a radio receiver. These circuits separate the synchronizing pulses from the composite video signal, then feed those pulses into the proper paths which take them where they are needed.

There are two types of synchronizing pulses. Or, to be more exact, there are differing types of sync pulses which perform differing services.

One type of sync pulse keeps the electron beam moving horizontally in synchronism with the beam in the camera at the transmitter. The other keeps the beam moving vertically at the correct instants of time. The first is referred to as the horizontal sync pulses, and the latter as the vertical sync pulses.

Horizontal sync pulses are separated from the composite video signal by a special type of circuit which is sensitive only to short, sharp pulses. It goes by the rather appalling name of *differentiating circuit.*

The general idea of a differentiating circuit is shown in Fig. 4. The essential requirements are that it should respond to a short, sharp pulse, but not be additionally affected if a longer signal pulse tries to get through. In this case a small-value capacitor is connected between the input of the circuit and the output. The capacitor has only 125 mmfd of capacity.

Connected across the line, and behind the capacitor, is a resistor which has a relatively low value of resistance. In the case illustrated it has only 2000 ohms of resistance.

When a voltage pulse strikes the circuit from the left, or input side, it immediately charges the capacitor, thus sending a voltage pulse through the capacitor to the output circuit at the right. The capacitor is almost instantly discharged by the presence of the low-value resistance across the line behind it.

In action the circuit responds to a short, sharp pulse. The sharply rising voltage of a longer pulse will also cause a short pulse to appear at the output of the circuit, but due to the discharging action of the resistor the pulse will not be nearly so long at the output as at the input.

If the pulse entering the input of the differentiating circuit is relatively long it will normally produce two pulses at the output of the circuit. One short, sharp pulse will appear at the output coincident with the rise of the voltage of the input pulse. The duration of the voltage pulse at the output will be very short because of the discharging action of the resistor across the circuit.

The voltage at the output will have returned to zero, or normal, before the end of the pulse voltage at the input.

When the pulse voltage at the input to the circuit returns to normal it causes the voltage on the other side of the capacitor to go in the

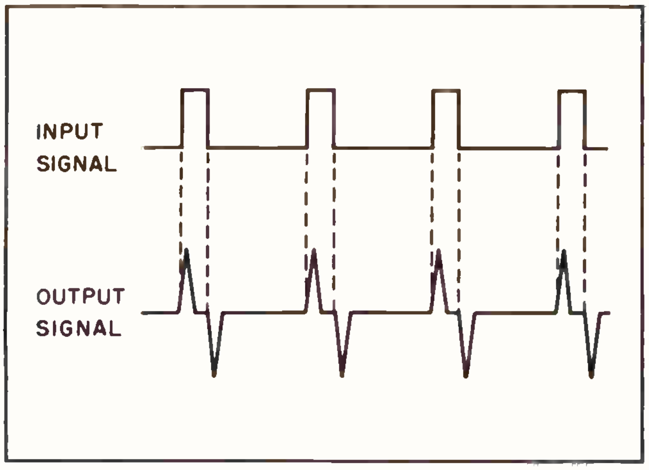

Figure 5. Wave-Forms at input and output of Differentiating Circuit when input pulse is longer than the Time-Constant of the Circuit.

opposite direction. This is a peculiar, but normal, action.

The net result is that *two* pulses appear at the output circuit, something like those shown in Fig. 5. One above the zero line, corresponding to the polarity of the input pulse; the other below the zero line, with an opposite polarity.

The presence of the second voltage pulse, the one below the zero line, is usually of little consequence. Its polarity is opposite to that needed to affect a circuit which is affected by the pulse above the zero line.

The circuit shown in Fig. 4 has a very short time-constant. Its time-constant is only 0.25 microsecond.

Any attempt to impress a voltage pulse longer than 0.25 microsecond on the input to the circuit results in the creation of a short 0.25-microsecond positive pulse at the output. When the voltage pulse on the input finally ends a second voltage pulse appears at the output; but the second will have opposite polarity.

The circuit which separates the vertical sync pulses from the composite video signal works almost exactly opposite to that of a differentiating circuit. It acts to *add together* the voltages from a succession of long pulses. Because it adds them together it is called an *integrator circuit.*

The elementary essentials of a simple integrator circuit are shown in Fig. 6. In that circuit a succession of long voltage pulses are applied to the 100,000-ohm resistor. After passing through the resistor the succession of voltage pulses are used to charge the .001 capacitor with a voltage which becomes progressively greater as one long pulse follows another.

The short, sharp pulses of the horizontal sync pulses are also applied to the input of the integrating circuit. But they have very little effect on it.

The horizontal pulses are short, so apply little charging voltage through the resistor to the capacitor. In fact the charging effect of one horizontal pulse is short, thus applies little charging voltage to the capacitor.

Furthermore the charging effect of one horizontal pulse is dissipated before the next comes along. None of the horizontal pulses has much effect on charging the capacitor, and the long space between pulses permits that little voltage to leak off.

All of which means that the horizontal sync pulses have little effect on the integrator circuit. Thus they have little effect on the vertical oscillator.

The long pulses of the vertical sync group presents an entirely different situation. The vertical sync pulse is actually a series of six long voltage pulses.

The vertical pulses are preceded by a group of short equalizing pulses which serve to equalize the voltage in the integrator circuit. By having

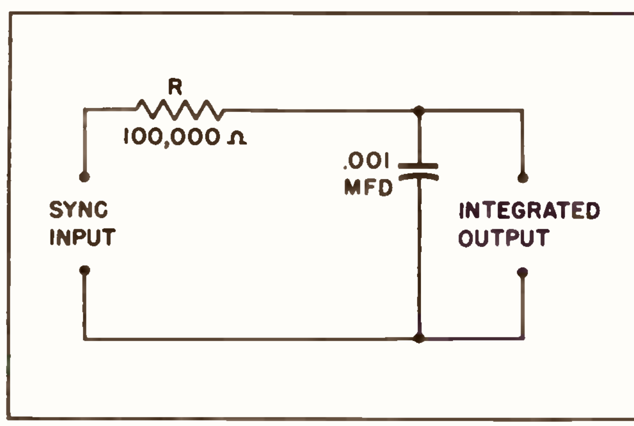

Figure 6. Integrator Circuit used to separate Vertical Sync Pulses from Composite Video Signal.

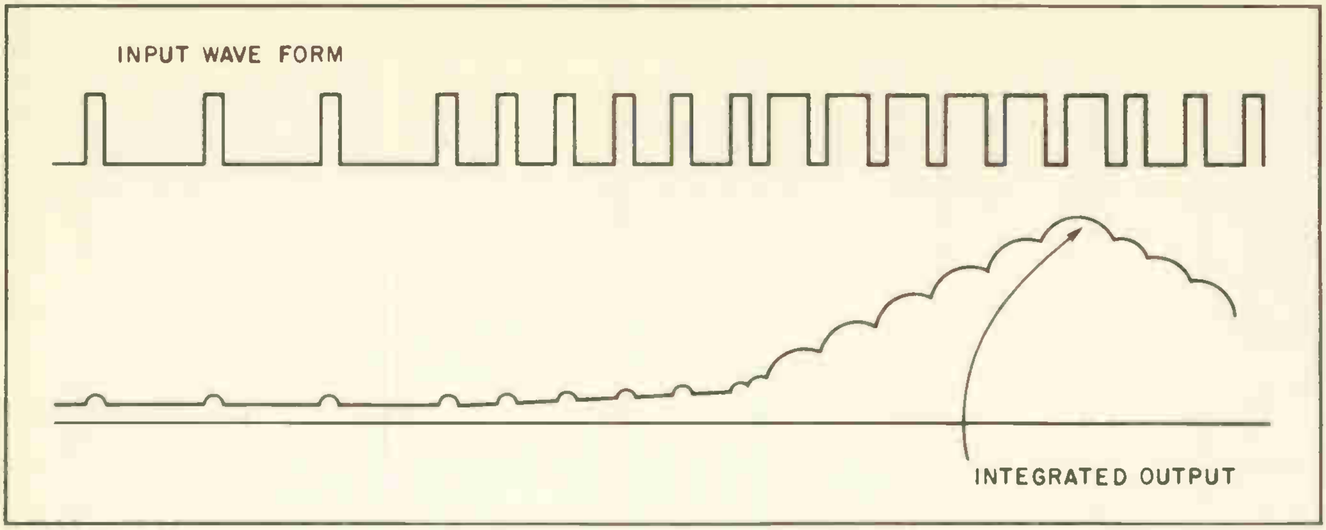

Figure 7. Input and output wave-forms at Integrator Circuit.

such a group of equalizing pulses appear just ahead of the vertical sync pulses it is possible to maintain the voltage on the capacitor at exactly the same level every time these vertical sync pulses arrive at the capacitor. This means that the vertical sync pulses always charge the capacitor to exactly the same level every time they appear.

It is rather interesting to note how the succession of vertical sync pulses build up a voltage on the capacitor. Fig. 7 makes that rather clear. The input pulses arrive at the integrating circuit in the form of regular voltage pulse waveforms. The action of the integrator circuit changes that. The group of long pulses are added together to create a relatively high voltage across the capacitor.

The circuit shown in Fig. 6 is a decidedly simple integrator circuit. Those used in actual television receivers are somewhat more complex.

Fig. 8 shows the type of integrator network used in at least one commercial television receiver. Others, using similar components, are used in other model receivers.

The values of the resistors and capacitors commonly used in TV integrator circuits have become so standardized that component manufacturers are now making printed circuits which include all those resistors and capacitors within a single unit. Such printed circuits reduce the number of components used in a television receiver, reduce the cost of its construction, and reduce the chance of error in wiring.

The internal circuitry of a widely used printed circuit unit for the integrator network is shown

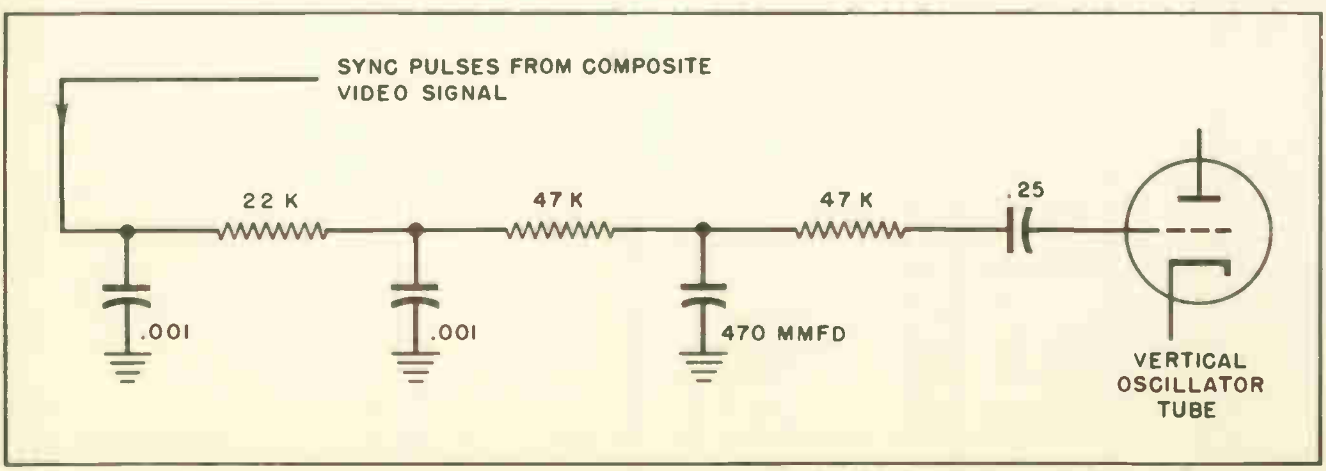

Figure 8. Typical Integrator Circuit used in a commercial TV receiver.

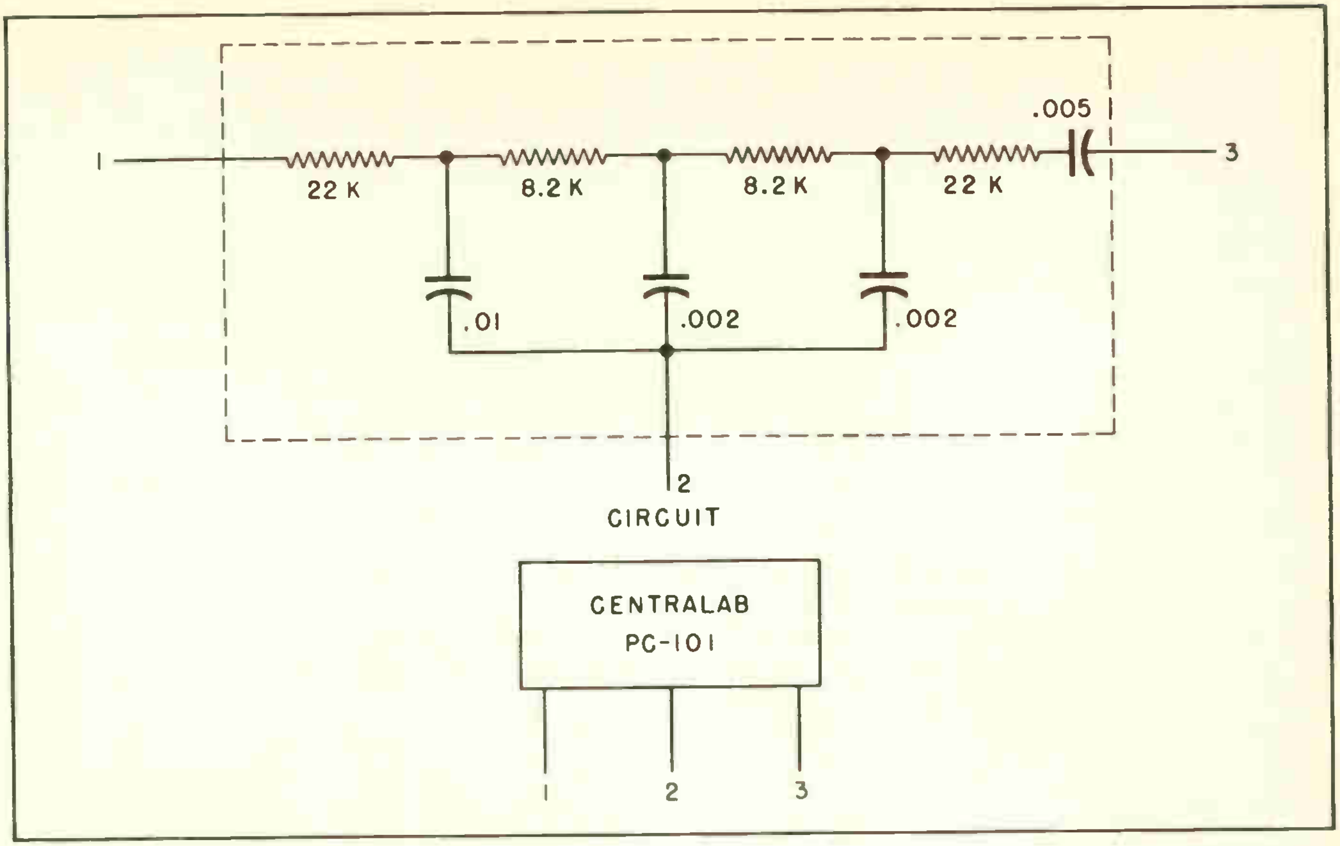

Figure 9. Circuit and appearance of Printed Circuit unit for Integrator Network.

in Fig. 9. There are four resistors and four capacitors within the network, which would normally mean making 16 wiring connections.

The 16 wiring operations are reduced to only three connections when the printed circuit unit is used.

Section 4. DEFLECTION CIRCUITS

We have neither the time nor the space to go into a full discussion of television deflection circuits in this lesson. Those circuits will be taken up and explained in lessons devoted solely to that subject.

Still, deflection circuits are not found in radio work, and those of you whose experience has been confined to radio servicing will find them new. You will also find them interesting.

There is something intensely fascinating about the manner in which the electron beam in the picture tube is taken in hand by the influence of the deflection circuits, and caused to do those things expected of it. The deflection circuits are assigned the duty of seeing that the electron beam reaches each of the many thousand spots on the screen at exactly the right instant of time it should be there.

Should the electron beam reach any given spot on the screen a few microseconds late, or a few microseconds early, the scene reproduced on the screen will not be the one viewed by the camera. In all probability the scene reproduced on the screen will not represent anything at all. All of which means that the deflection circuits must operate with incredible speed and incredible precision. They perform a highly precise function.

Deflection circuits exert their control over the electron beam in one of two different methods.

Early television receivers used deflection circuits which exerted their control through the medium of electrostatic voltages impressed on parallel plates inside the neck of the tube.

As picture tubes grew progressively larger a different kind of deflection came into existence. Instead of electrostatic voltages being applied to the electron beam inside the tube, electromagnetic forces have been applied to the beam. That has been done by placing special coils of wire around the outside of the neck of the picture tube. These things will all be discussed more fully later.

Deflection circuits include some type of oscillator capable of generating a very special type of voltage wave-form. In all cases these are saw-tooth oscillators.

The oscillators are then used to drive special types of amplifiers. In the case of electrostatic tubes the amplifiers are voltage amplifiers. When electromagnetic picture tubes are used the amplifiers are some form of power amplifier.

The horizontal amplifiers used with electromagnetic picture tubes are often capable of generating surprisingly large amounts of power.

Horizontal deflection circuits in many of the modern television receivers have been further modified to permit them to perform still additional functions.

In some cases special types of circuits are included in the deflection circuit to boost the B plus voltage for the use of certain tubes.

Even more common is the practice of using the collapsing voltage in the horizontal output transformer, during the "flyback" period, to generate the extremely high voltage needed by the final anode of the picture tube. This has now become so common it is almost a universal practice.

Section 5. CONTROLLING MOVEMENT OF THE BEAM

Some degree of confusion often exists concerning deflection circuits and sync circuits.

It should be kept clearly in mind that the function of the deflection circuits in a television receiver is to move the electron beam around over the face of the picture tube screen. The horizontal deflection circuits move the beam back and forth from one side to the other. The vertical circuits move it up and down from top to bottom.

The interaction between the two deflection circuits makes it possible for the beam to touch each and every spot on the surface of the screen.

The synchronizing circuits act in conjunction with the deflection circuits, but they perform a different function. The sync circuits act to lock the deflection circuits of the receiver into synchronism with the deflection circuits at the camera.

The deflection circuits act independently to move the beam to all parts of the tube screen regardless of whether there are sync pulses present or not. Thus, the horizontal circuits move the beam back and forth across the screen, even though no sync pulses are present. In the same manner, the vertical circuits move the beam up and down across the face of the screen, even though no sync pulses are present.

But when sync pulses come through from the transmitter, by way of the composite video signal, they pass through the sync separator circuits. The horizontal sync pulses are directed to the control of the horizontal deflection circuits, while vertical sync pulses are directed to the control of the vertical deflection circuits.

In that manner the deflection circuits of the receiver are locked into synchronism with the transmitter deflection circuits.

All of these circuits will be discussed in greater detail in other lessons. We are merely introducing them at this time.

Section 6. IMAGE ON THE PICTURE TUBE

Before proceeding with our discussion of the many circuits in a television receiver which are different from those found in radio or other electronic devices we will take a few minutes to examine the image on the picture tube. We will examine the things which contribute to its existence, and look into the many circuits which make that image possible.

Technical information needed to create the image is supplied by the TV signal receiver through the antenna.

We must never lose sight of the fact that the image on the screen of a picture tube is created by a fast-moving pin-point of light. Since the intensity of that pin-point of light corresponds at one instant with one picture element and the

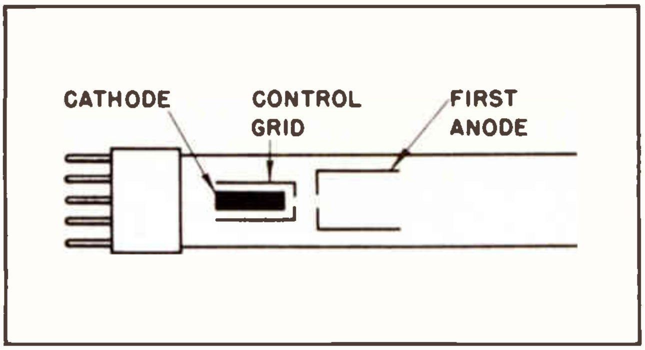

Figure 10. Where electron beam originates.

next instant with another picture element it is understandable that the intensity of that spot of light is constantly changing. Those changes are brought about by the rapid changes in the TV signal.

The pin-point of light on the screen of the picture tube is created by a concentrated beam of electrons striking the screen.

The beam of electrons, in turn, is created in the electron gun in the neck of the picture tube. Differences in the intensity of the beam result in differences in the brilliance of the screen from one tiny area to another. One tiny spot on the screen is caused to be brilliant because the beam at that spot is intense. An adjacent area is dark because the beam is weak.

Those differences in the intensity of the beam are brought about by the action of the control grid in the picture tube. The control grid is a part of the electron gun. Changing voltages in the TV signal are applied directly to the control grid.

It is always interesting to examine into the way the electron gun creates that beam. It is neither desirable nor necessary for us to examine into all those details at this time, but we can take a quick peek at the more obvious actions.

Something of the arrangement of the various elements composing the electron gun can be seen by studying Fig. 10. That is not a pictorial diagram, nor does it pretend to include all the necessary parts in an electron gun. But it does help visualize the action which takes place in the neck of the tube where the electron beam originates.

The cathode is heated by a wire filament in a manner similar to other types of vacuum tubes. Instead of the control grid being a grid of wires, as is true in many other types of tubes, it is almost cylindrical in shape. The end of the grid pointing toward the screen is almost closed, except for a small hole in the center.

Electrons escape through that small hole, then pass through the first anode. The first anode is often referred to as the *accelerating* anode. Various sections of the industry also refer to it occasionally by other names.

The control grid has a negative voltage polarity with reference to the cathode, while the first anode is positive with respect to both the control grid and the cathode.

Presence of a positive voltage on the first anode creates an electric field between the control grid and the anode, and thus imparts an accelerating force to the electrons in the beam. This causes them to move in the general direction of the screen.

The control grid, the first anode and various other elements inside or outside the neck of the tube act upon the beam of electrons. The beam is focused, controlled, and manipulated. Considerable energy is created within the electron beam due to the fact the individual electrons attain an extremely high velocity while moving from the electron gun to the screen.

When the electrons in that beam strike the screen the kinetic energy in the fast-moving electrons is changed into light energy. That causes the screen to *flouresce*, or become light, at the point where the electrons strike it.

As the electron beam recreates one picture element after another on the screen of the picture tube it is moved from one position to another by the influencing forces of the deflection circuits.

The difference in the brilliance of one picture element from that of another is brought about by the influence of the control grid on the strength of the electron beam. The voltage on the control grid is negative with respect to the cathode. It is not usually sufficiently negative to fully prevent the passage of electrons from the cathode to the screen, but the presence of the negative voltage on the control grid restrains the movement of the electrons to some extent.

By varying the strength of the negative voltage on the control grid from one instant to the next it is possible to control the degree of brilliance of the many thousand picture elements on the screen. That varying negative voltage is the TV video signal.

The exact manner in which the beam is caused to move from one position to another on the screen is determined by the peculiar characteristics of the individual tube. If the picture tube uses what is called electrostatic deflection the beam is influenced by varying voltages which appear between the various deflection plates within the neck of the tube.

The top drawing in Fig. 11 provides a rough outline of the essentials of an electrostatic picture tube. The beam is brought into existence within the electron gun in the extreme end of the picture tube neck. The electrons in the beam are accelerated to high speed by the various other elements. Finally, as the beam passes between the two pairs of deflection plates it is deflected upward or downward, or to one side or the other, depending on the voltages which happen to be present there at any given instant.

The several electrostatic fields which are present within the neck of the tube serve to focus the beam so the electrons are bunched into a very small area at the point where they strike the screen. The essential features of the actions described here become more clear when the upper illustration in Fig. 11 is carefully studied.

The glass surface inside the flaring bulb of the picture tube is coated with black conductive material. (Except for the actual screen surface.) It is a black substance with the trade name *aquadag*. Electrical contact is made with the aquadag by means of a special high-voltage connection through the glass envelope of the tube. See Fig. 11.

Applying high voltage to the aquadag provides the final accelerating force needed to speed up the moving electrons in the beam to the velocity necessary to make the phosphors on the screen flouresce when the electrons in the beam strike the screen. The voltage applied to the aquadag, or final anode, varies from one type of tube to another. It ranges from around 6000 volts for the smaller electromagnetic tubes to 16,000 volts or more, for larger tubes.

Electrostatic picture tubes are limited to relatively *small* sizes. None larger than 10 inches have ever come into popular use.

Electrostatic tubes, by their peculiar nature, are longer from the face of the screen to the tip of the neck than comparable electromagnetic tubes. As demands grew for increasingly larger picture tubes it became clear the overall length of electrostatic tubes would be unreasonable when the screen sizes exceeded 10 inches.

Another limiting factor was the voltage. An electrostatic tube requires an abnormally high voltage on the final anode, and unusually high deflecting voltages on the deflecting plates. These high voltages pose very serious problems for design engineers.

Electromagnetic tubes can operate on much lower final anode voltages than comparable electrostatic tubes. But such tubes require several external parts not needed by electrostatic picture tubes. They require, for example, a magnetic deflecting coil around the outside of the neck of the tube, and some means to anchor and position the coil.

They also need some type of external focus magnet. At least this is true of many types of electromagnetic tubes. Some of the newer electromagnetic deflection picture tubes are employing electrostatic focus inside the tube.

The lower illustration on Fig. 11 provides a pretty good idea of the essential parts of an electromagnetic picture tube using external focus magnet. Such tube is much shorter from front to back than a comparable electrostatic deflection picture tube, and employs much lower voltages on the anodes. All of which simplifies many of the problems of the design engineer.

Another lesson has been devoted to the more precise details concerning the construction and operation of various types of picture tubes. This will give you the information you need now.

Section 7. ANTENNA SIGNAL

The antenna signal, the way it is picked up by the antenna, the way it is handled by the transmission line, and the things which are done to it in the tuner section of the TV receiver, are all highly technical subjects. We can let ourselves

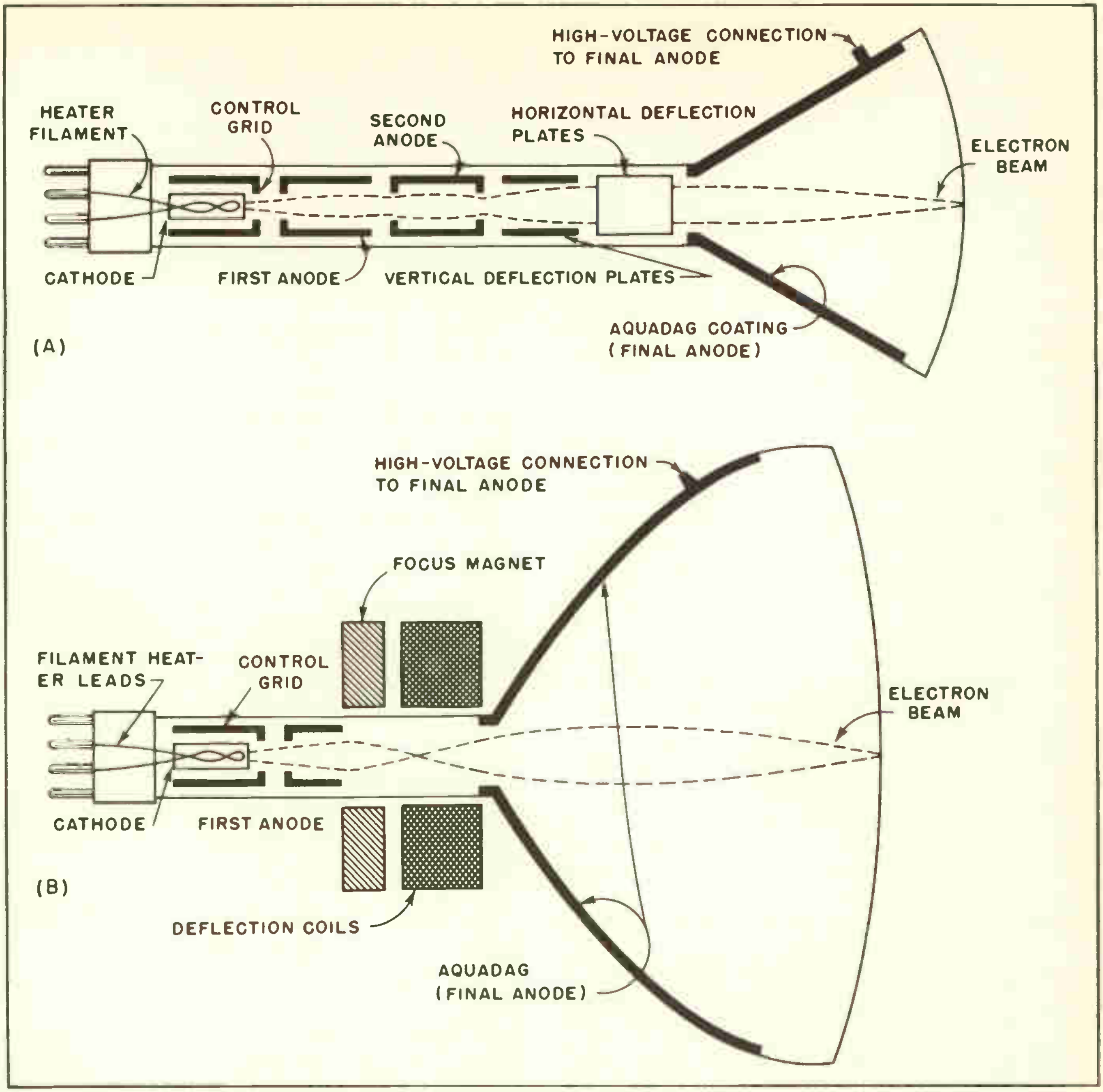

Figure 11. Electrostatic and Electromagnetic picture tubes.

in for a lot of grief by trying to explain all the actions which involve the antenna signal before we are ready to understand those things.

Each of those subjects will be taken up in turn, and explained. Entire lessons are devoted to some of them. In some cases we devote one or more lessons to the job of preparing you to understand the material.

To the inexperienced eye there is little about television which appears more simple than an ordinary TV antenna, unless it is the transmission line which connects the antenna to the receiver. Yet the electrical principles which cause an antenna to operate are exceedingly complex. To really understand how to obtain the best performance from a TV antenna it is necessary to first understand those basic electrical principles.

But that does not keep us from taking a good look at the television signal as it appears at the time it is intercepted by the antenna and sent through the transmission line to the tuner section of a TV receiver.

The television signal, as transmitted from the broadcast station, consists of two completely independent carrier signals. One is the sound carrier which carries voices and music connected with the scene being viewed by the TV cameras. The other is the video carrier which carries the picture information needed to reproduce the scene in the receiver.

These two carrier signals are operated on set frequencies within one of the TV channels assigned by the FCC. Their frequencies differ from each other by 4.5 megacycles. The carrier frequency of the sound carrier is 4.5 megacycles higher than the carrier frequency of the video carrier.

It is the purpose of the TV antenna at the receiver to intercept those carrier frequencies and feed the signals to the transmission line, through which they reach the tuner of the receiver. Fig. 12 shows something of the manner in which this is accomplished.

The receiver antenna is designed to be sensitive to the frequencies of the two carriers. It responds to both, then feeds the intercepted signals to the tuner section of the TV receiver.

It should be kept constantly in mind that the two carrier signals are modulated differently. The video carrier is *amplitude* modulated. The sound carrier is *frequency* modulated.

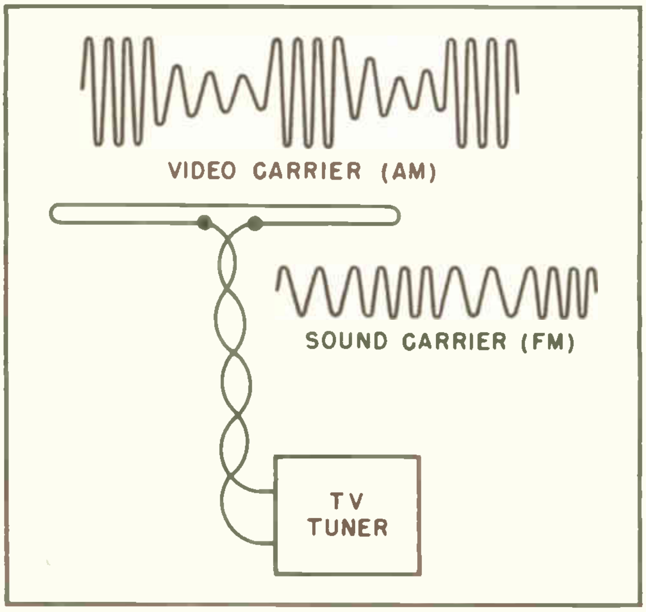

Figure 12. Signal Wave-Forms at antenna and tuner.

Because of the apparent simplicity of construction of TV antennas many students seem to think there is little of technical importance to them. Often we are asked to provide technical information about antennas long before a student reaches the part of the course where they are explained.

We try to help in special cases where we think we can be helpful, but we know it is a mistake to believe antennas are simple, or that one can learn all that should be known about them without a lot of preliminary preparation.

The electrical theory behind antennas is relatively complicated. It is necessary to have a good understanding of mutual inductance, surge impedance or characteristic impedance, line reflection, impedance matching and similar technical subjects before attempting to understand how antennas operate.

Transmission lines which bring the signal from the antenna to the tuner of the receiver are equally important for successful operation of a TV receiver. This is especially true in those remote areas where the signal is normally weak.

Like an antenna, a transmission line looks quite simple. But for its successful operation it depends on electrical principles at which we have scarcely hinted thus far in the course.

Electrical voltages and currents at the high frequencies used for TV carrier signals appear to behave differently from those at ordinary AC power line frequencies. Before one can understand how a TV carrier frequency signal can pass through a transmission line it is first necessary to understand how those high frequency signals behave. Acquiring such knowledge is not always simple nor easy.

While we do not pretend to explain the technical background of antenna signals at this time, we can look into some very practical aspects of how these signals are handled.

There are more than eighty channels assigned for television use by the FCC. These are divided into two groups of channels, the Ultra High

Frequency (UHF) group, and the Very High Frequency (VHF) group.

The UHF group of TV channels fills the entire radio spectrum from 470 megacycles to 890 megacycles. Channel 14 uses that group of frequencies between 470 mc and 476 mc; channel 15 uses those between 476 and 482 and so forth all the way up to 890 megacycles. There are a total of 70 separate TV channels in the UHF group. No other radio service occupies any portion of the radio spectrum from 470 mc to 890 mc.

The VHF group of TV channels is somewhat different from the UHF group. The lowest frequency channel is number 2. It occupies the band of frequencies from 54 mc to 60 mc. Channels 3 and 4 occupy the two adjacent 6-megacycle bands above 60 megacycles.

Then there is a gap of four megacycles between 72 mc and 76 mc which are assigned to other radio services. Those frequencies are not used by television.

Above 76 mc there are two additional TV channels adjacent to each other. These are channels 5 and 6; channel 5 occupying the frequencies from 82 to 88 megacycles.

Above channel 6 there is a very wide band of radio frequencies which are assigned to other radio services besides that of television.

Channel 7 occupies the band of frequencies from 174 megacycles to 180 megacycles. This band of frequencies is nearly 90 megacycles higher than those used by channel 6. From this it can be seen that the VHF group of TV channels can be sub-divided into two other groups, the "low-band" group of channels 2-6, and the "high-band" group of 7-13.

All the frequencies up to 216 megacycles are occupied by the other VHF television channels. They are channels 7 through 13.

From this it can be seen that there are 12 television channels in the VHF group, and 70 television channels in the UHF group. This vast group of television channels covers an extremely wide range of radio frequencies; they range from 54 megacycles, at the low end of channel 2, to 890 megacycles at the upper end of channel 83.

The fact there is such a wide range of radio frequencies used in television work imposes a burden on the tuner section of the television receiver. It is the duty of the tuner to separate the one desired TV channel from all the others on the air, amplify the signals within that channel, then convert them into lower I-F frequencies for further amplification.

The manner in which the TV tuner accomplishes this job is a subject to which we later devote an entire lesson.

Section 8. HANDLING ANTENNA SIGNAL IN THE TUNER

Television manufacturers approach the problem of designing a receiver tuner from several different angles. There has been a growing tendency among many receiver manufacturers to purchase tuners from companies which specialize in the manufacture of tuners. Probably half of the television receivers now being built in the United States use tuners built by the Standard Coil Products Company, but some receiver manufacturers use other types of tuners.

In any case, the building of television receiver tuners has become a highly specialized business.

All, or virtually all, television receivers are equipped with tuners capable of picking up all the stations within the VHF group of channels. But many receivers are not equipped to pick up UHF stations.

We will make no attempt to explain the technical problems involved in the reception of the various high and low frequency channels at this time. We want to touch only on the general manner in which the signal frequencies are handled in the tuner section.

A study of Fig. 13 shows how the carrier signals reach the tuner section from the antenna. They arrive from the antenna through the medium of the transmission line which connects the receiver tuner with the antenna.

The carrier frequencies shown arriving at the tuner section in Fig. 13 correspond to those used

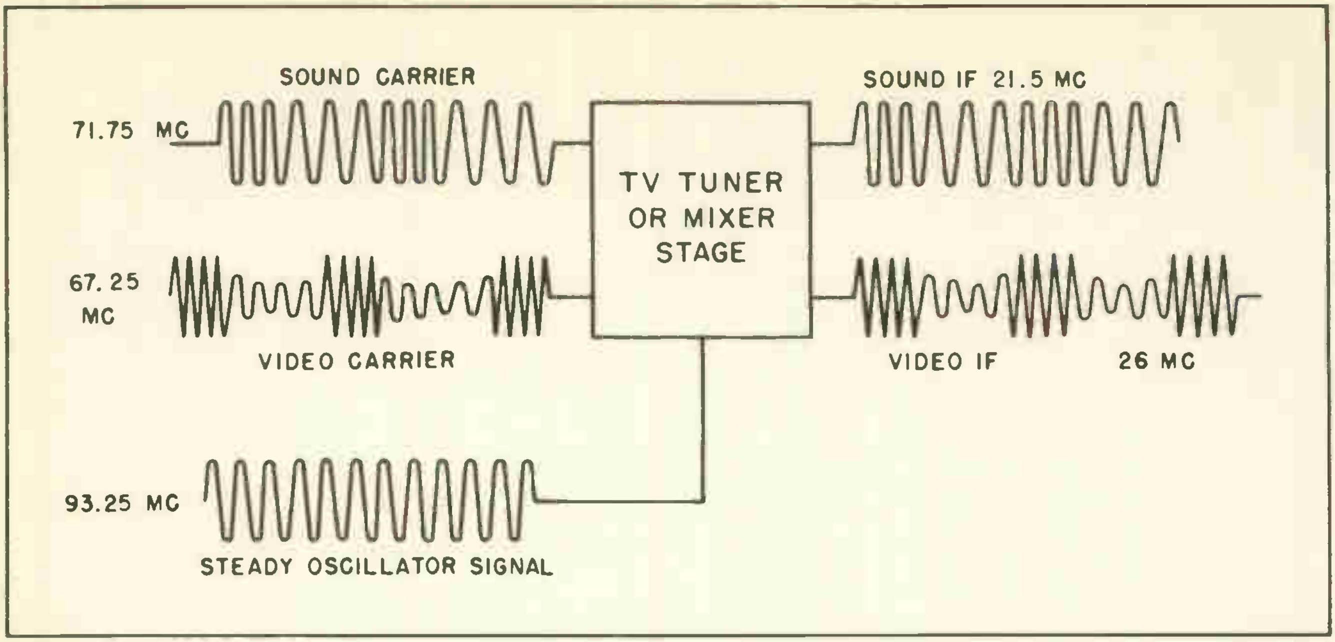

Figure 13. Frequencies of Carrier Signals from antenna changed in Tuner.

by TV broadcast stations assigned channel 4. The sound carrier is operating on a frequency of 71.75 megacycles, the video carrier on 67.25 megacycles. Careful observation discloses these two carriers operate on frequencies 4.5 megacycles apart, but both are within the frequency limits provided for stations operating on channel 4.

The exact manner in which the carrier signals are handled within the tuner section differs from one type of tuner to another. Some amplify the RF carrier signals before they are mixed with the signal from a local oscillator; others do not.

In either case, the RF carrier signals are mixed with a local oscillator signal somewhere within the circuits of the tuner section.

A local oscillator signal operating on a frequency of 93.25 megacycles is shown as being mixed with the carrier signals in Fig. 13. This is a typical action, especially in the older types of television receiver tuners.

The oscillator signal has a fixed, unmodulated frequency. When it mixes with the sound carrier it provides an I-F frequency of 21.5 megacycles. This results from mixing the 93.25 megacycles of the oscillator with the 71.75 megacycles of the sound carrier. The 21.5 megacycles I-F signal represents the difference between these two signals.

The fixed frequency of the local oscillator is also heterodyned against the 67.25 megacycles of the video carrier. The result of this mixing is another I-F signal. It is the 26-megacycle signal of the video I-F shown in Fig. 13.

From all this it can be seen that we now have two I-F signals instead of the one I-F signal to which we are accustomed in radio work. You should also note, and keep in mind, that those two I-F signals have frequencies 4.5 megacycles apart. We keep repeating this because it is important, and we want to impress it on your mind.

In this particular instance we are dealing with I-F frequencies of 21.5 megacycles and 26 megacycles. These are frequencies which have been widely used throughout the television industry, especially up to about 1953.

Since that time there has been an increasing tendency within the industry to use higher I-F frequencies than those described here. Many of the more modern receivers are using I-F frequencies in the neighborhood of 40 to 45 megacycles.

Using higher I-F frequencies in the I-F stages of a television receiver has both advantages and disadvantages. Under ordinary circumstances there would not be the same amount of gain per stage when using the higher frequencies, and theoretically it should be harder to control the radiation of the oscillator signal from the antenna.

Good engineering design, and improved amplifier tubes, have enabled the manufacturers to obtain virtually the same amount of gain at the higher frequencies as they had at the lower ones. One big advantage is that I-F frequencies of 40 to 45 megacycles do not cause as much interference as was true of the lower I-F frequencies.

The lower frequencies fell into radio bands where they caused a lot of interference, and harmonics of the I-F signal could get into other nearby TV receivers and create annoying interference there. Furthermore, short-wave radio signals operating in the 21 megacycle bands frequently caused TV interference.

I-F frequencies between 40 and 45 megacycles do not cause serious interference with other services, even when part of the I-F signal is radiated. But careful design, and careful shielding, has reduced most of the radiation. Furthermore, an I-F signal of 40 to 45 megacycles does not cause serious interference in other nearby TV receivers. This is because the harmonic relationship is such that any interference which does occur is not noticeable on nearby receivers. Nor is it so easy for a 40-megacycle radio signal to reach the TV I-F circuits.

In the earlier days of television it was the regular practice to feed the sound I-F signal to special sound I-F amplifier stages, while the video I-F signal was fed to special video I-F amplifiers. That practice is still followed to some extent, especially in the more expensive television receivers.

But there is a growing tendency among manufacturers to use what is called *intercarrier* amplification, in which both the sound and video I-F signals are amplified by the same circuits. There is little purpose in trying to explain at this time how intercarrier amplification is accomplished, but it will all be explained to you in due time.

Section 9. I-F AMPLIFIER AND DETECTION ACTION

There is not nearly so much gain in the I-F stages of a television receiver as in comparable radio circuits. The I-F circuits in a radio are tuned to very narrow bands of frequencies, thus great gain can be brought about in each stage of amplification. The I-F circuits in a television receiver are different. They must be tuned so broadly that a range of frequencies more than 4 megacycles wide can get through. This means the amplifying ability of each stage is greatly reduced.

Few, if any, modern television receivers have less than *three* stages of I-F amplification. Some have more. In fact, four stages are quite common.

The final stage of I-F amplification feeds into the video detector circuit.

In many ways the video detector in a television receiver is closely similar to the diode detector which is so common in radio receivers. Some of the circuits associated with it are different; they are more broadly tuned, they are differently loaded, and there are other minor differences. But essentially, they are much the same.

A study of Fig. 14 provides a pretty good idea of the video signal wave-forms as they are applied to the video detector, and as the video signal leaves that circuit. The action of the video detector is to separate the composite video signal modulation from the video I-F carrier signal. This is very similar to the action of a diode detector in a radio receiver.

Most of the modern television receivers incorporate some form of Automatic Gain Control (AGC). This circuit operates much the same as the AVC circuit in a radio, and serves very much the same purpose.

The AGC circuit tends to prevent the signal becoming stronger or weaker from instant to instant, and thus causing the picture on the receiver to become alternately light and dark. Irregular reflections are one of the principal causes of such irregular brilliance on the picture. Such irregular reflections occur when portions of the transmitted TV carrier signal are reflected from a fast moving body. Reflections from an airplane are typical of what we are describing.

As an airplane moves swiftly through the sky television signals are reflected from its surface.

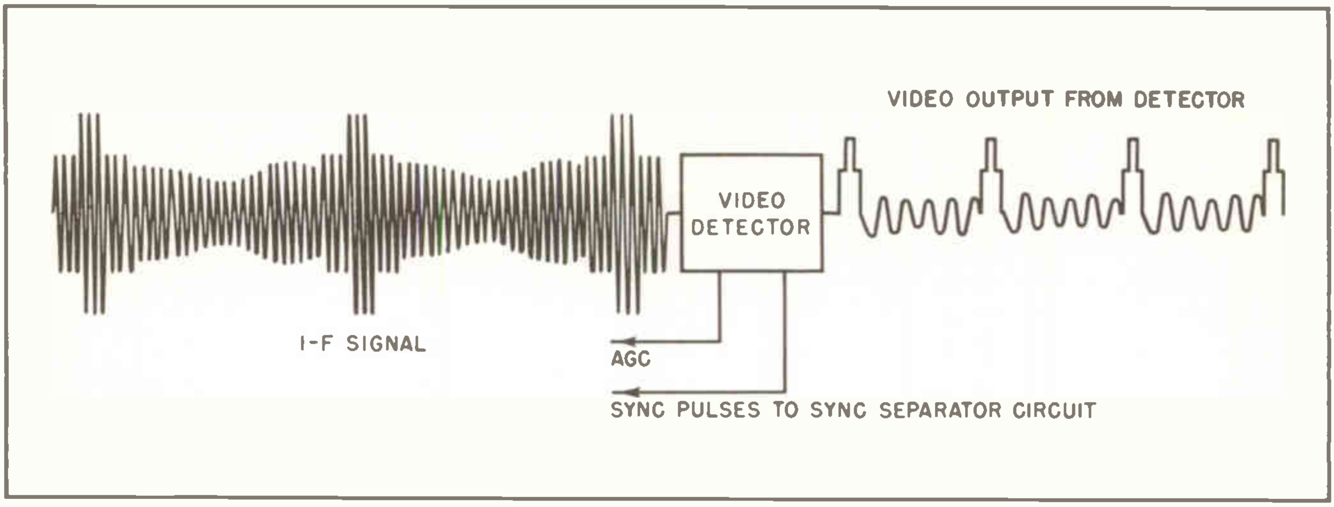

Figure 14. Signal wave-forms at Video Detector.

Because the airplane is constantly changing position the signals which are reflected from its surface will alternately reinforce those moving directly from the transmitter to the receiver, then the signals will oppose each other. The net result is that the signal at the antenna of the receiver will be strong one instant, then weak the next. See Fig. 15.

When an automatic gain control circuit is incorporated in a television receiver it tends to hold the signal strength at the detector to a more constant level. This is done by changing the bias on the RF and IF amplifying tubes as the strength of the signal varies. When the signal is coming in strong a higher negative bias voltage is placed on the control grids of the amplifier tubes, thus reducing their amplifying ability. When the signal strength weakens, some of that negative bias is removed; and the tubes become better amplifiers.

AGC voltage is usually tapped off at the video detector as indicated in Fig. 14. Some receivers incorporate special types of AGC circuits which are designed to meet special conditions. These subjects will be discussed in greater detail as we progress.

Synchronizing pulses needed to lock the receiver deflection circuits into synchronism with those in the transmitter are often tapped off at the video detector. This is indicated in Fig. 14.

In some cases the sync pulses are tapped off a later stage, one of those in the video amplification section.

Section 10. TV POWER SUPPLIES

Television receivers need *two* types of power supplies.

One is called the *low-voltage* power supply. It is similar in most respects to those commonly used in radio receivers and other types of electronic devices. Its purpose is to supply the filament voltages needed to properly heat the cathodes of the various amplifier tubes, and the B plus voltages needed for the anodes and screen grids of those tubes.

Television receivers also use a second power supply which is generally referred to as the *high-voltage* power supply. Its purpose is to supply the extremely high voltage needed to operate the final anode of the picture tube.

We cannot hope to mention all the various items of interest associated with television power supplies, but we can mention a few things which are of immediate interest to you.

The low-voltage power supply varies from one model receiver to another just about as much as is true of power supplies used in radio receivers. Possibly, somewhat more so.

There are full-wave vacuum tube-rectifier type power supplies employing a heavy power transformer and a rectifier tube on the general order of the 5U4. The 5U4, and improved modifications of that tube, are widely favored by television manufacturers because of their power handling ability.

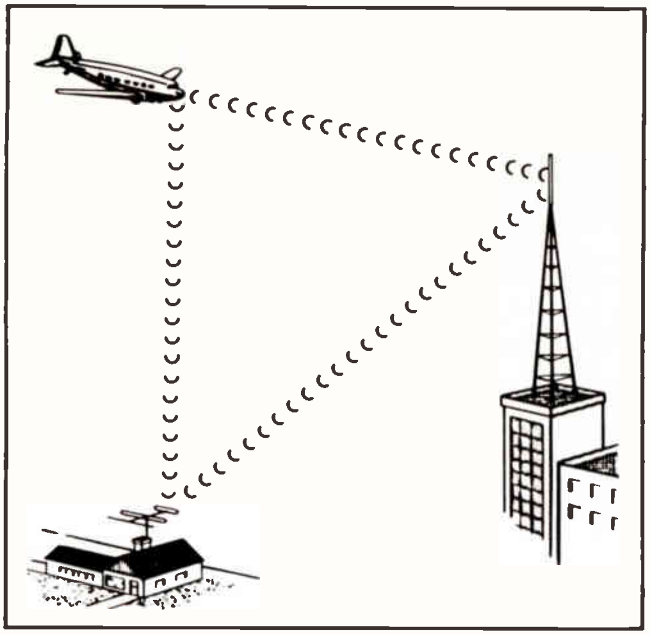

Figure 15. Constantly changing position of plane causes length of reflected path to change from instant to instant.

Many television power supplies use two 5U4 tubes so there will be ample power for the various amplifier tubes in the circuit.

Other manufacturers favor half-wave power supplies using selenium rectifiers and high-capacity electrolytic capacitors. These types of power supplies are usually found in the less expensive television receivers, although some of the largest manufacturers of supposedly fine receivers also favor this type power supply.

Despite these variations the fact still remains that the low-voltage power supply in a television receiver is not materially different from that used in radio receivers.

High-voltage power supplies for television receivers introduce types of circuits not found in radio receivers. These are the circuits which generate the voltages ranging up to many thousands of volts which are required for the proper performance of picture tubes.

The exact amount of high-voltage needed by a television receiver depends on the type of picture tube used in it. Modern direct-view picture tubes require voltage ranging from some 6000 volts to almost 20,000 volts. Projection tubes require voltages ranging up to 50,000 volts; some even requiring as much as 100,000 volts.

There is little point in attempting to describe the various types of circuits used in the high-voltage power supply circuit of modern television receivers. Some of those circuits employ principles we have not previously covered. But each will be taken up in turn, and explained in careful detail.

Section 11. CARE IN HANDLING PICTURE TUBES

Perhaps this is not exactly the proper place to mention this subject. But it is something which should be kept in mind, and since we will soon be describing the various types of picture tubes it seems appropriate to mention the matter here.

Direct-view picture tubes, the types found in the vast majority of home television receivers, have a relatively large surface area. This is especially true of the larger size picture tubes.

Pressure of the air on the surface of these tubes becomes very great, far greater than most people realize.

We are not normally aware of it, but the fact remains there is air pressure on us amounting to approximately 15 pounds per square inch of surface. That is the pressure of air at sea level. That does not seem like a great deal, but when the surface area of an evacuated body becomes quite extensive the pressure on that body is very great.

The one evacuated body with which most of us have had most experience is the common incandescent lamp bulb. Such a bulb has a relatively small surface area, in terms of square inches, therefore the pressure on its surface never becomes very great. Nevertheless, most of us have had the experience of dropping and breaking such a lamp bulb, and hearing the rapid inrush of air into the evacuated space.

Consider, then, the pressure which is present on the surface of a television picture tube which has such a radically increased amount of surface area — even for a small picture tube. See figure 16.

A small 10-inch picture tube, now virtually obsolete except for portable receivers, has a surface area of about 250 square inches. Multi-

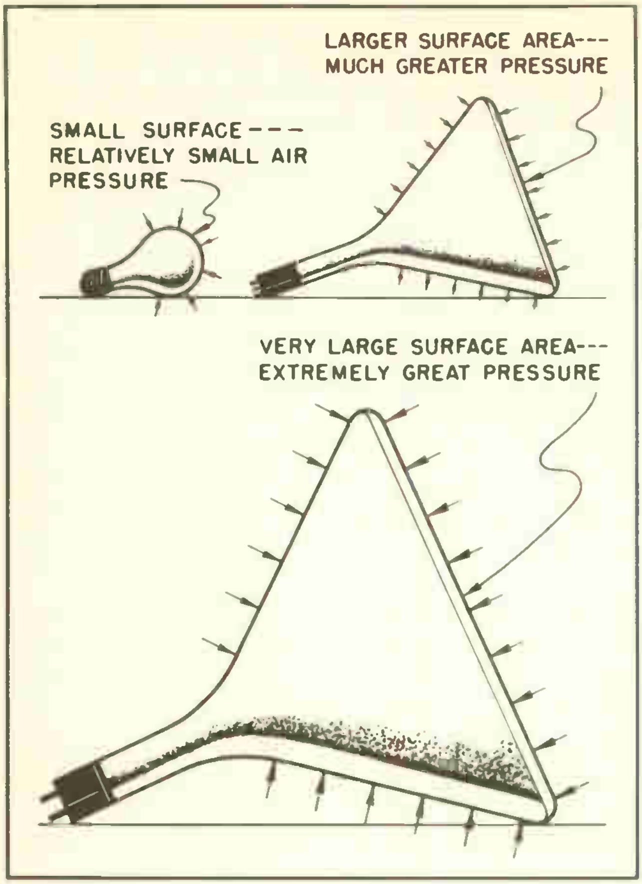

Figure 16. Comparative sizes of tubes, and air pressures on them.

plying 250 inches by **15** pounds per square inch discloses the fact there is a total pressure on the surface of that small picture tube amounting to 3,750 pounds. It is hard to believe such tremendous pressure is present on what appears to be such a small surface area, but figures don't lie.

It is because of the great pressure which is always present on the comparatively fragile glass body of a picture tube that it is necessary to exercise caution whenever tubes are handled.

Manufacturers warn against attempting to pick up a picture tube by grasping the neck of the tube. Such action places a strain on the glass where the neck joins the flaring bulb of the tube. There is always danger of subjecting the glass to sufficient strain so it breaks.

Breakage of the glass envelope of an evacuated picture tube results in what is known as an "implosion." An implosion is the direct opposite of an explosion. In an explosion there are forces acting to force everything outward; in an implosion the forces are acting to force everything *inward.*

Even so, an implosion can be extremely dangerous. There are instances on record where the metal electron gun at the rear of the tube neck is forced forward so rapidly that it flies completely through the heavy glass plate at the front of the tube and buries itself deeply in soft wood or other material. Should a person be standing in front of such a tube at the instant of implosion the gun might bury itself in the person's body.

There are always bits of flying glass surrounding an implosion. These can be exceedingly dangerous. They can flay the skin of one's face like a thousand knives, and destroy the eyes. Other unexpected dangers, often of a freakish nature, are occasionally disclosed after an accident involving an implosion.

It is never safe to permit an old picture tube to lie unused around a shop or other place where uninformed persons have access to it. Special tools are available for breaking the seal at the end of the neck, and thus permitting air to enter the tube. Another practice followed by many is to place the old tube in a large carton, then the neck of the tube is broken by striking it with a piece of metal.

The present tendency to turn in old picture tubes in exchange for new ones, so the old ones can be rebuilt, requires that the old one not be seriously damaged. However, old tubes can be easily rendered harmless, and still permit them to be rebuilt, by breaking the neck close to the base of the tube.

Placing a metal wire around the neck of the tube, then heating it electrically, is a favorite method used by many to make such old tubes harmless.

Another is to remove the base, then break the small exhausting tip under it.

Section 12. PROJECTION PICTURE TUBES

The American public has given a hearty endorsement to direct-view types of television receivers. In so doing they have turned a cold shoulder to the projection-type receivers.

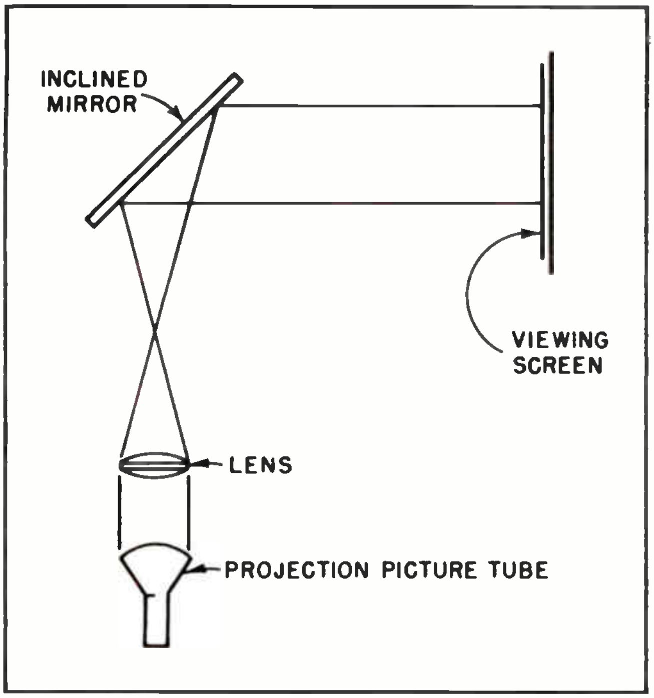

Figure 17. Projection of TV picture onto special Viewing Screen.

Nevertheless, projection type receivers are used in some places. Probably the greatest use of projection-type receivers is in theaters, and similar places where a very large screen is needed.

Projection type receivers require more complicated circuits than direct-view receivers, and must provide radically higher anode voltages for the projection tubes. As stated earlier, voltages ranging up to 100,000 volts are not uncommon.

Several systems for projecting television images have been used, but the drawing in Fig. 17 gives a good idea of the system most widely favored.

The extremely high cost of the complicated lenses and mirrors has prevented projection types of television receivers achieving a high degree of popularity in the United States. Relatively few have found their way into actual use in homes, although some have been installed in public places.

Projection receivers are in a class by themselves. They employ circuits not generally found in the more common types of direct-view television receivers. A full explanation of projection receivers would be practically a course by itself.

Since there are so few such receivers in common use, and they are usually serviced by the manufacturer's own representatives, there seems little reason to discuss them very extensively. There are too many other things of more immediate practical benefit to you to spend your time on something that can have little value to you.

NOTES FOR REFERENCE

Many circuits used in television receivers are closely similar to those used in radio receivers and other electronic devices.

In addition to circuits which are similar to those used in radio, there are a number of others in TV receivers which are different from anything found in radio.

Sync separator circuits are very important in TV receivers, but are not used in radio receivers.

A television receiver must be capable of picking up, amplifying, and handling two entirely separate RF carrier signals. One is the sound carrier, which handles the voice and other audio sounds; the other is the video carrier, which carries the picture information needed to reproduce the scene viewed by the camera.

The frequency of the sound carrier and that of the video carrier are separated from each other by 4.5 megacycles.

Some TV receivers employ separate amplifying systems for sound I-F signal and the video I-F signal. Others use a single I-F amplifying system for both sets of signals.

Sync pulses, needed to synchronize the horizontal deflection circuits at the receiver with those at the transmitter, are separated from the composite video signal by means of a special circuit called a *differentiating circuit*.

Vertical sync pulses are separated from the composite video signal by an *integrating circuit.*

Sync pulses from the transmitter are not used to deflect the electron beam in the picture tube, they merely act to lock the deflection oscillators into synchronism with those at the transmitter.

The electron beam in a picture tube originates in the electron gun in the neck of the picture tube.

Varying the intensity of the electron beam varies the brilliance of the screen where the beam strikes it.

When using an electrostatic picture tube the movement of the beam is completely controlled by forces which are exerted upon it from *inside* the tube.

The final anode of a picture tube consists of a black, conductive covering which is smeared on the inside of the glass of the tube. That conductive material is called *aquadag*.

High voltage is applied to the aquadag on the inside of the picture tube by means of an electrical connection through the glass envelope of the tube.

Advantages of the electromagnetic picture tubes are that they are shorter from front to back, and require smaller voltages on the active elements within the tube.

The purpose of a receiver antenna is to intercept the passing TV carrier signal so it can be sent to the tuner section of the receiver.

The antenna signal is brought from the antenna to the tuner through the medium of the transmission line.

Electrical and physical characteristics of a transmission line are carefully controlled so its *characteristic impedance* will match that of the receiver tuner and that of the antenna.

Mismatch of the impedances between the antenna and the transmission line can result in a very much reduced signal. Mismatch also introduces "ghosts".

An impedance mismatch between the transmission line and the tuner of the receiver can create "line reflections" and ghosts, and also seriously weaken the strength of the signal.

The tuner separates the desired TV carrier signal from all the others "on the air", mixes it with a local oscillator signal, and converts it to a much lower I-F frequency signal.

Automatic Gain Control (AGC) circuits in television receivers hold the picture strength to an even level, and prevent fluctuation between extreme darkness and extreme brightness when the level of the signal changes.

The low-voltage power supply in a TV receiver is not much different from those used in radio receivers, and other electronic devices.

High-voltage power supply circuits in TV receivers are intended to provide the extremely high voltages needed by the picture tube for proper operation.

Extreme care should be used when handling picture tubes to prevent them breaking or "imploding".

Used picture tubes and new ones are equally dangerous so long as they contain a high vacuum inside.

NOTES

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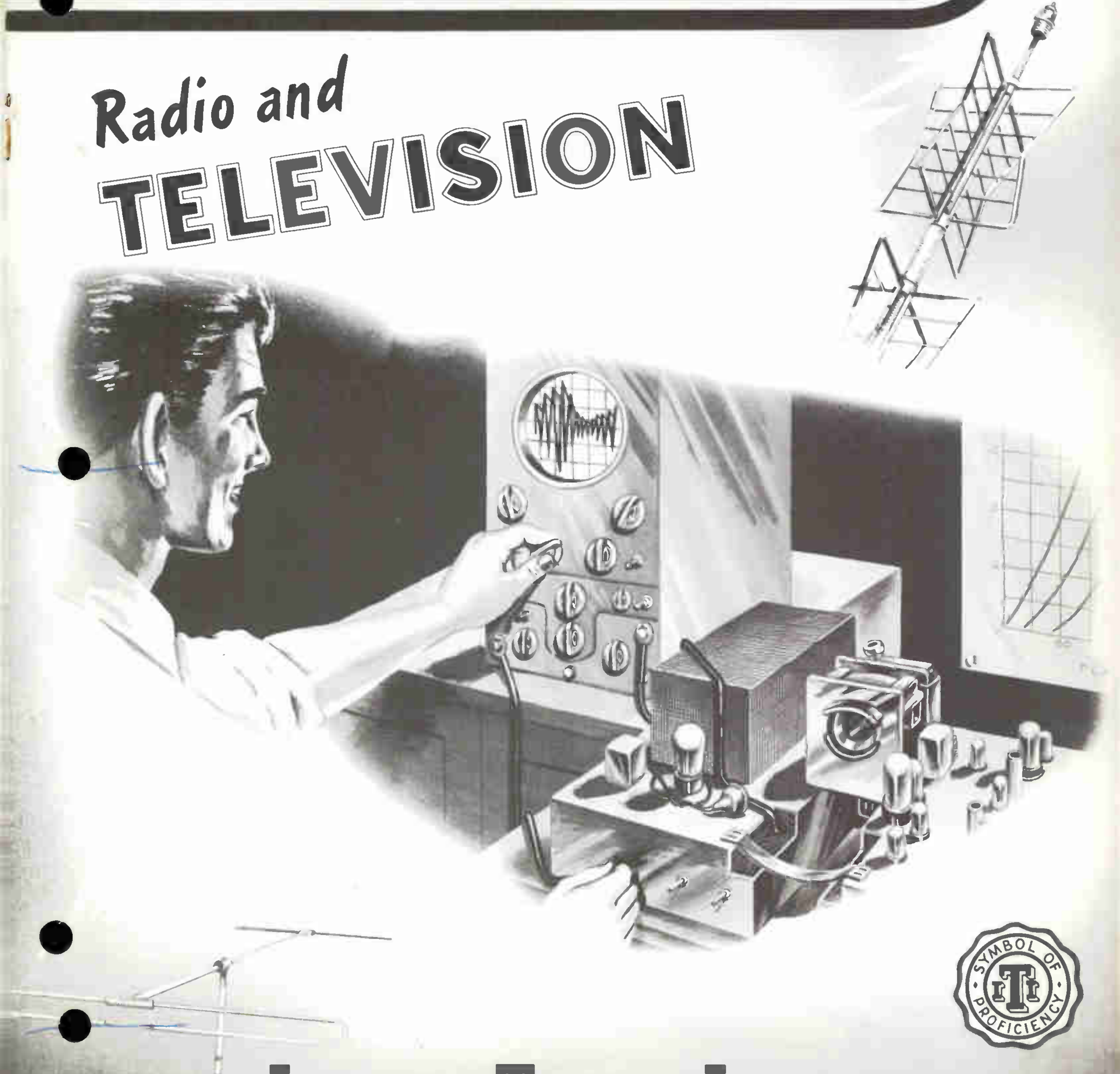

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RADIO TELEVISION

PICTURE TUBES

Contents: Introduction - The Kinescope - Deflection and Focus - The Ion Spot - Deflection and Focus Coils - Comparing Electrostatic and Electromagnetic Tubes - Screen Phosphors - Metalized Screens - Types of Picture Tubes - Picture Tube Requirements - Rectangular Tubes - Deflection Angle and Deflection Yoke - Base Pin Connections - Ion Traps - High Voltage Connection to Metal Tubes - Testing for High Voltage - Grid Control-Cathode Control — Notes.

Section 1. INTRODUCTION

In our previous studies we have made many mentions of the picture tube. In the lesson on cathode ray tubes we went rather deeply into the discussion of some of the peculiar characteristics of the tube used to reproduce the scene which is viewed by the camera tube.

But there are still a good many things we have not mentioned. We have scarcely touched upon the subject of the phosphors which go to make up the screen. Nor have we said much about the persistence with which the screen continues to glow after the scanning beam has passed over it. These will all be discussed in detail in this lesson.

The troublesome "ion spot" which can be found in tubes using magnetic deflection will also be discussed, and the methods used to correct the spot, or the manner in which the spot is prevented.

Section 2. THE KINESCOPE

Perhaps in your reading you have come across such names as the *iconoscope* and the *kinescope* and you have wondered what they meant. We have already described the iconoscope at considerable length. It is one of several types of camera tubes. As a matter of fact the iconoscope was the original camera tube which was invented by Dr. Zworykin. This has all been discussed in a previous lesson.

In his experiments Dr. Zworykin needed a picture tube as well as a camera tube. He called his first picture tube — a variation of the cathode ray tube — a *kinescope*.

There have been a number of changes in picture tubes since Dr. Zworykin's first kinescope. The face of the screens have increased in size. Some are now rectangular instead of being round. The necks of some are shorter and the bulbous parts flare out more. We have also been introduced to the "Black" tube, the "Daylight" tube and numerous others.

Yet in all its essentials there are few radical differences between the present day picture tubes and Dr. Zworykin's first kinescope. An internally heated cathode is

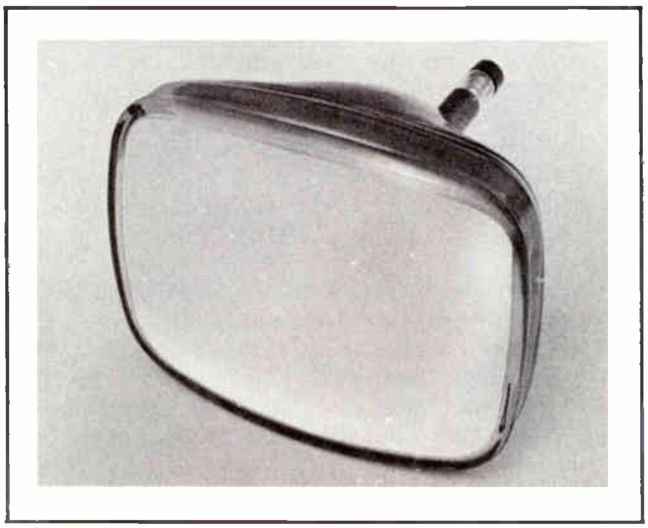

Fig. 1. Picture Tube Which Uses Electromagnetic Deflection.

still used to emit the electrons which go to form the beam which strikes the screen to reproduce the picture. The strength of the beam is still controlled by the varying voltages on the cylindrical control grid which partially surrounds the cathode.

There have been a few changes and improvements in the method of deflecting the electron beam, but even here the changes have not been anything really radical. There have been changes in the composition of the phosphors which are used on the screen, and there will probably continue to be improvements in them.

The picture tube, or kinescope, has the peculiar funnel-like shape of the conventional cathode ray tube. Its internal construction is not greatly different from the cathode ray tube used in oscilloscope work. It also contains the electron gun, some type of deflection system, and of course the fluorescent screen on which the picture is painted.

The electron gun serves the purpose of producing and directing a narrow beam of electrons. The beam of electrons originate in the electron itself, and are then directed down the length of the tube toward the screen. The shaping and direction of the beam are also functions of the electron gun.

The screen is formed on the inner surface of the front end of the tube. That part of the tube is flattened out so as to present a good, smooth, flat base for the fluorescent screen. The screen itself is a coating of luminescent material which is spread over the inner surface of the glass which composes the front of the tube. The impact of the high-velocity electrons as they strike the screen produces a light at the point where the electrons strike. The light, or luminescence, does not decay instantly. With some materials the act of decaying, or dying out, is accomplished much more rapidly than with others, but in none of them does the light die out instantly.

The beam is moved around over the surface of the fluorescent screen as the result of the action of the deflection system. The deflection system is located in the neck of the tube. Sometimes the deflection is caused by the opposite voltages which are set up on two opposing flat metal plates. This is the familiar electrostatic deflection we have mentioned so many times. When this type of deflection is used the entire deflection system is contained within the tube itself, with all the connections being made through the pins at the base of the tube.

The other type of deflection is brought about by means of magnetic coils which surround the neck of the tube. This is called electromagnetic deflection. In electromagnetic deflection systems the deflection voltages and current do not enter the tube at all -- only the magnetic field passes through the glass to act upon the passing electron stream.

Section 3. DEFLECTION AND FOCUS

Just as the deflection of the electron beam can be brought about either through the medium of an electrostatic field between two plates or an electromagnetic field between two coils, so can the *focusing* of the electron beam be accomplished by electrostatic or electromagnetic means. Whenever electrostatic deflection is used it is the customary practice to also use electrostatic focusing. Electrostatic focusing is brought about by varying the anode voltage on the first anode of the tube with respect to the voltage on the second anode.

It is the customary practice to use electromagnetic focusing when electromagnetic deflection is used. When magnetic focusing is used the voltage on the first anode is fixed. A separate focus coil is mounted externally on the neck of the tube, and directly over the electron gun. Fig. 2 indicates how the magnetic coils look when they are correctly positioned on the neck of the tube.

The physical position of the focusing coil and the deflection coils can be adjusted by loosening the wing nuts which hold them in position, then moving them along the neck of the tube to the desired location. The coils are free to move around the neck of the tube as well as longitudinally along it. The proper positioning of the coil has a great effect on the focusing of the electron beam.

It should be mentioned that the amount of current flowing through the coil is of great importance also in the focusing of the beam. It should be remembered that the focusing of the beam is dependent upon the strength of the magnetic field, and its exact location. The location can be adjusted by physically adjusting the coil on the outside of the neck of the tube. The

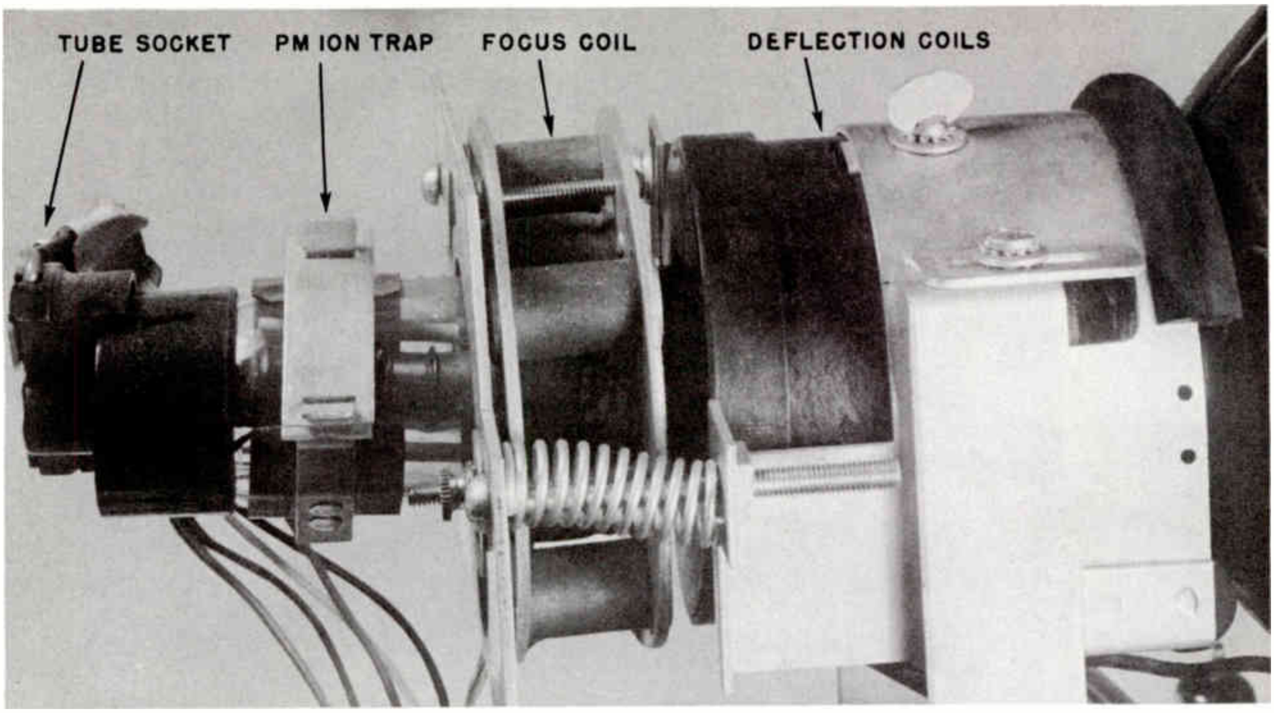

Fig. 2. Electromagnetic Deflection and Focusing Coils. Note How They Surround the Neck of the Picture Tube.

strength of the magnetic field can be controlled by controlling the amount of current which flows through the coil.

What this adds up to is this: the adjustment of the focus on the screen of a tube using magnetic focusing can be accomplished in either of two ways: by physically adjusting the position of the coil, or, by adjusting the amount of current through the coil by the use of a rheostat or potentiometer. Some television receivers use one method, some use the other. On some receivers both methods can be used to adjust the focusing.

The deflection coil yoke must be properly mounted on the neck of the tube. If it should be rotated so that the vertical coils are not in a vertical position and the horizontal coils are not in a horizontal position the picture on the screen will be rotated so that it is not square with the cabinet of the receiver.

Furthermore, the deflection coils must also be mounted at the proper longitudinal position on the neck of the tube. If they are too far back they will have too much effect on the electron beam and the size of the picture will be enlarged out of proportion. This is because of the increased distance between the coils and the face of the screen. Thus, if the coils are very much behind the location they should be the picture will be enlarged to such extent it will be deflected off the screen.

On the other hand, if the coils are too far forward the size of the picture will be too small. This is because the coils are too near the screen to have the proper effect on the electron beam.

On most receivers the coils are so mounted that they are very near the point where the tube flares out from the neck. This provides a scanning pattern on the screen which is of the correct size, and will be properly aligned to fit the mask over the picture tube.

Section 4. THE ION SPOT

When the cathode of a picture tube is heated to its proper temperature it emits electrons just as does any other highly evacuated vacuum tube. But in addition to free electrons there are frequently *negative ions* also emitted from the cathode. You

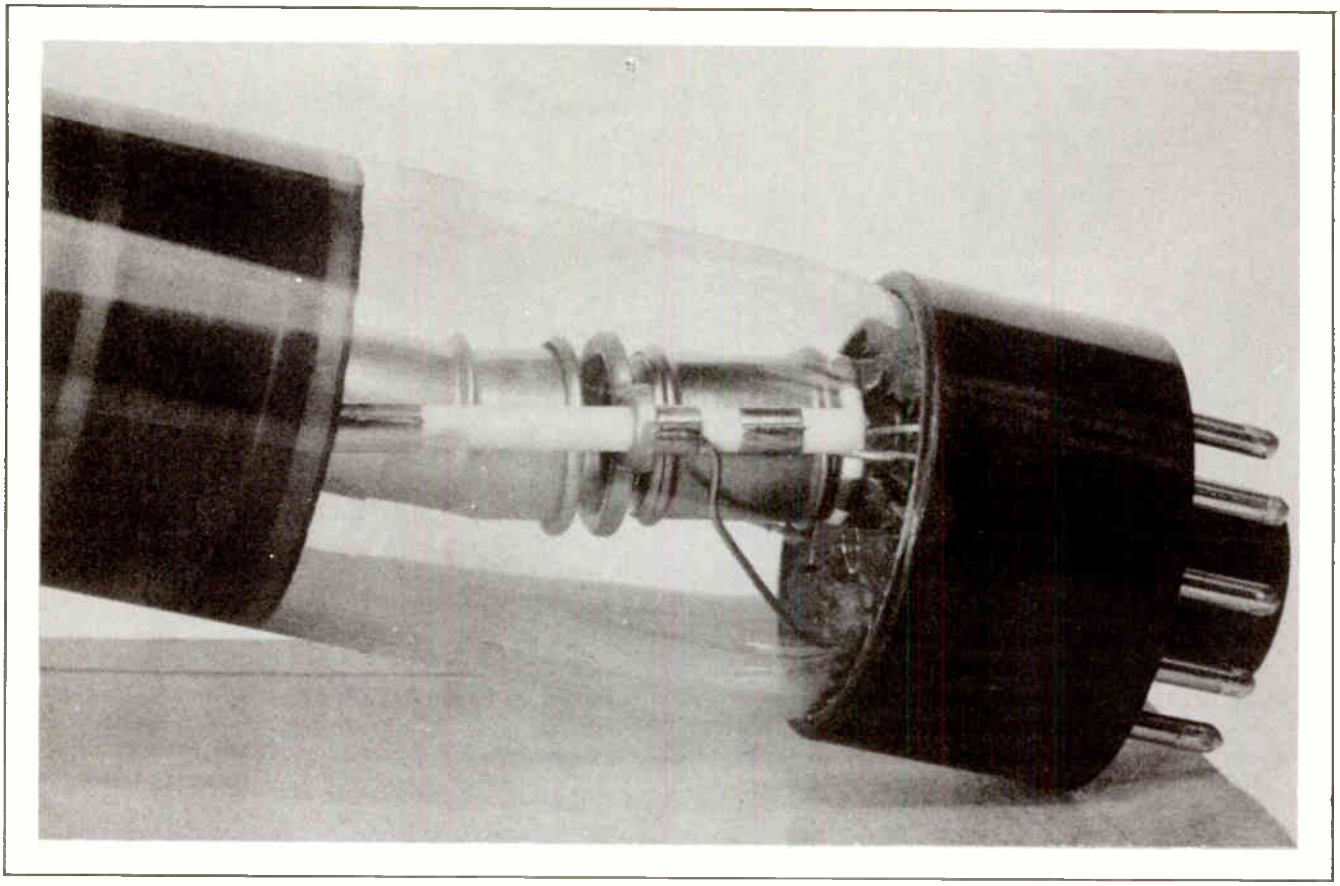

Fig.3. Electron Gun in a Magnetic Tube.

will recall from our previous studies that we frequently become involved with *positive* ions -- those atoms which have lost an electron -- but seldom encounter *negative* ions -- those atoms which have acquired an extra electron.

One of the few places we ever encounter *negative* ions is in the beam current from the cathode of a picture tube.

Negative ions have the same electrical charge as the free electrons which form the major portion of the beam. But they have a much greater mass.

When electrostatic deflection is used in the picture tube the electrostatic field has the same effect on the negative ions that it has on the free electrons. That is, the electrostatic field causes the negative ions to deflect in the same manner as the free electrons in the beam. This means that the negative ions will strike many places on the surface of the fluorescent screen.

But when electromagnetic deflection is used we find an entirely different situation. The ions have a much greater mass than the electrons. This has the effect of a very low velocity for the negative ions. Since the ions travel at a much lower velocity than the electrons it means the ion current is much weaker than that of the electrons.

Due to their extremely high velocity the electrons have a relatively high current value, thus producing a relatively high magnetic field. This magnetic field created by the electrons reacts with that of the deflection coils and causes the beam to bend from its course.

But the negative ions traveling at a much lower velocity, thus producing a much weaker current, does not create a very strong magnetic field. This being true there is relatively little reaction between the magnetic field created by the ions and that created by the deflection coils. Since there is relatively little reaction between them the ions have the tendency to travel straight ahead. If left alone most of the negative ions would strike the fluorescent screen almost in its center. All the heavy ions striking in the same place would, in turn, produce a brown spot in the center of the fluorescent screen. This spot is called an "ion spot".

To prevent the formation of the "ion spot" on the screen some means must be provided to prevent the heavy ions bombarding the screen. This is generally accomplished by preparing what is known as an "ion trap" in the neck of the picture tube.

As a part of the trap the electron gun in the magnetic tube is so oriented that all the electrons and all the negative ions would strike the neck of the tube soon after emerging from the gun, provided nothing was done to change their course. This is shown rather clearly in Fig. 3.

It is not desirable that we permit the electrons to strike the neck of the tube. But we do not care what happens to the negative ions, just so they do not strike the fluorescent screen.

To deflect the electrons from the path which would normally allow them to strike the neck of the tube we place a magnet around the outside of the glass neck. The magnet is so positioned that it will deflect the electrons in the direction of the screen. But the heavier, slower moving ions are not deflected by the magnet. Instead they keep going straight ahead until they strike the side of the tube and are then conducted to the external circuits where they will do no harm.

The magnet which forms such an important part of the "ion trap" is readily adjustable so that the maximum number of electrons are deflected toward the screen where they are wanted. Sometimes the magnet is a permanent magnet such as that shown in the illustration of Fig. 4. But the magnet for the trap may also be an electromagnet. Both types are widely used, the exact one which is used in any specific receiver is usually determined by the requirements of that particular manufacturer.

The location of the ion trap magnet with respect to the other control elements is shown rather clearly in Fig. 2. It can be seen by studying the illustration that the ion trap magnet is the external control element closest to the socket of the tube.

Section 5. **DEFLECTION AND FOCUS COILS**

Fig. 2 gives a pretty good idea of the positioning of the deflection coils and

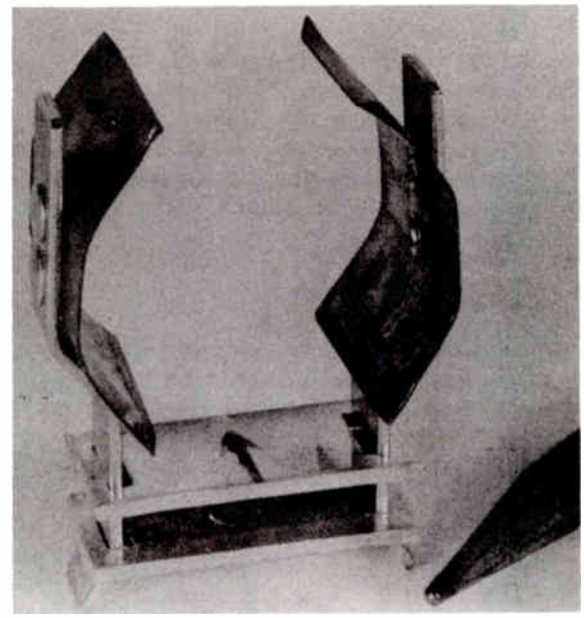

Fig. 4. A Permanent Magnet Used as an "Ion Trap" on Magnetic Deflection Tubes. Size is Shown in Comparison With the Pencil.

the focusing coil as well as the location of the ion trap magnet. It is the usual practice to arrange the coils on the neck of the picture tube in such a manner that they are readily adjustable. But provision is also made so that the coils can be locked in position once the best position has been found.

It is not intended to represent the arrangement shown in Fig. 2 as being the one which is always followed. It is not. Nevertheless, it is a typical arrangement, with most of the coils being installed in a somewhat similar manner.

In order to attain the best possible position for each of the coils it is the general practice to install them so the deflection coils can be moved forward or backward along the neck of the tube. To insure that the picture will be positioned correctly on the face of the tube -- that is, not be tilted to one side or the other -- the coils can be rotated around the neck within reasonable limits.

The appearance of a common set of deflection coils is shown in Fig. 5. It will be noted that one pair of coils are located directly opposite each other so that one

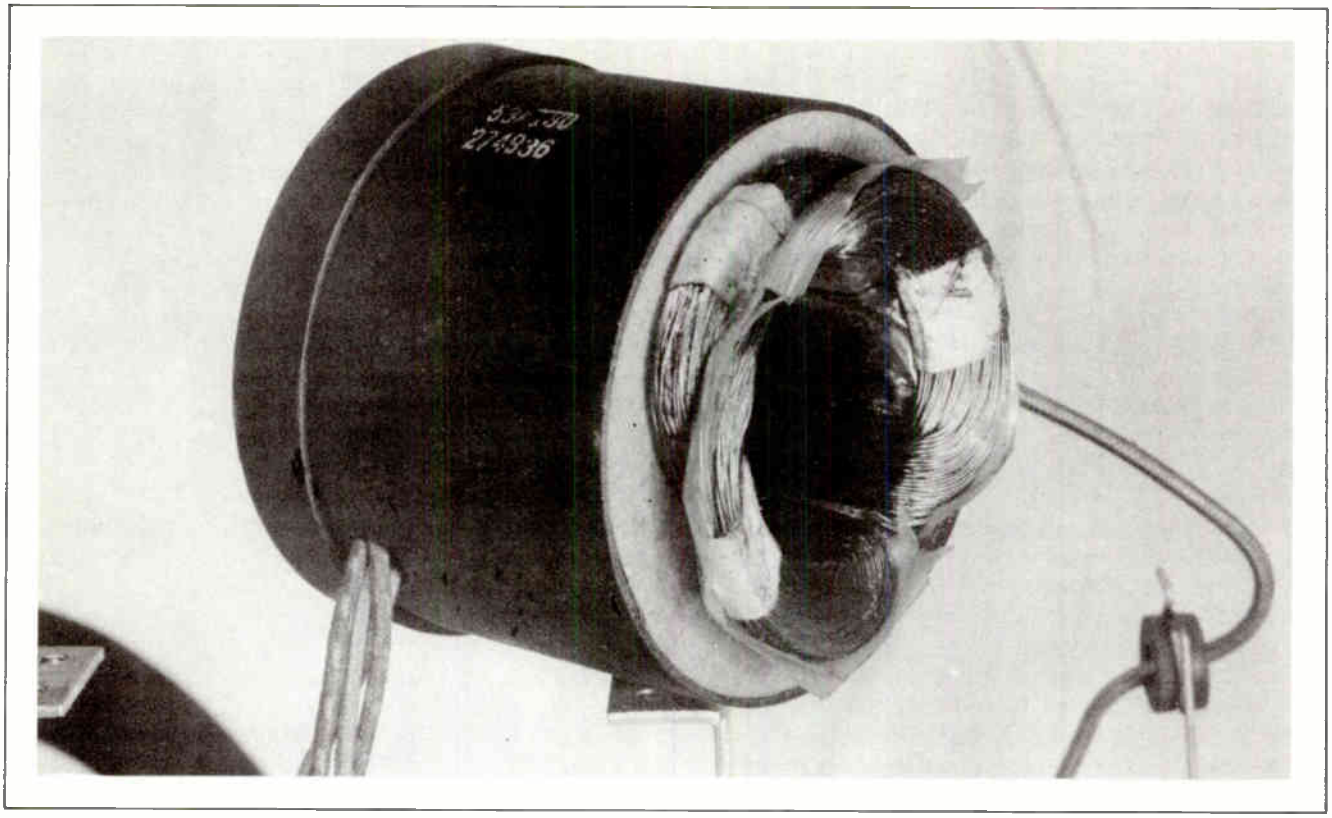

Fig.5. Deflection Coils. Note How the Four Coils are Arranged.

will be on the top side of the picture tube neck and the other will be on the under side. These are the horizontal deflection coils.

It will also be seen that another pair of coils are positioned between the first two so that one of them will be on the right side of the tube neck while its mate will be on the left side. These are the vertical deflection coils.

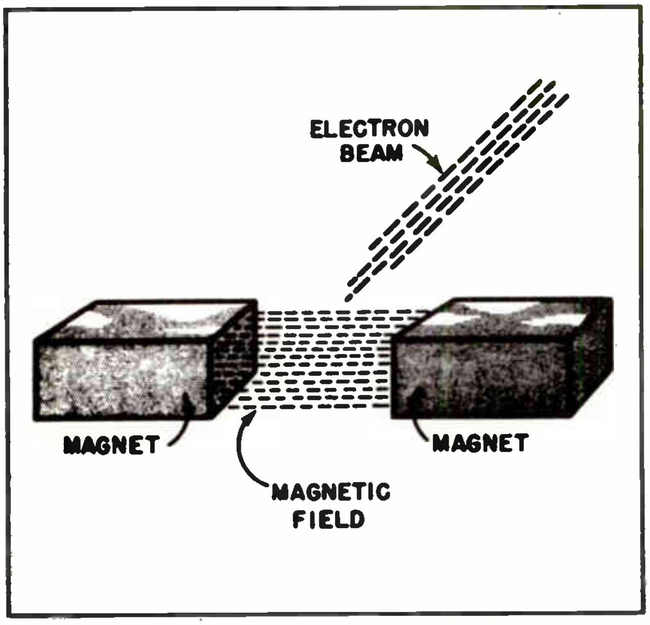

Fig.6.

It might seem at first glance that the vertical coils should be above and below the tube neck rather than on either side. But a moment's reflection concerning the action of an electron in a magnetic field will tell you why the coils are positioned as they are.

The two coils, one on each side of the tube neck, will create a magnetic field between them. When a beam of electrons passes through the field at right angles to the field they will be deflected from their original path. Furthermore, they will be deflected at right angles to both their original direction and to the direction of the magnetic field. Fig. 6 shows the original direction of an electron beam. Fig. 7 shows how the beam would be deflected from its original course by the action of the magnetic field.

If the poles of the magnet were to be reversed the beam would be deflected downward. In this event the deflection would

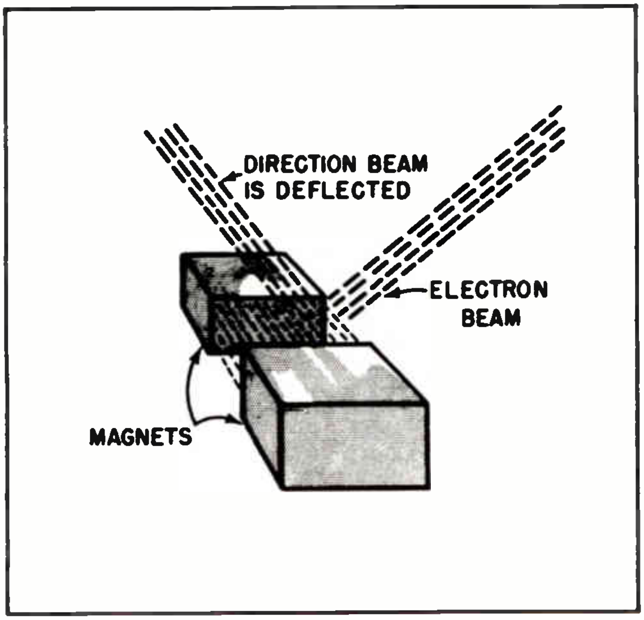

Fig. 7. Direction of Deflection of Electron Beam When It Passes Through a Magnetic Field. The Beam is Deflected at Right Angles to Its Original Direction and to the Direction of the Field.

still be in a direction at right angles to both the direction of the field and the original direction of the beam.

The purpose of the focus coil was explained in an earlier section of this lesson. The appearance of the focus coil in a typical television receiver is shown in Fig. 8. The focus coil is also adjustable. Various methods are used to provide proper positioning of the focus coil. The essentials are that the coil can be moved into the exact position needed to focus the electron beam on the screen, and to be able to lock the coil permanently in that position once the correct position has been found.

Since no two picture tubes are exactly alike, regardless of how closely they may resemble each other, it is necessary to provide these mechanical adjustments so that new tubes can be correctly installed in a television receiver. These adjustments are not necessary for those tubes using electrostatic deflection, of course, since their deflection elements are contained within the tubes themselves. But the coils must generally be adjusted for correct operation whenever a new magnetic type picture tube is installed in a receiver.

Furthermore, the cathode emission changes as the tube ages. Other changes take place within the picture tube, and among the other associated elements which go to make up a television receiver. It is occasionally necessary to change the adjustments of the deflection coils and the focus coil even though the picture tube itself is not changed.

For all these reasons the coils are so arranged that adjustments can be readily made.

Section 6. COMPARING ELECTROSTATIC AND ELECTROMAGNETIC TUBES

We could see the general appearance of a common type of 12 1/2-inch electromagnetic picture tube in Fig. 1. The general appearance of a common electrostatic tube is shown in Fig. 9. Two views of an electrostatic tube is shown in Fig. 9. It should be noted that the length of the electrostatic tube is, comparatively, much greater than that of the electromagnetic tube. There is a much more pronounced flare from the neck of the electromagnetic tube to the screen than is the case of the electrostatic tube.

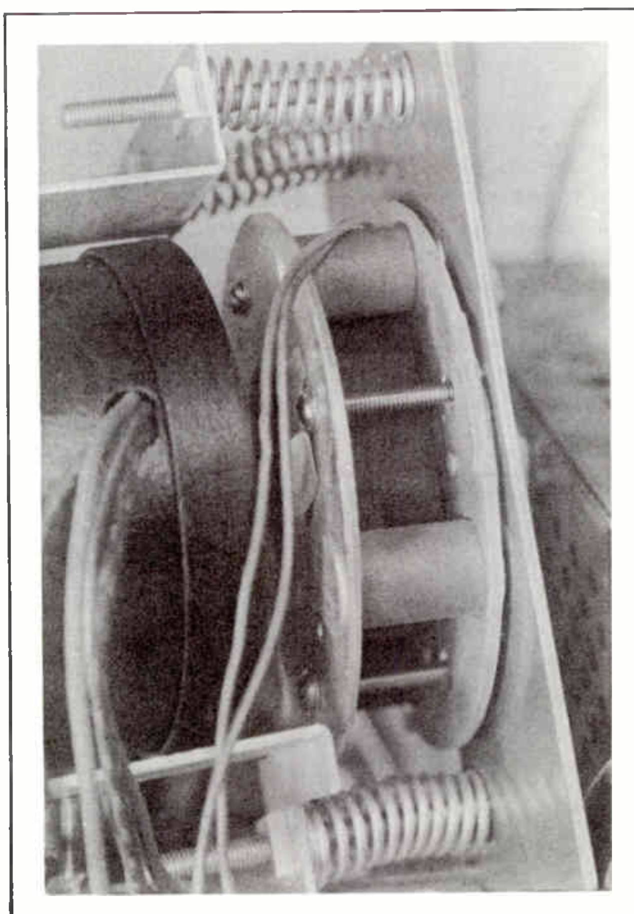

Fig. 8. Focus Coil.

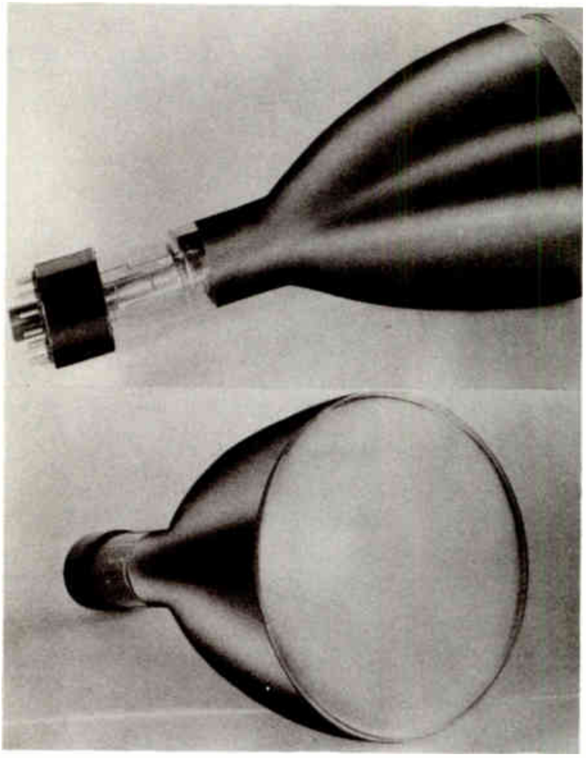

Fig.9. Electrostatic Deflection Tube. Two Views.

There is a difference in the appearance of the electron guns of the two types of tubes. The guns can be seen through the glass of the tube neck which surrounds them. (See Figs. 3 and 10.)

We have already studied the appearance of the electron gun of the electromagnetic tube. A photograph of such a gun is shown in Fig. 3. One of the principle characteristics of the electron gun for the electromagnetic tube is that it is pointed toward one of the walls of the glass neck. Furthermore, it is relatively short.

A photograph of the electron gun in the neck of an electrostatic tube is shown in Fig. 10. The photograph shows the electron gun so positioned that it is exactly in the center of the glass neck, and instead of pointing toward one of the sides of the neck it points toward the screen of the tube. Because of the extra elements which go to make up the gun in an electrostatic tube it will be noticed that the gun is longer than that in the electromagnetic tube.

The glass neck of the electrostatic tube is generally somewhat larger than that of an electromagnetic tube. The elements of the electron gun are somewhat larger, which requires a neck which is a little larger.

There is also a difference in the tube base and tube socket. Although the electrostatic tube in Fig. 9 is considerably smaller than the electromagnetic tube in Fig. 1 the base and socket of the electrostatic tube are much larger.

Fig. 11 shows the base of the electrostatic tube. It can be seen that a 14-hole tube socket is necessary to accomodate the base. This is true although this particular tube does not have two of the pins normally used with a 14-pin socket.

The electrostatic tube requires connections to the filament, the control grid, the cathode, the anodes and so forth just as in any other tube. But in addition to them it must have connections for the four deflection plates, the focusing anodes, the accelerating anodes and the return from the aquadag which coats the inner surface of the tube. So many elements within the tube require many connections at the tube socket.

The electromagnetic tube, on the other hand, does not require nearly so many connections to the inside of the tube. A pair of connections to the filament, the cathode, the control grid and the first anode are all that are needed. A glance at Fig. 12 shows there are only five pins on the base of the electromagnetic tube. The tube socket, in fact, is only half a socket. All this is understandable when it is remembered that so many of the control elements of the magnetic picture tube are on the outside of the tube.

Even the high-voltage connection to the final anode (aquadag) of the magnetic tube is made to the outside of the tube. This is shown in Fig. 13. A special rubber-covered connector is clipped onto the cap shown in the photograph of Fig. 13. The connector provides the high-voltage connection for the final anode.

Section 7. **SCREEN PHOSPHORS**

We have mentioned many times that the inside of the front face of all cathode ray tubes is coated with a fluorescent material to form the screen. This fluorescent material is some kind of a chemical phosphor. All such materials have the property of emitting light when bombarded with electrons. This action effectively converts the energy

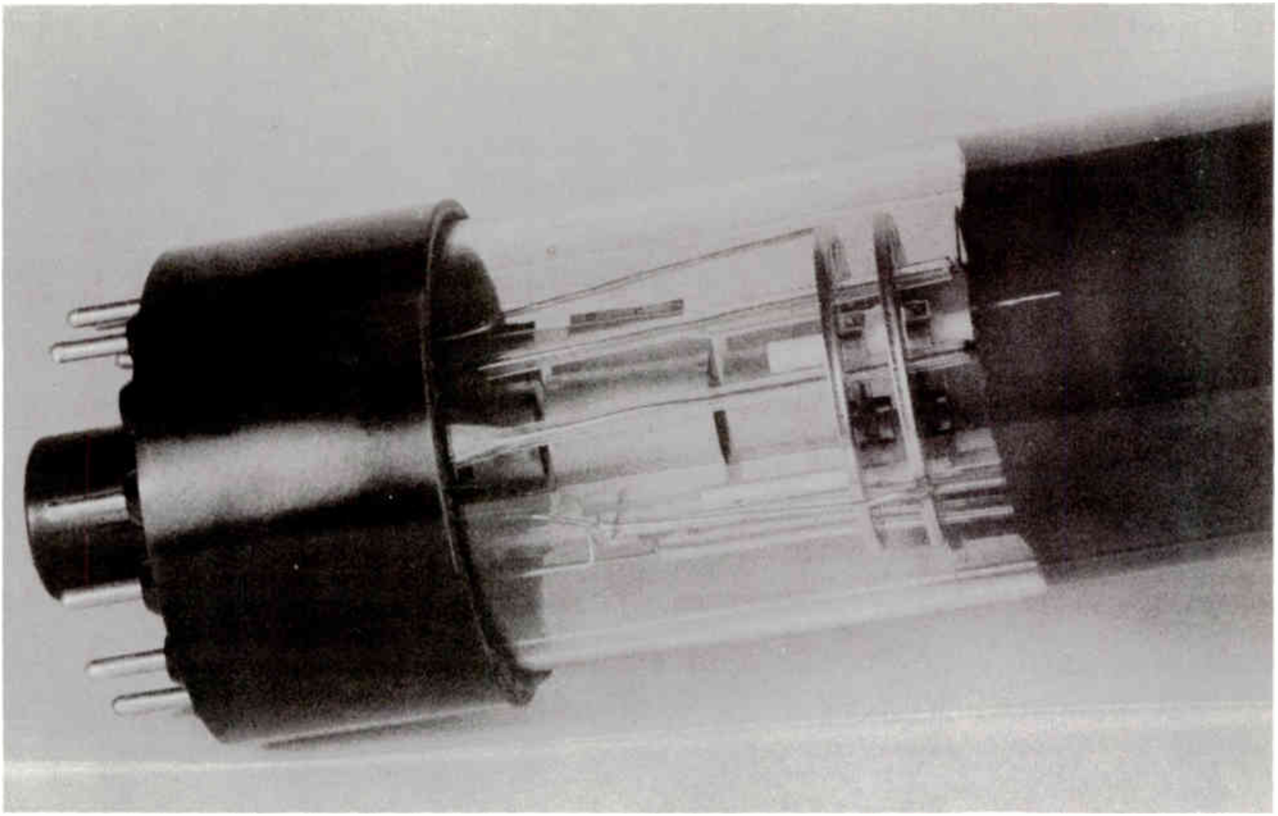

Fig.10. Electron Gun in an Electrostatic Tube.

of the high-velocity electron into visible light.

It would be well to explain the technical meaning of several commonly used words. It should be mentioned that when the light from the screen is radiated as the screen is excited by the electron beam the action is called *luminescence*. When the radiated light is extinguished almost instantly when the excitation ceases the screen is *fluorescent*. Long continued emission of light after the excitation has ceased is called *phosphorescence*.

Table I on page 10 lists the most common of the screen phosphors and gives their most important characteristics. The Table shows the purposes for which each of the phosphors are generally used.

Generally some persistence of screen illumination after the excitation has ceased is a desirable characteristic. Such persistence tends to increase the brightness of the screen. On the other hand, however, the persistence cannot be too great. If it exceeds 1/30th of a second it will lap over into the next frame. Such over-persistence will tend to blur moving objects when they appear in the picture.

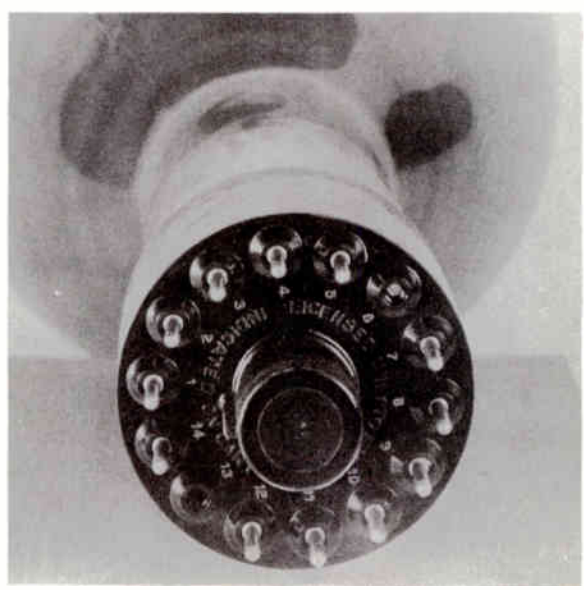

Fig.11. 14-Pin Base of an Electrostatic Tube.

TABLE I	
Phosphor Number	CHARACTERISTICS
P1	Green fluorescence with medium persistence. Used for oscilloscopes.
P4	White fluorescence with medium persistence. Used for television.
P5	Bluish fluorescence with very short persistence. Used in photographic work involving films moving at high speeds.
P7	Long persistence, double-layer screen. Bluish fluorescence of short persistence which is followed by a greenish-yellow phosphorescence which lasts for several minutes. Useful for observing low-speeds.
P11	Blue fluorescence with short persistence. Used in photography.

In the case of television picture tubes it is desirable for the light from the screen to be white. This rules out some of the phosphors which are commonly used in cathode ray tubes for oscilloscope work and for other purposes. Picture tubes require a white light which has a medium persistence. It can be seen, therefore, by studying the Table of Phosphors that P4 phosphor is the one most suitable for picture tube work. There have been many kinds of phosphors used on the screens of cathode ray tubes since

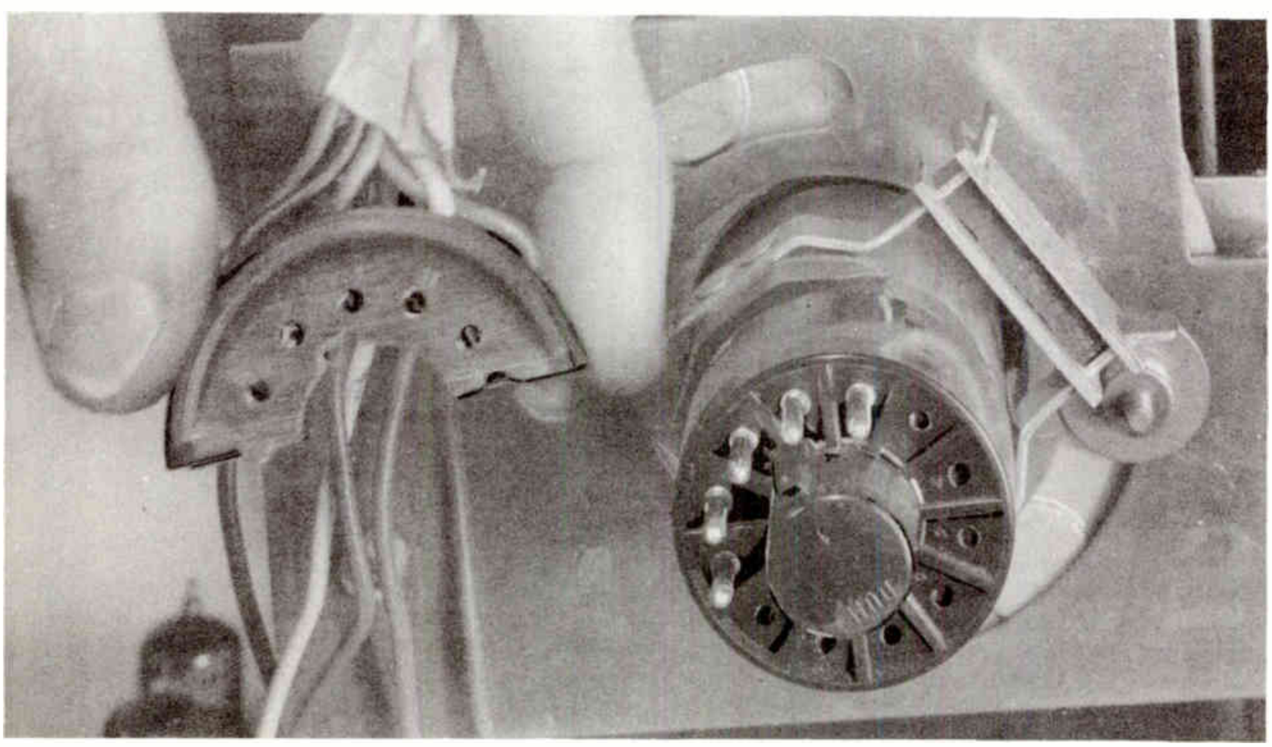

Fig.12. 5-Pin Base of an Electromagnetic Tube.

they were first introduced. But the ones most generally used for picture tube work are compounds of light metals such as cadmium, calcium and zinc. It is the general practice to make the screen a compound of several phosphors. These are combined in the proper proportions to obtain the color and persistence characteristics most desired for the particular purpose for which the tube is to be used.

The phosphors for the screen material are ground until they are reduced to very fine proportions. Then the material is applied to the glass face of the tube. It is applied in a uniform layer.

The useful life of the screen depends on many factors, but the most important are the types of phosphors used and the operating conditions of the tube. Under normal operating conditions it is reasonable to expect a tube life of about 750 to 2000 hours. Discoloration of the screen and a gradual decrease in brightness are indications that the useful life of the tube is nearing an end.

Section 8. **METALIZED SCREENS**

A number of improvements have been made in the composition of the screen of cathode ray tubes since they first came into existence. The present wide-spread use of such tubes as picture tubes in television receivers has intensified the activities of the tube manufacturers in their search for better ways to build better tubes.

One of the most important recent developments has been the introduction of the metalized, or metal-backed, tube. Such tubes have had a very thin, smooth layer of metal coating, usually aluminum, applied over the back surface of the screen.

The metal film is thin enough to allow the electron beam to pass through to the phosphors of the screen when the anode voltages are high enough. These tubes are designed to be operated with anode voltages of 10,000 volts or more.

There are several reasons why aluminum is chosen as the metal for the backing. One reason is that it can be readily vaporized and can thus be spread as a film. Another is that it reflects light well. Thus any light from the screen which would normally tend to extend into the interior of the tube is reflected back to the face of the screen,

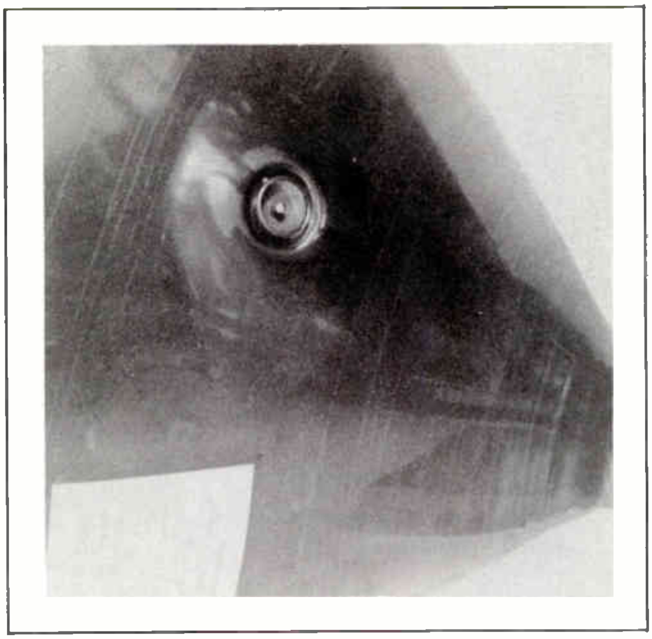

Fig.13. Anode Cap Connection to Aquadag Used as Final Anode in Magnetic Tube.

and thus adds to the brightness of the screen. The aluminum can be applied thin enough to permit the electron beam to pass through readily. Furthermore, the aluminum does not react with the phosphors of the screen, and thus does not spoil the characteristics of the screen.

What all this adds up to is that although the layer of aluminum is very thin, it does nevertheless provide a good light-reflecting surface and an electrical conducting path on the back of the screen. Both of these features are very helpful in overcoming difficulties which were experienced with the earlier cathode ray tubes.

In the earlier tubes, and in those not provided with a metalized backing, the return path for the electrons which strike the screen must be provided through the medium of secondary emission. These secondary electrons are emitted from the screen under the impact of the fast moving electrons in the electron beam, and are then picked up by the second anode. This allows the charge on the screen to approximate that on the second anode.

But the amount of secondary emission from the screen is limited. When extremely high voltages are used the screen may not be able to charge up to that of the anode -- it will remain at the highest potential to which it can charge. This is called the *sticking potential* of the tube. This is the highest effective voltage that can be applied to the tube.

If the sticking potential of the tube is 10,000 or 12,000 volts the anode potential could be 15,000 volts or 20,000 volts or an even higher voltage. But the effective gun voltage would rise no higher than 10,000 or 12,000 volts because this is the potential difference between the anode and the screen.

Where it is desirable to use voltages running from 20,000 to 50,000 volts in an effort to obtain brighter pictures on larger screens such *sticking* can be a serious disadvantage. The use of aluminized screens has made it possible to apply the higher voltages to the tubes and thus obtain the desired brightness.

Early models of aluminized tubes were used only when exceptionally high anode voltages were available. Improvements in the tubes make it possible to use them at somewhat lower voltages, but they continue to need higher voltages than non-metallized tubes.

Another advantage originally claimed for aluminized tubes was that accidental "ion spots" would not develop on the screen. It was believed the metal film would trap the ions, and prevent them from striking the screen. Experience has disproven these claims. It is necessary to guard against "ion spots" with these tubes, just as with the non-metallized types.

Section 9. **TYPES OF PICTURE TUBES**

It is interesting to learn just what the type numbers of picture tubes really mean. The first symbol consists of one or two numbers. These numbers stand for the screen diameter of the tube in inches to the nearest 1/2 inch. Thus the 7JP4 has a screen 7 inches in diameter, the 10HP4 has a screen 10 inches in diameter and the 12JP4 has a screen 12 1/2 inches in diameter.

The second symbol is a letter, or a double letter, to distinguish between tubes which have the same screen size but different electron gun structure. Thus the 10HP4, mentioned before, has an electron gun structure designed for electrostatic deflection while the 10FP4 has electromagnetic deflection. But it should not be thought that all 10-inch tubes which have magnetic deflection are type 10FP4 tubes. The 10FP4 has an aluminized screen while the 10BP4, also a magnetic deflection tube, uses an ion trap. What all this means is that the second symbol distinguishes between tubes of the same size but which have different internal structures, and are operated differently.

The final symbol always consists of the letter P and a number designating the phosphor. In the case of television tubes it will be found that all use a P4 phosphor, one which provides a white light with a medium persistence.

There are several types of bases for the tubes. A base which has 11 pins is called a *magnal*. A tube base with spacing for 12 pins, whether or not it actually uses that many, is called a *duodecal* base. A tube base with spacing for 14 pins is called a *diheptal* base.

Many picture tubes are made so as to have practically a flat face. Such tubes have a face approximately 1/2 inch thick. For a given diameter of face such tubes can provide pictures of a larger size than those on which the screen surface is slightly curved.

Another development in the manufacture of tubes is that of the metal tube. The face of the tube and the neck of the tube are glass. But the widely flaring part is made of metal. The use of metal here enables manufacturers to build larger tubes more economically than if the entire tube were made of glass.

Section 10. **PICTURE TUBE REQUIREMENTS**

There are several requirements which must be met if a picture tube is to function the way it is intended to operate. Among these are such things as correct operating voltages and the necessary signal voltages. These must be furnished by the other circuits of the receiver. Such requirements include:

1. *Filament power.* In order to obtain the electron beam needed to paint a picture on the face of the screen we must provide heating power for the cathode of the tube. The heated cathode will provide a beam of electrons. If there is no filament power, or if the filament of the tube is open, the cathode cannot be heated. In that case there will be no electron beam and no scanning spot regardless of whether or not the other elements of the receiver are functioning correctly.

2. *High-voltage.* A special high-voltage must be supplied to the second anode of the tube. If the high-voltage is missing there will be no beam and the screen will be completely blank.

3. *Low-voltage.* Often there will be a separate low-voltage power supply. Such power supply provides the necessary potentials for the grid bias and the voltage for the first anode of the tube. The low-voltage power supply must be functioning correctly for the receiver to operate.

4. *Video signal.* Regardless of how the other circuits of the receiver are working, if there is no video signal there will be no picture. If the video signal is missing there can be a well-defined raster on the screen, and the receiver will appear to be "alive" in other respects. But there will still be no picture. The video signal must be picked up by an adequate antenna system, converted in the mixer circuit, amplified by the I-F channel, detected by the detector circuit, and finally coupled to the control grid of the picture tube.

5. *Deflection signals.* The video signal can be amplified properly, and fed to the control grid of the picture tube in the proper manner. But if the deflection circuits are not functioning properly there will still be no picture. Without the deflection circuits the electron beam will merely create a dot in the center of the screen.

   If the horizontal deflection circuits are working but not the vertical ones there will appear to be only a single white line across the center of the screen. On the other hand, if the vertical deflection circuits are working but not the horizontal circuits there will be only a white line up and down through the center of the screen.

From all this it can be seen that there are many things which must all be functioning properly before we can hope to create a picture on the screen of the picture tube.

The picture tubes are important elements, but they cannot re-create a picture by themselves.

Section 11. RECTANGULAR TUBES

With the passage of time there have been many changes in the construction and physical appearance of picture tubes used with television receivers. Sizes have grown from the microscopic 7-inchers used in the "prehistoric" days which followed the second World War. There was that first daring leap from the conventional 7-inch tube to gigantic 10-inch tubes. Then there was the monumental step which introduced the electromagnetic deflection tube. From then on additional changes followed each other with bewildering rapidity.

For a short time it seemed the industry would settle down and standardize on the 10-inch picture tubes. For a brief period the principal difference between the tubes used in various brands of television receivers was that some used electrostatic deflection while others used electromagnetic deflection.

The public had scarcely become accustomed to the "large" 10-inch picture tubes before a manufacturer announced an amazing new 12½-inch tube. Other manufacturers followed suit. The same year saw the introduction of 14-inch tube. Picture tube sizes continued to increase with almost every change of the seasons.

The next major change in picture tubes was the introduction of the rectangular picture tube. The rectangular tube has grown so popular that more television receivers now use rectangular tubes than round ones -- far more.

The principal advantage of the rectangular tube is that it provides a larger raster on the screen with less of the screen area wasted. This makes it possible to provide a larger picture with smaller receiver.

Figure 14 makes this somewhat more clear. The raster, it must be remembered, is actually rectangular in shape. The aspect ratio, which is 4-to-3, is established at the transmitter.

When the raster is placed on the screen of a round tube as at A in figure 14 much of the screen surface is not used. There is a large unused area at the top of the screen and an equally large area at the bottom. Similar, but somewhat smaller, areas are unused at the right and the left sides of the screen.

Despite the fact that much of the screen area is never used for picture reproduction

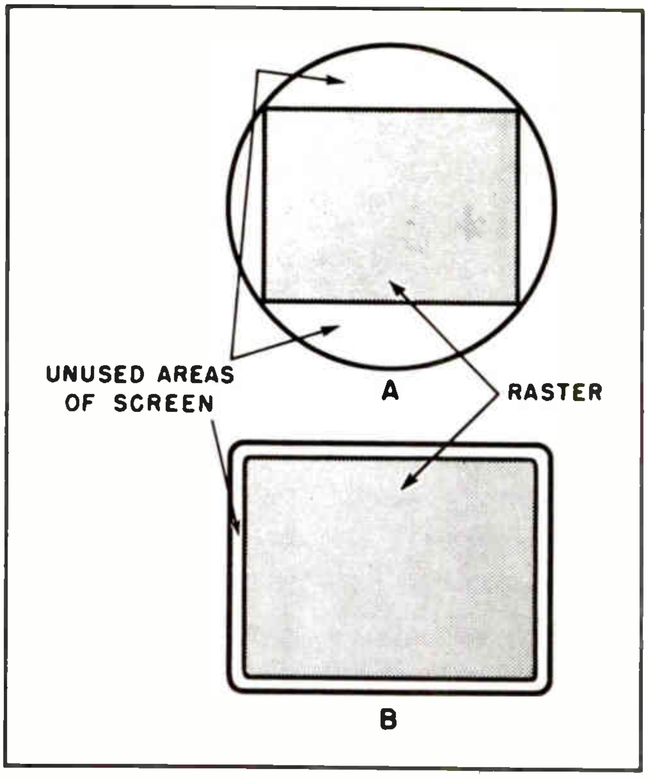

Fig.14. Comparison of Rasters on Round and Rectangular Tubes.

it is still necessary to provide physical space inside the cabinet of the receiver to accommodate the tube. The unused portions of the screen means that much space inside the cabinet is not used.

It can be seen by studying B of figure 14 there is much less unused space on a rectangular tube whose screen is shaped to fit the aspect ratio of the transmitted picture. The illustration shows minor areas of unused screen on each of the sides of the raster; but in actual practice the raster covers the entire screen area. It often extends slightly beyond the edges.

Soon after the introduction of rectangular tubes the trend toward larger sizes was resumed. 16-inch and 17-inch tubes became quite popular, but it was not long before they began to take a back seat to 20-inch and 21-inch tubes. Nevertheless, the 16-inch and 17-inch tubes have retained their popularity longer than any other group of tubes; it seems probable that they will be with us a long time.

Almost a year passed after the 21-inch tubes became commonplace before the 24-inch tube came on the market. Later the 27-inch and the 30-inch tubes were introduced.

For the time being tube sizes seem to be reasonably stabilized, at least temporarily. 17-inch television receivers continue to attract a lot of buyers; it seems likely their popularity will continue. The 17-inch receiver fits well into the small living rooms in modern homes and apartments. Often the picture reproduced on a 17-inch screen is more sharp and clear than that on a larger screen, especially when the picture must be viewed from close up.

Furthermore, the 17-inch receiver is less expensive than the larger sizes.

The 21-inch picture tube — and the same holds true for the other larger sizes -- is more popular in those homes which have larger living rooms, or which are so arranged that the picture can be observed from a greater distance. The 27-inch and 30-inch receivers have achieved a limited popularity among those owners who have the space to accommodate such monsters.

Most of the picture tubes larger than 16 inches are rectangular. Exceptions are the 19AP4, which is a 19-inch round tube with a metal shell, and the 24AP4, which also has a metal shell. It is possible other larger-size round tubes will yet be designed. But the overwhelming majority of the larger tubes are rectangular.

From the standpoint of space the rectangular tubes have another advantage over round tubes. In general, rectangular tubes are shorter from the screen to the base than round tubes of an equivalent size. Figure 15 shows how this is true.

The upper diagram in figure 15 is the outline of a 16AP4 tube. The 16AP4 is a round tube with a metal shell. It can be seen that the 16AP4 has an over-all length from the tip of the base pins to the front face of the tube amounting to 22¼ inches. This length may vary by ¼ inch, more or less, but this indicates quite clearly the length of that tube from extreme front to extreme back -- the space to be provided inside the cabinet.

The lower diagram in figure 15 is the outline of a 16KP4 picture tube -- a rectangular tube. It is only 18-3/4 inches from the front of the face to the tip of the base pins -- 3½ inches less than the 16AP4.

Because the 16KP4 tube is much shorter from front to back than the 16AP4 it is

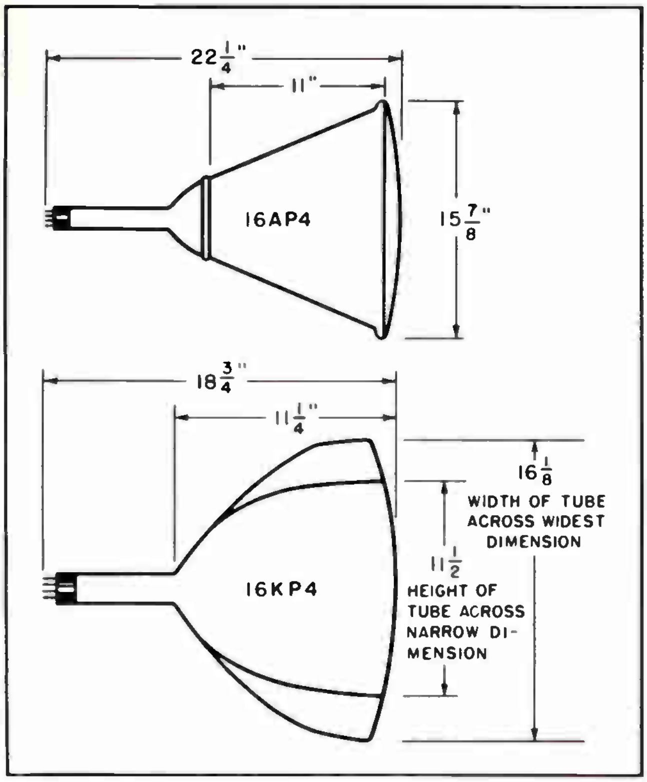

Fig. 15. Comparison of Dimensions for Round and Rectangular Tubes.

possible to use it with a much smaller cabinet than is needed by the latter tube.

The difference of the dimensions of the two types of tubes has still another effect on the size of the cabinet needed to house them. By comparing the two diagrams in figure 15 it can be seen that the 16AP4 tube is 15-7/8 inches high, while the 16KP4 tube is only 11½ inches high. This is a saving of more than 4 inches in favor of the 16KP4, meaning the rectangular tube can be used with a cabinet which is neither as high nor so deep as that needed for the round tube.

Yet both tubes provide the same size picture.

All of which means that a television receiver using a rectangular 16KP4 tube can get by with a much smaller and less expensive cabinet than one using the round 16AP4, yet the picture on both receivers will be the same size.

These factors would seem to relegate the round tubes into obsolescence. And such is largely true. Rectangular tubes have almost completely replaced round tubes in recently designed receivers.

Yet, the long round tubes have one attractive feature which causes them to appeal to designers. The longer tubes do have a narrower deflection angle. The deflection angle refers to the degree to which the electron beam is deflected by the magnetic field of the deflection yoke. The smaller deflection angle carries with it certain technical advantages. The matter of the deflection angle will be touched upon next.

Because the deflection angle of the long round tubes is narrower some designers contend such tubes provide a better quality picture than the rectangular tubes with their sharper deflection angle.

Section 12. DEFLECTION ANGLE AND DEFLECTION YOKE.

Figure 5 is a good illustration of a deflection coil, or "deflection yoke" as it is becoming more frequently known. One of the pair of coils, in which the coils are positioned opposite each other, is used to deflect the electron beam inside the tube in a horizontal direction. The other pair of coils deflects the beam in a vertical direction. This has been discussed in a previous lesson, and will be gone into more in a later one. It is mentioned at this time solely for the purpose of emphasis, and as an introduction to a further discussion of the coils.

The manner in which the current through the coils is controlled will also be discussed in another lesson.

The original magnetic picture tubes were quite long -- although shorter than existing electrostatic deflection tubes -- and the angle of maximum deflection not excessive. A maximum deflection angle was about 50° to 55°, with an angle of 53° being most popular. The 16AP4 tube, which is mentioned several times in this text, has a maximum deflection angle of 53°. This is indicated by the outline diagram at the top of figure 16.

It is desirable, of course, that the electron beam be moved across the face of the screen at a uniform speed. Otherwise, the picture will be distorted so parts are either compressed or expanded out of normal shape.

Many factors must be considered when engineering a deflection amplifier. The deflection amplifier circuits, and the de-

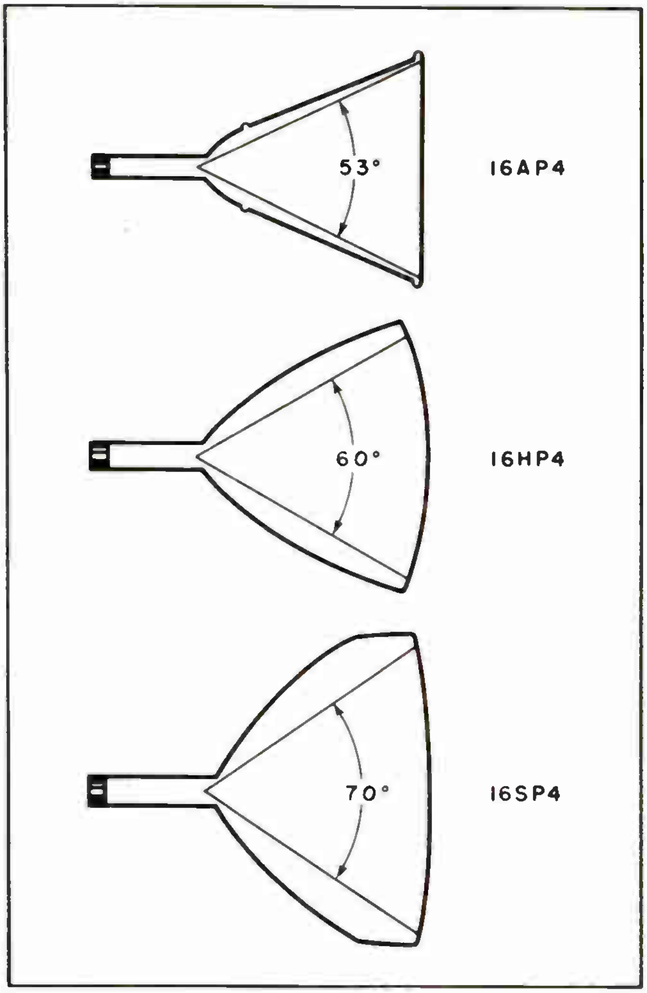

Fig.16. Deflection Angle in Three Types of Picture Tubes.

flection coils which are driven by that amplifier, must be given careful thought. Among things to be considered are the number of turns on the coils in the deflection yoke, and the amount of current permitted to flow through them. Even the shape of the coils, and the arrangement of the layers of the windings, becomes important and must be taken into consideration.

A deflection yoke, whose coils have been designed to work with tubes whose maximum deflection is 53°, might be forced to work with a tube which has a deflection angle of 60°. This could be done by forcing more than the normal amount of current through the coils, and by other modifications. But it is probable such attempts will affect the linearity of beam movement, and thus distort the picture.

A more satisfactory method of deflecting the beam in a tube with a wider deflection angle is to use a deflection yoke which has been specially designed to work with the wider angle tube. Fortunately, manufacturers of deflection yokes and other component parts have designed such yokes.

The same problem arose again when tubes with still wider deflection angles were designed. It became necessary to again design new types of deflection yokes for the wider angle tubes. Figure 16 shows the deflection angles for three types of picture tubes. The 16AP4 is shown to have a deflection angle of 53°. The 16HP4, shown in the middle of the illustration, has a deflection angle of 60°. The 16SP4, shown at the bottom of the illustration, has a deflection angle of 70°

As the sizes of the picture tubes have continued to increase the manufacturers have been forced to use progressively wider angles of deflection. The 24CP4, for example, has a maximum deflection angle in a horizontal direction of 85°; but the maximum deflection angle in a diagonal direction is 90°. A diagonal direction would, of course, mean toward one of the corners of the raster. The 27EP4 and the 27GP4 have the same deflection angles as the 24CP4.

The serviceman is seldom or never interested in the design problems of the engineer. But knowing something of those problems enables him to better understand what is likely to result if an attempt is made to use the wrong component in any given situation.

When a serviceman is confronted with a service problem which is traceable to a defective deflection yoke usually the only satisfactory correction is to replace the defective yoke with a new one. It is not always possible to obtain an exact replacement from the manufacturer, or the manufacturer's distributor. It is then up to the serviceman to substitute.

If an exact replacement is not available the serviceman can replace the defective yoke with one which has similar characteristics. Among the characteristics of the yoke which must be considered are those of inductance in michrohenries, resistance in ohms -- and maximum deflection angle in degrees. In many ways the last mentioned characteristic is most important of all.

Fortunately, it is not difficult to deter-

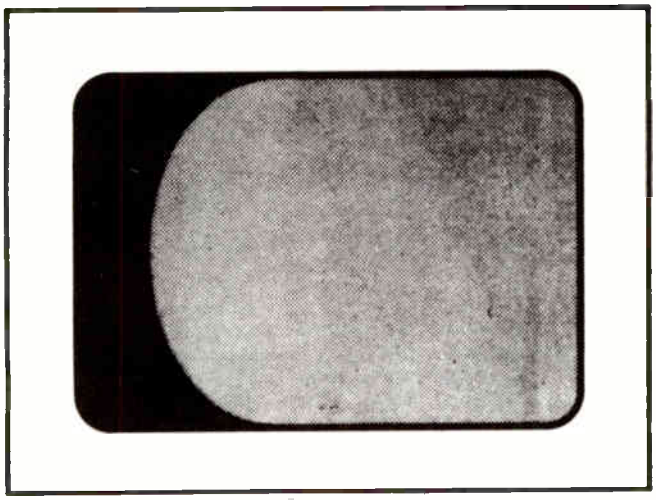

Fig.17. Raster Partially Shadowed; Yoke Out of Position Vertically.

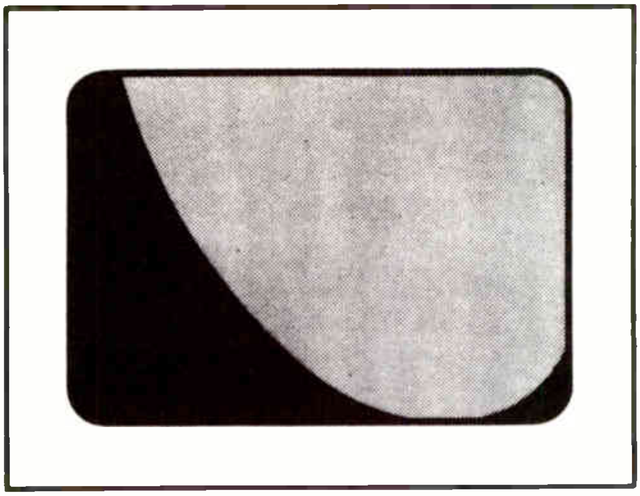

Fig.18. Shadowed Raster Caused by Yoke Out of Position Vertically and Horizontally.

mine the deflection angle of any given picture tube, even though the other information concerning the deflection yoke characteristics is not immediately available. All that is necessary is to look up the picture tube type number in any tube manual. The tube manual always gives the maximum deflection angle of the tube as one of its characteristics. With that information available it is possible to obtain a deflection yoke which will do a satisfactory job.

The matter of positioning the deflection yoke on the neck of the picture tube is something which sometimes requires considerable attention. If the yoke is a little too high, or too low -- or a little too far to one side or the other -- the raster on the screen will be affected. Positioning the yoke forward or backward on the neck of the tube also affects the condition of the raster.

It is not possible to picture every appearance of the raster when it is disaffected by the position of the deflection yoke. But figures 17, 18 and 19 provide a pretty good idea.

Figure 17 shows how the raster will look when the vertical position of the yoke is incorrect. Moving the yoke up or down, with reference to the neck of the picture tube, causes shadows to appear at the right or left side of the screen.

If the yoke is incorrectly positioned in a vertical direction, and also is slightly dislocated in a horizontal direction, shadows will appear at one side and at either the top or the bottom of the screen. Figures 18 and 19 show the appearance of the raster with this condition.

Figure 18 shows the yoke a little out of position in a horizontal direction to cause the shadow in the lower part of the screen. It is also a little out of position in a vertical direction to cause the shadow to appear at the left side of the screen.

Figure 19 also shows the yoke out of position both vertically and horizontally. But the position of the yoke is reversed from that which caused the shadows in figure 18.

It is difficult to explain just how the condition shown in figures 17, 18 and 19 can be corrected by changing the position of the

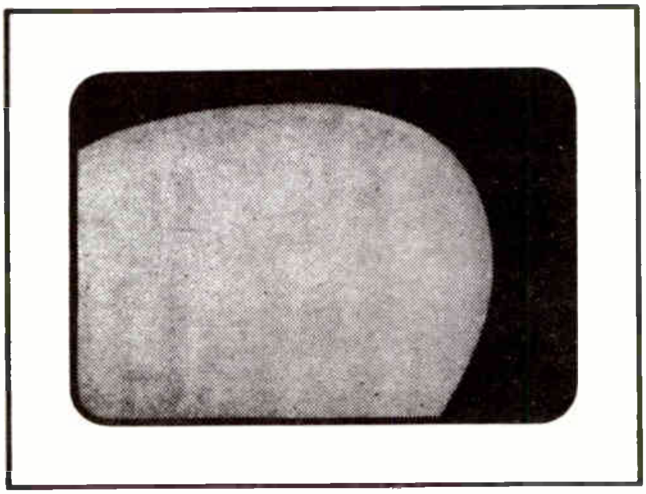

Fig.19. Yoke Improperly Positioned Vertically and Horizontally.

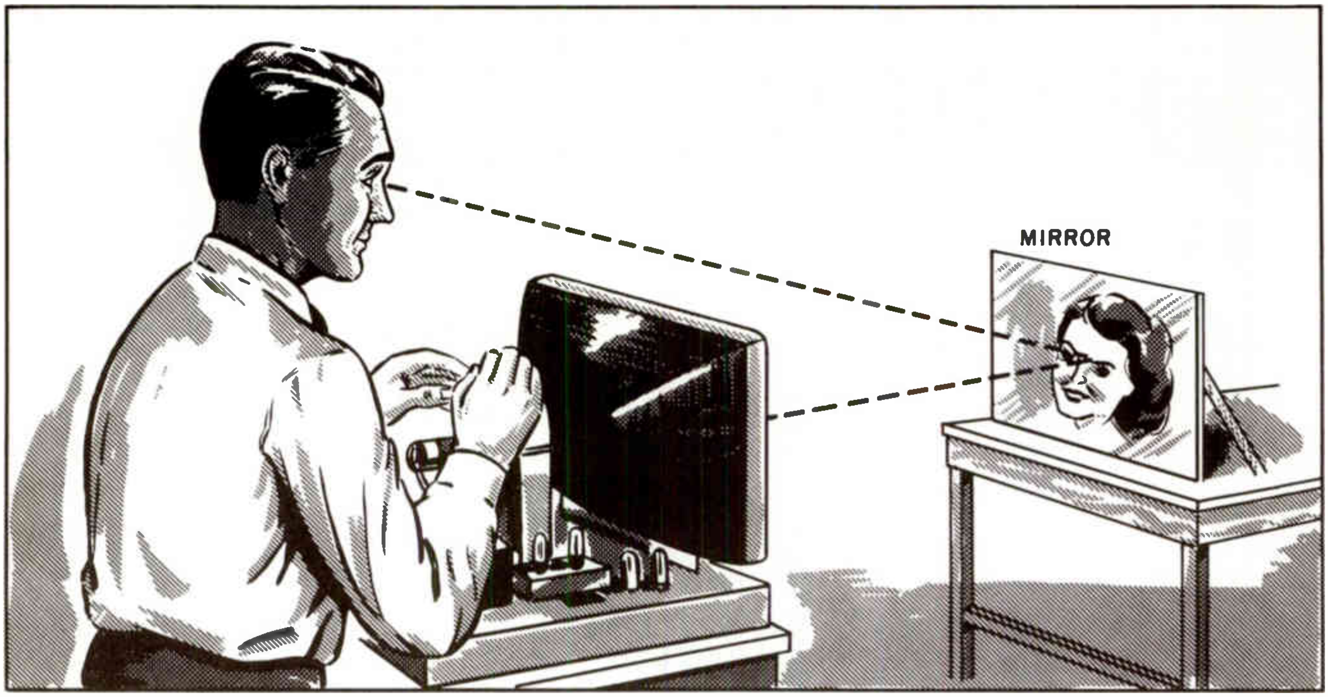

Fig. 20. Using Mirror to Observe Screen While Adjusting Yoke.

yoke. The adjustment must be made while observing the appearance of the screen. One good method is to place a mirror in front of the receiver, as is shown in figure 20. The screen can then be observed by watching the mirror, and the raster brought to the correct size and shape by adjusting the position of the yoke.

Adjusting the deflection yoke to the correct position is a matter of mechanical adjustment. Most television receivers are so designed that the yoke can be moved vertically or horizontally, and also rotated to a small degree around the neck of the tube.

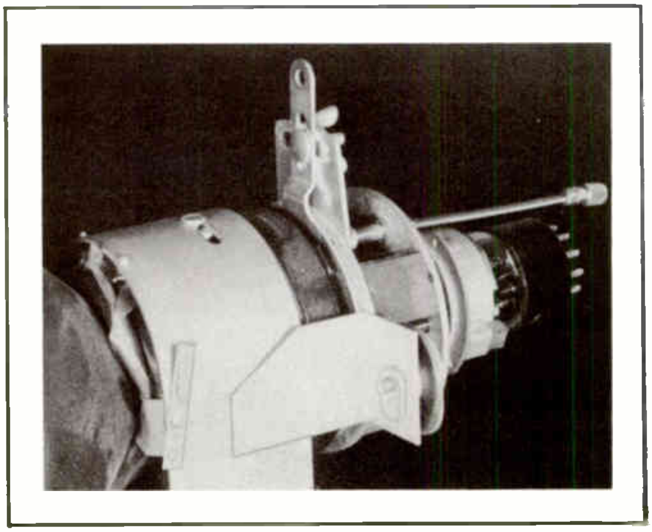

Fig. 21. Mechanical Arrangement of Adjustments for Yoke.

The exact method by which such mechanical positioning is achieved differs from one receiver to another. All manufacturers do not follow the same method. In fact, the exact method used to position the deflection yoke often differs from one model to another built by the same manufacturer.

Figure 21 shows the method followed by one manufacturer. There is a horizontal slot in one of the pieces of metal mounted on the tower to support the yoke. There is a vertical slot in the other piece of metal. The two pieces of metal are held rigidly together, and rigidly in position, by a screw and wing-nut which passes through the two slots. Once the correct position is found the wing-nut is tightened and the yoke held rigidly in place.

Sometimes the adjustment of the yoke position is accomplished by means of a long rod which projects beyond the rear of the cabinet. This method makes it possible to adjust the position of the yoke without removing the back panel from the receiver. For that reason such a method has an advantage over some other methods.

There is a drawback to that method which partially offsets its advantages. The projecting rod is easily moved by a housewife when cleaning or dusting. When the rod is accidentally moved the picture on the screen is distorted or partially shadowed, and is often ruined.

It is not possible to describe all the possible methods which have been used at one time or another to position the deflection yoke. Once the need for such an adjustment is understood it is not difficult to understand the methods actually used for any given receiver. A study of figure 2 shows an adjustment method which is different from that in figure 21.

Section 13. BASE PIN CONNECTIONS

Figure 11 shows the appearance of a 14-pin base for use with an electrostatic deflection picture tube. As picture tube sizes have grown larger, electrostatic deflection has been used less and less. It seems safe to say that electrostatic deflection is not being used in any standard home receivers now being manufactured. Probably the only type television receivers in which electrostatic deflection is being used are the small so-called "portable" receivers.

Despite all this, television receivers using electrostatic deflection can still be found in use in substantial numbers in isolated parts of the country. And electrostatic deflection will probably continue to be used in portable receivers for many years.

But by far the bulk of a serviceman's work is with receivers using electromagnetic deflection. So it is only natural for us to devote more attention to them.

Figure 12 shows the base of an electromagnetic deflection picture tube, and the socket used with it. Fortunately, the base connections of electromagnetic picture tubes have been standardized far more closely than any other item in the entire field of elecronics. Electromagnetic deflection picture tubes--except new types using electrostatic focus--use five pins. These use six pins.

Pins 1 and 12 are the filament connections on all electromagnetic deflection picture tubes. Those two pins are the ones immediately adjacent to the spline, one being on each side of the spline. The location of the spline, and the location of the filament pins with respect to it, is clearly shown in figure 12.

Pin No. 2 is the control grid connection. That is the pin on the extreme right side of the tube base shown in figure 12. That pin is always used for making the necessary electrical connections to the control grid of all electromagnetic picture tubes.

The pin at the extreme left on the base of the picture tube in figure 12 is pin No. 10. That pin is used to make an electrical connection to the "screen grid", or the accelerating anode, of the picture tube. Pin No. 10 is always used for that same purpose on all magnetic picture tubes.

Pin No. 11 is adjacent to No. 10, and located between it and No. 12 pin, which is one of the filament connections. Pin No. 10 can be seen quite clearly by studying figure 12. Pin No. 11 is the connection to the tube cathode. It is the cathode connection on all magnetic picture tubes.

These are the only base pins needed to make the necessary electrical connections to the elements inside the tube. Deflection is accomplished through the medium of magnetism from outside the neck of the tube; thus no electrical connection with any elements inside the tube is needed for that purpose. Nor do most tubes which use magnetic deflection require any electrical connection with elements inside the tube to bring about proper focusing. Most magnetic deflection tubes also use magnetic focusing, and the magnetic field is applied from outside the neck of the tube without any electrical connections to elements inside the tube.

Despite the fact that magnetic focusing is used with most tubes which use magnetic deflection, there are some exceptions to this general rule.

After magnetic deflection tubes had been in use for a number of years a tube manufacturer came out with a new type which used magnetic deflection -- but which substituted electrostatic focusing for the time-honored magnetic focusing. At the cost of nothing more than one additional electrical connection to the picture tube socket it became possible to eliminate the focus coil, or focus magnet, and all the circuits and mechanical arrangements necessary for that type of focusing. Costs were reduced, and circuits simplified.

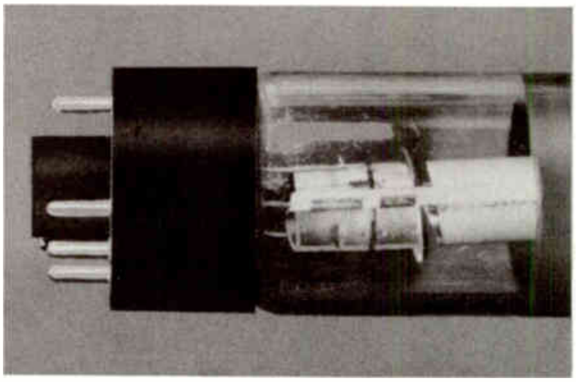

Fig.22. Diagonal Slot Type Electron Gun.

The 17HP4 and the 17LP4 are among the smaller magnetic deflection tubes which use electrostatic focusing. Larger ones are the 20HP4, the 21FP4 and the 21XP4. A few other tubes also use electrostatic focusing, but the ones mentioned are typical examples. All these tubes, of course, use magnetic deflection.

When selecting a picture tube as a replacement for one being used in a television receiver one must keep in mind the type of focusing being used. It is not generally practical to substitute an electrostatic focus tube to replace a magnetic focus tube, nor is it practical to replace an electrostatic focus tube with a magnetic focus tube. This is not to say that such substitution is not possible -- but it certainly is not generally practical.

The focusing voltage required on the focusing grid of an electrostatic focus picture tube is relatively low with respect to that needed by the final anode. The exact voltage needed varies somewhat from one tube type to another, but usually ranges from about 500 volts negative to about 1000 volts positive. The exact voltage required for any given set of conditions depends on those conditions.

Magnetic deflection picture tubes which use electrostatic focusing require one additional pin -- one more than is shown in figure 12. That extra pin is the connection to the electrostatic focusing element inside the tube. That connection is made to pin No. 6.

If you have a picture tube, and you are not certain whether it has electrostatic focusing or magnetic focusing, and you do not have ready access to a tube manual, you can quickly dispel the uncertainty by glancing at the base. If there is a No. 6 pin on the base you can be reasonably certain the tube employs electrostatic focusing. If there is no pin in the No. 6 spot it uses magnetic focusing.

Section 14. ION TRAPS.

In an earlier section in this lesson we mentioned the matter of "Ion spots", and the need for taking steps to prevent them. At that time we described the so-called "bent-gun" which was designed to cope with ion spots. We explained how that type of construction prevents ion spots forming.

Figure 4 shows one type of "ion-trap" used with a bent gun. The presence of the ion-trap causes the electron beam to bend in the bent gun, and then strike the fluorescent screen. The magnetism of the ion-trap has no material effect on the heavy ions.

It should be understood that the "bent-gun" method of handling the ion spot problem is a patented method. It must also be understood that other manufacturers have devised other methods for coping with the same problem. It is probable that still other methods will be worked out in the future.

One other method used to control the ion spot problem is to use a somewhat differently constructed electron gun. Figure 22 illustrates rather clearly the appearance of the gun. Instead of the gap between the accelerating anode and the control grid being at exactly right angles with the neck of the tube, as one would normally expect to find it, the gap has a diagonal angle, or slant. This can be seen by studying figure 22.

The shape of that gap is such that a positive voltage field is reached by one side of the fast-moving electron beam sooner than the other side reaches it. This would normally tend to bend both the electron beam and the moving ions in the same beam.

A magnetic field in the form of an ion-trap is placed across the neck of the electron gun. The presence of a magnetic field at that location affects the electrons to a greater extent than it affects the heavier ions. The net result is that the ions, under the influence of the distorted electric field, will change direction slightly -- enough to make them miss the screen --

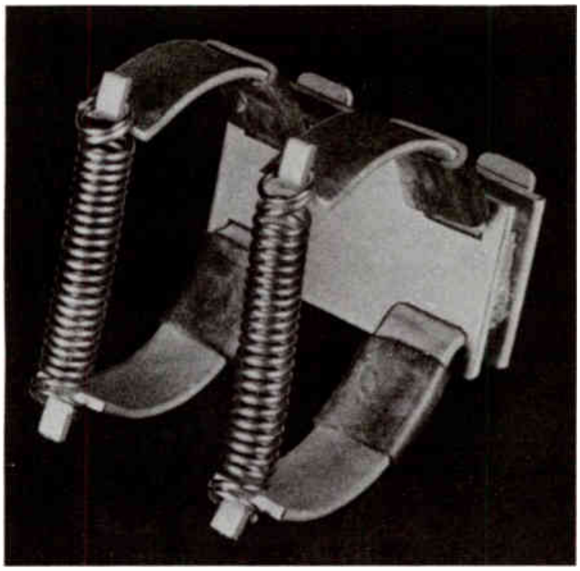

Fig.23. Double Ion-trap.

but the influence of the magnetic field of the ion-trap counteracts the pull of the electric field on the electrons, and keeps them moving straight ahead toward the screen.

Some picture tubes use an ion-trap with only one pair of magnets, such as the one shown in figure 4. Others use what is called a double ion-trap. A double ion-trap is shown in figure 23.

Tube manuals which detail all the other characteristics of picture tubes also indicate whether the tube uses a single ion-trap, a double ion-trap, or no trap at all. This is a part of the technical information about tubes which is contained in tube manuals. In this connection it should be kept in mind that tubes which use an aluminized screen do need ion traps.

There is only one correct position for the ion-trap on the neck of a picture tube. That correct position can be found only through the process of trial and error. The exact position depends on the exact geometric construction of the gun inside the tube, the strength of the magnet in the trap, and other mechanical items which can never be predicted precisely.

When installing a new picture tube, or when replacing one which has been removed from the chassis, it is always necessary to reposition the ion-trap. This is because it is impossible to remove or install a picture tube without removing the ion-trap.

Finding the correct position is sometimes very simple -- at other times exasperating. BUT, THE EXACTLY CORRECT POSITION MUST BE FOUND BEFORE THE RECEIVER CAN BE USED.

To find the correct position the ion-trap is placed around the neck of the tube. Usually the trap must be installed while the socket is disconnected from the base, but this is not always necessary.

With the ion-trap on the neck of the tube the power is turned on the chassis and the tubes permitted to warm up. When it is judged that sufficient time has elapsed to permit the tubes to warm up, the job of positioning the ion-trap is begun.

To find the correct position the ion-trap is slowly rotated around the neck of the tube. At the same time the trap is moved slowly forward and backward along the neck of the tube. It is a good idea to have a mirror in front of the receiver, something like that in figure 20, so the screen can be observed while the ion-trap is being moved around.

As the ion-trap approaches the correct position the screen begins to show some signs of light. That is an indication some electrons are beginning to strike the screen. When that occurs the trap should then be moved more slowly and carefully.

Once light begins to appear on the screen the trap is moved slowly until the brilliance of the screen reaches its maximum. It will be found that moving the trap in a given direction will cause the screen to become brighter and brighter; then, after passing the maximum, it will begin to grow dimmer. When the light begins to get dimmer the movement should be reversed.

Both the rotational movement and the back-and-forth movement should be continued until the one spot is found where the screen is most brilliant. When that spot is found you have found the correct position for the ion-trap.

During the interval in which the correct position for the ion-trap is being sought it is highly desirable to keep the brightness control positioned so the brightness is somewhat less than maximum. A setting about half-way of the brightness control is usual-

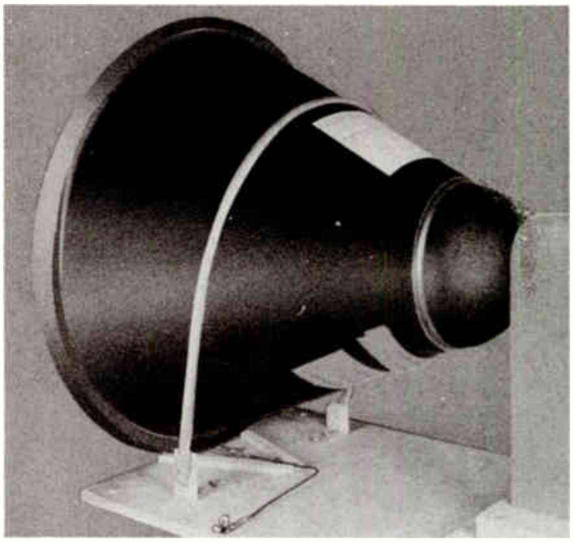

Fig.24. Metal-shell Picture Tube.

ly about right; but a setting for slightly more brilliance or less brilliance may be necessary for certain chassis.

There is a good reason for positioning the brightness control at about the midway point. It is a precaution against ruining the picture tube.

It has been found that when the brightness control is turned too high there is too strong a concentration of the electrons in the beam against the lip of the accelerating anode. Concentrating the electron beam so it strikes one small spot of the electrode can create a situation which causes the beam to actually vaporize the metal of the electrode. When that occurs gases are released inside the tube, and the tube becomes "gassy". The picture on the screen of a "gassy" tube is never sharp and clear; it is always fuzzy. If the gassiness is pronounced the gas may set up so much interference with the electron beam that few of the electrons are permitted to reach the screen. In that case the picture is so dim that little or no picture is visible. In short, the tube is no longer any good.

Occasionally the gassiness of a picture tube can be reduced by permitting the tube filaments to remain heated, and the high-voltage continuously applied to the main anode of the tube, while the brightness control is adjusted for minimum brightness. This action is sometimes enough to cause the high positive voltage of the main anode to collect electrons and ions from the vacuum of the tube, while permitting no additional electrons and ions to pass the control grid. This action sometimes reduces the gassiness to a level where the tube can still be used.

This is not a dependable solution for a gassy tube. Often it will not work. But it is something worth trying before throwing away a high-priced picture tube.

Section 15. HIGH-VOLTAGE CONNECTION TO METAL TUBES.

In figure 13 we showed you the manner in which the high-voltage is connected to the aquadag on the inside the glass walls of the picture tube. The aquadag forms the second anode on most glass picture tubes. The method of making that electrical connection, and as shown in figure 13, is the one generally followed by tube manufacturers.

A different method is followed in making the high-voltage connection to metal-shell picture tubes.

Figure 24 is a photograph of a metal-shell picture tube. It is a 16AP4. By checking the photograph in figure 24 with the outline drawing in figure 15 the metal portion of the shell can be better understood. The portion of the tube is that part of the tube in figure 15 which is shown as being 11 inches long.

The face of the metal tube is glass, of course. Also that slightly bulging bulb just behind the metal part shown in figure 15. But the main shell of the type is metal.

Since the main shell is metal, and since metal is a conductor, it is not necessary to use aquadag inside the tube, nor is it necessary to provide a special connection for the high-voltage. Lack of the high-voltage connection is apt to be confusing to some students when they first inspect a metal-shell tube. Especially so if they have already had experience with glass picture tubes. We know servicemen to become so upset when trying to find the high-voltage connection to a metal tube they would insist the tube was defective because no such connection was present.

The most common method of making the high-voltage connection to the metal tube is to permit the rim of the tube -- which is metal

-- to rest on a small metal bracket or strip. The bracket is then insulated from all other parts of the chassis and other circuits. It is customary to fasten a solder lug to the metal bracket.

When the high-voltage lead is then connected to the solder lug on the metal brackets a good electrical connection will be made to the metal shell of the tube. That is the only connection needed.

Since the shell of a metal tube is at high-voltage when the receiver is working it is necessary to insulate the tube very carefully from the other parts of the chassis. Often a receiver which uses a metal tube is so constructed that the picture tube is mounted separately in the cabinet. Often it has no mechanical connection to the chassis of any kind except that provided by the cabinet.

Such mounting requirements are different from those needed by glass picture tubes. It is customary to mount glass picture tubes directly on the chassis of the receiver.

One method of connecting the high-voltage to the metal shell can be seen by studying figure 24. The metal bracket on which the tube rests can be seen, as well as the high-voltage electrical connection to it.

Section 16. TESTING FOR HIGH VOLTAGE

When there is no raster on the screen of the screen of the picture tube the symptoms might result from any of several causes. It might mean the tube has become defective; that the AGC has killed the picture and the raster; that the horizontal oscillator has creased to function; that high-voltage has been lost; or that something else is wrong.

It is usually impossible to check for other troubles, or their causes, unless it is known whether or not there is sufficient high-voltage. Therefore, when the screen of a picture tube is completely dead, one of the first things a serviceman should do is check for high voltage.

Checking the high-voltage in a television receiver is a relatively simple thing for an experienced technician; yet it bothers the novice greatly. Many servicemen believe, when they first enter the business, that they must measure the high-voltage when in doubt. They believe this despite the fact nearly every instruction manual, every textbook, and every other source of technical information constantly warn against such measurements.

Few service technicians have instruments which are designed for measuring the voltages found in the high-voltage circuits of a TV receiver. Attempts to measure that voltage are often disastrous. There is danger of burning out the meter, danger of ruining the high-voltage circuits of the receiver, and danger of a serious shock. Furthermore, even though nothing bad results from the attempt there remains the strong probability the values derived from the attempted measurement are wrong.

It is rarely necessary for a service technician to know the EXACT voltage placed on the high-voltage connection of a picture tube. An approximate idea of the voltage magnitude is normally sufficient.

The quickest, most simple, and reliable method for determining the high-voltage on a picture tube is to use a screwdriver with an insulated handle. A screwdriver with a tenite handle like the one in the tool-kits we have prepared for the convenience of our students is ideal.

Grasp the extreme end of the insulated handle. Move the metal shank of the screwdriver toward the high-voltage connection of the picture tube or the metal shell of a metal tube. As the metal shank of the screwdriver approaches close to the picture tube high-voltage a spark will leap between the screwdriver and the high-voltage.

If that spark leaps a gap of 3/8 inch or more there is sufficient high-voltage. If it leaps less than ¼ inch it is reasonable to suspect lack of high-voltage.

This method of testing for high-voltage is frowned upon in some quarters as being inaccurate and unscientific. Nevertheless, it is a practice followed widely throughout the service industry.

The metal shank of the screwdriver should not be permitted to touch any other part of the chassis while making a high-voltage test of this kind, nor should it be permitted to approach any other part of any circuit. To do so may permit the high-voltage to leap from the screwdriver shank to that circuit, and damage the circuit. So long as there is no electrical connection between the screwdriver and any other circuit there is no

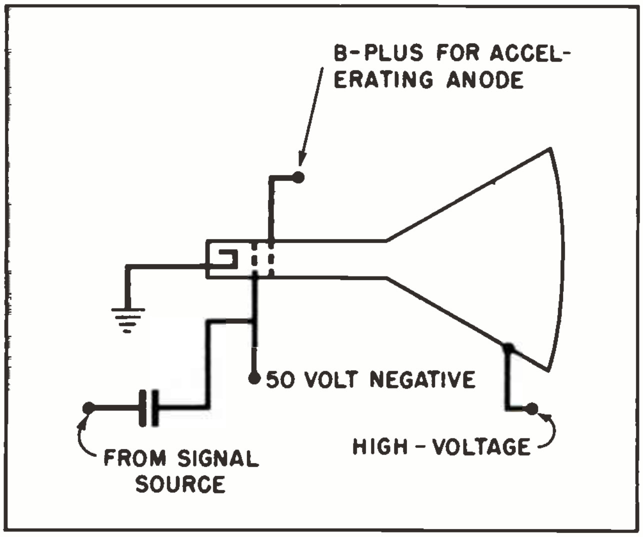

Fig.25. Grounded-cathode Picture Tube.

actual current flow -- other than momentary RF -- to or from the high-voltage circuit.

Permitting the screwdriver to create a short-circuit between the high-voltage circuit and the chassis, or any other part of the receiver circuits, may cause damage inside the high-voltage circuit itself. One critical location is the high-resistance filter resistor in the high-voltage circuit.

Usually that is a carbon resistor. In fact, it is virtually always a carbon resistor. The carbon grains are spaced rather widely inside a resistor which has such a high resistance.

Normally the current flow in the circuit connected to the picture tube is very low. So very low that it can leak through the resistor without difficulty.

Placing a short-circuit on the high-voltage supply causes a high current surge. That high current has difficulty getting through the resistor. The result is to overheat the resistor and cause it to "open".

It may not be a complete "open" insofar as the high-voltage is concerned. The high-voltage will be great enough to bridge the gap inside the resistor with an arc.

That arc often causes both electrical noise and audible noise. The audible noise is often in the form of a high-pitched squeal or whine, but should not be mistaken for the normal horizontal oscillator "squeal". Arcs inside the filter resistor will usually cause it to fail sooner or later. Then more trouble piles up.

The point is, try to avoid short-circuiting the high-voltage supply to the picture tube. But a high-voltage test such as was described here will do no damage. That is because there will be no surge of current through the carbon resistor.

Section 17. GRID CONTROL -- CATHODE CONTROL.

This is a subject which could be left for later consideration. Nevertheless it is one which can be understood at this time just as well as later. This is because it touches on a subject which is no different in the case of a picture tube than that encountered in any other type of vacuum tube circuit.

A picture tube contains a heated cathode which emits electrons. It has a control grid normally biased negative with respect to the cathode in the same way as any other type of vacuum tube is biased. Furthermore, the picture tube contains an accelerating anode, which is similar to the screen grid in other types of vacuum tubes; and a highly positive anode, which is also similar to the anodes in other vacuum tubes.

One thing to keep in mind is that the control grid should be maintained negative with respect to the cathode, just as other control grids are maintained negative with respect to their respective cathodes. That relative voltage polarity can be achieved in either of two ways -- the cathode can be more positive than the grid, or the grid can be made more negative than the cathode.

In practice, both methods are used.

In later lessons of this course we use more diagrams in which the cathode is at ground potential and the grid maintained at a negative potential with respect to ground and the cathode. This is the conventional method of biasing long used with all types of vacuum tubes -- including picture tubes -- and has been discussed in detail and at length in early lessons of this course.

Figure 25 shows the cathode of a picture tube connected directly to ground. In that diagram the picture signal is fed to the grid of the tube in the conventional manner just as any other signal would be fed to any other type of vacuum tube. The control grid is biased with the 50-volt negative voltage.

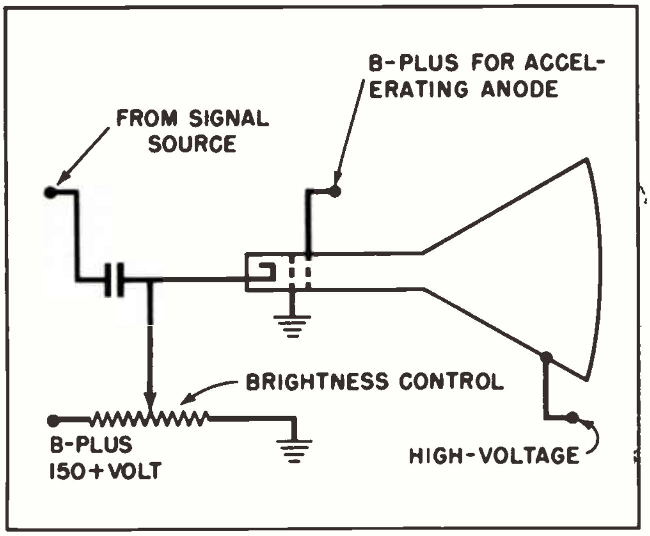

Fig. 26. Grounded-grid Circuits.

B-plus voltage is applied to the accelerating anode, just as positive voltage is fed to any kind of accelerating element in any kind of tube. The high-voltage is applied directly to the picture tube in the conventional manner.

Figure 26 is a little different. There we see the grid connected directly to ground, or B-minus. In short, the control grid is maintained at ground potential.

Instead of the cathode being connected to ground, as in figure 25, it is connected to a source of positive voltage. Usually it is connected to the positive voltage through some form of potentiometer so the exact degree of voltage on the cathode can be controlled. This is the normal brightness control. Much more will be said about the brightness control in other lessons.

Instead of the picture signal being placed on the grid of the picture tube, as is the normal practice with other types of vacuum tubes, the signal in figure 26 is injected on the cathode. In brief, the signal is injected so it varies the voltage on the cathode with respect to ground -- and to the grid.

Since the control grid is at ground potential any variation between it and the cathode will affect the electron stream in the same manner it would if the cathode was at ground potential and the voltage on the grid was being varied with respect to it.

There are certain advantages in maintaining the control grid at ground potential and varying the voltage on the cathode in accordance with the changes in the strength of the picture signal. Sometimes it is possible to eliminate the coupling capacitor between the video amplifier tube and the picture tube. Sometimes it is possible to reduce the number of stages of video amplification. It is also possible to use grid-leak biasing in the D-C Restorer circuit without running into the drawbacks otherwise encountered when the signal is injected on the picture tube grid.

"Grounded grid" circuits are coming into wider use in television work. The subject will be discussed at greater length later. It is mentioned at this time to prepare you for some of the other things which will soon be brought to your attention.

NOTES FOR REFERENCE

Kinescope is the name originally given to cathode ray tubes used to create pictures in television receivers.

The electron beam in a picture tube can be deflected by means of an electrostatic field or by an electromagnetic field.

The electrons in the beam can be focused either by a magnet or by an electrostatic field.

Picture tubes using electrostatic deflection are generally longer than similar size tubes using electromagnetic deflection.

An ion trap is needed in the neck of the tube when electromagnetic deflection is used. The ion trap allows the heavy ions to strike the coated glass at the side of the tube, but deflects the lighter electrons toward the screen at the front end of the tube.

If a trap is not provided the negative ions will cause a brown spot to appear in the center of the screen when magnetic deflection is used.

It was originally claimed for aluminized tubes that ion spots would not appear even though traps were not used. Experience has proven this claim is not founded on fact.

Rectangular tubes provide a larger screen area with less space occupied by the tube. This reduces size of the cabinet.

In general, rectangular tubes have a wider deflection angle than round tubes.

Rectangular tubes are wider in a horizontal direction then in the vertical direction. This conforms closely to the 4-to-3 aspect ratio at which pictures are transmitted.

A deflection yoke contains the vertical and horizontal deflection coils, and the mechanical means to anchor them to a tower which helps support the neck of the picture tube.

The horizontal deflection coils include two coils. They are placed on opposite sides of the picture tube neck, one above and the other below it.

The vertical deflection coils also include two coils. They are positioned on each side of the picture tube neck.

The vertical and horizontal deflection coils are rigidly and firmly mounted in the deflection yoke so they are not free to move around. Any adjustment of the yoke must be accomplished by moving the entire yoke as a unit.

Deflection yokes are built as a single, complete unit by the yoke manufacturer.

Unless the deflection yoke is correctly positioned around the neck of the picture tube the raster will be affected. There is only one position which is absolutely correct. Any deviation from that position darkens some part of the raster.

Yoke manufacturers build yokes so they can be mechanically adjusted and positioned for best operation. The manner of adjustment varies from one manufacturer to another.

Wires in the deflection coils occasionally become short-circuited or open-circuited. When this occurs it is a waste of time to attempt repairs; best solution is to replace the entire yoke.

Best way to adjust the deflection yoke to its correct position is to place a mirror in front of the screen so the effect of each mechanical adjustment can be observed from the rear. It is then easy to find the correct position.

Position of the ion trap also affects appearance of the raster. If it is not correctly positioned it may prevent raster from appearing, or obscure portions of it.

The only way to find the correct position for the ion trap is by experimentation. It should be carefully adjusted to the one position where it provides the brightest raster which completely fills the screen.

If the ion trap is not correctly positioned it can shorten the life of the picture tube. Incorrect positioning causes the electron beam to strike metal parts of the electron gun, which acts to release gas. This will eventually cause a "gassy tube".

The brightness control should be turned as *low* as possible during the adjustment of the ion trap. This helps prevent damage to the gun and the tube during the period of adjustments.

The video signal is sometimes fed to the control grid of the picture tube. When so arranged the picture tube is said to use "grid control".

In other receivers the signal is fed to the cathode. That is called "cathode control".

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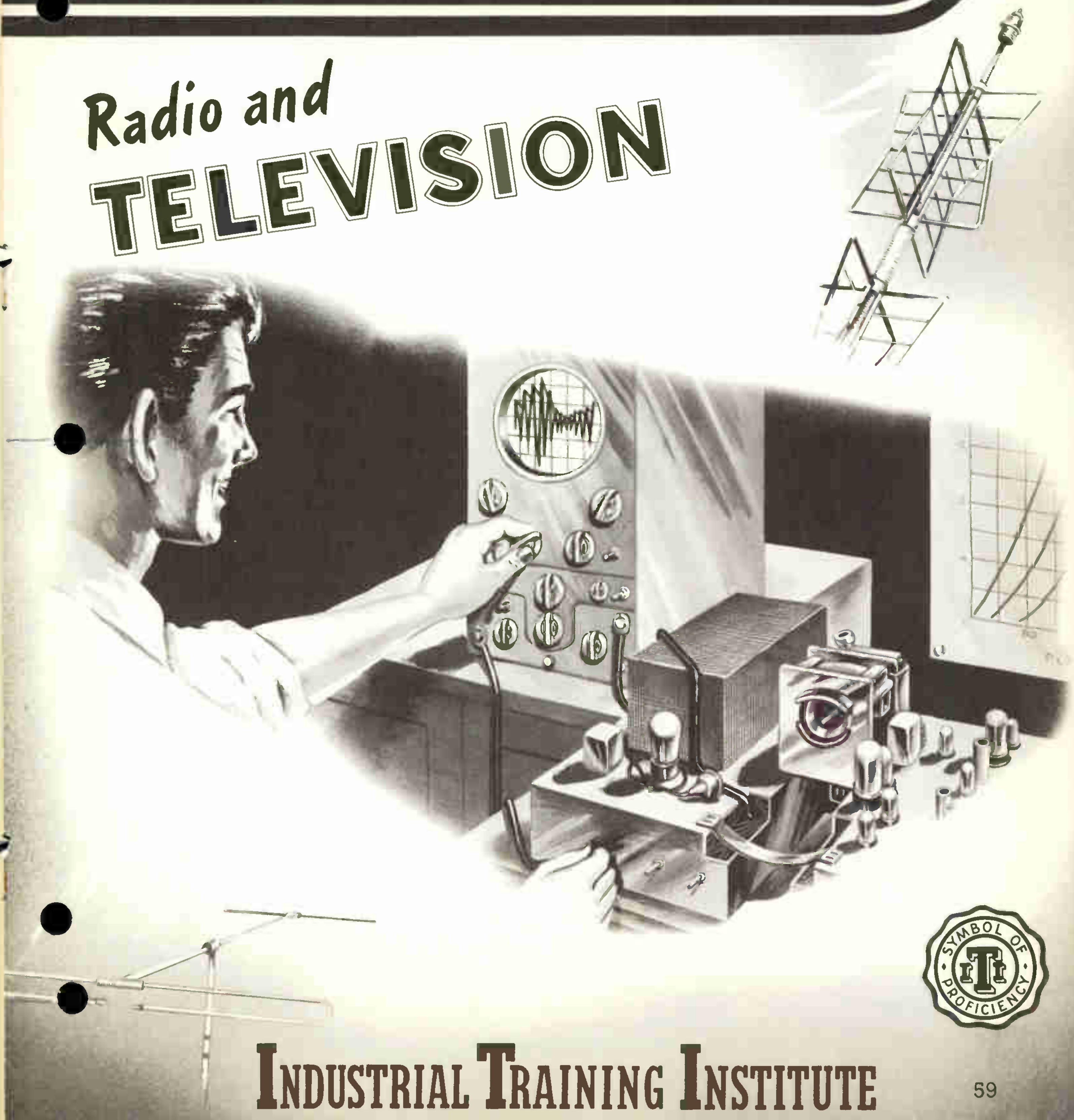

INDUSTRIAL TRAINING INSTITUTE

TECHNICAL TRAINING SERVICE

RADIO TELEVISION

TV POWER SUPPLIES

Contents: Typical Low-Voltage Section — Two-Level Low-Voltage Supply — TV Power Supply for AC-DC Operation — Low-Voltage Supply for Earlier Models — Typical Bleeder Circuits — Bleeder Circuit for Electrostatic Tubes — High-Voltage Power Supply — Safeguards Around High-Voltage Circuits — Generation of X-rays — Protecting Against High-Voltage — High-Voltage Filter Capacitor — High-Voltage Directly from AC Power — RF Power Supply Circuits — High Voltage from Flyback Transformer in Horizontal Circuits — The "Boot-Strap Circuit" — Notes.

Section 1. INTRODUCTION

Television receivers, like radio receivers and other electronic devices, must have a source of power for the amplifier anodes and filaments. Heating current must be available at the correct voltages to heat the filaments, and higher voltages must be available to power the anodes and screen grids of the amplifier tubes.

Knowing the wide differences in the types of power supplies which are used in radio receivers it should come as no surprise that a variety of power supplies are also used in TV receivers. In some respects the power supply circuits found in TV receivers are not materially different from those found in radio receivers. Because of this fact you find the things you have learned about radio power supplies very useful and helpful to you when working with TV.

In other respects there are great differences between the power supply circuits required for TV receivers and those used in radio receivers. Much of the emphasis in this lesson will be on those differences.

Probably the most apparent difference between the types of power supplies required by TV receivers and those needed by radio receivers lies in the fact that TV receivers use *two* power supplies. One is called the *low-voltage power supply*. The other is called the *high-voltage power supply*.

The low-voltage power supply in most TV receivers is quite similar to radio receiver power supplies. It supplies the filament heating power for most of the amplifier tubes, usually including the picture tube. It also supplies the B plus

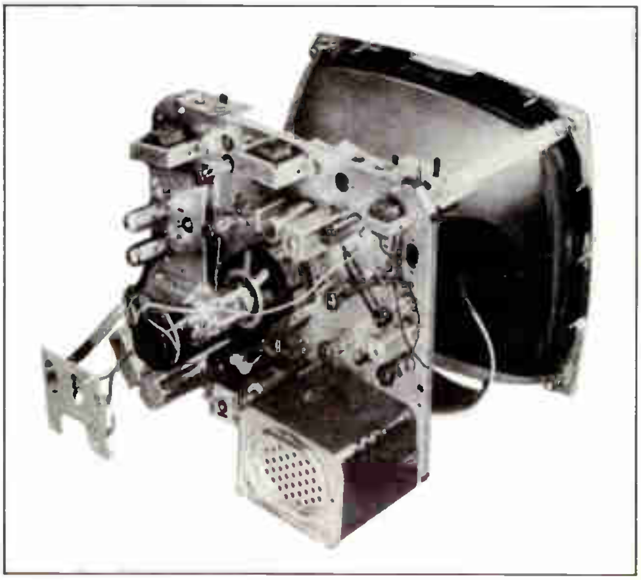

Figure 1. Upright chassis of TV receiver showing location of High-Voltage Power Supply. (Courtesy Raytheon.)

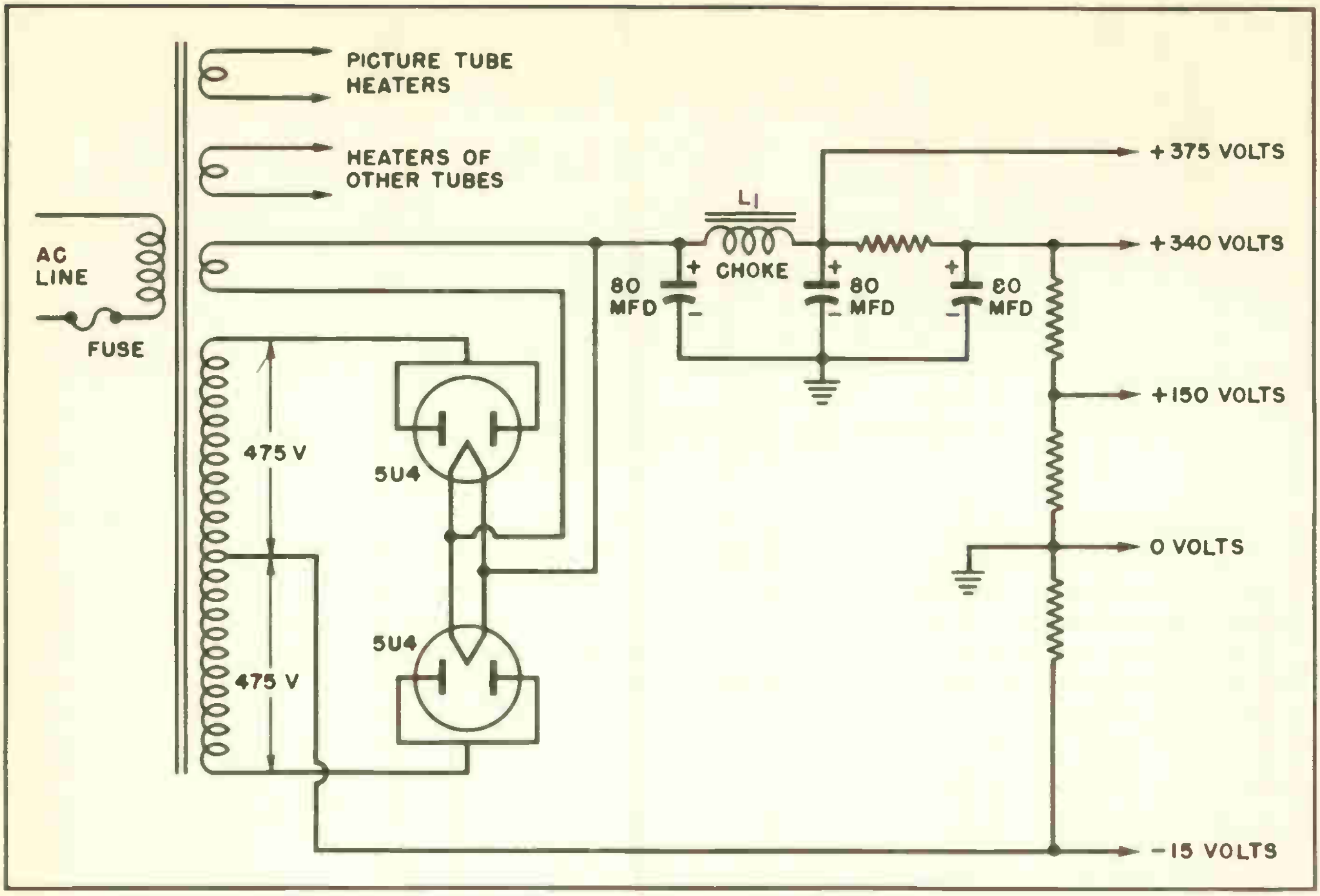

Figure 2. TV Power supply circuit using two Rectifier Tubes for Full-Wave Rectification.

voltage needed by the various amplifier tubes, and often the positive voltage needed by the accelerating anode on the picture tube.

The high-voltage power supply is designed to deliver a very high voltage at low current drain; it is deliberately designed to deliver very little power. The less power the circuit can deliver the safer it is.

There have been radical changes in the power supply circuits used in television receivers, especially those used in the high-voltage section. We will touch briefly on the earlier circuits so you will know something about them, but most of our attention will be reserved for those in use at this time.

Evolution in the design of power supply circuits has been most pronounced in the high-voltage section. Because these circuits are so different from those in the low-voltage section, and also greatly different from those found in radio work, we will devote much attention to them.

Section 2. TYPICAL LOW-VOLTAGE SECTION

A power supply capable of delivering ample power to the amplifier tubes in a reasonably well-designed TV receiver is shown in Fig. 2. A study of the circuit reveals that two 5U4 rectifier tubes are used instead of the single tube as is the common practice in radio circuits. Each rectifier has its anodes tied together so the two sections supplement and aid each other. Such a circuit is capable of delivering twice as much power as a single 5U4 connected for full-wave rectification.

A separate heater winding is shown in the diagram for use of the picture tube filaments. This practice is not so widely followed at this time as formerly, but it is still used to some extent.

Instead of having a separate filament winding for the picture tube filaments, many manufacturers use a separate filament winding for the damper tube. In that case the picture tube may also have its own private filament-heating supply, but more often it does not. If it does not have a separate filament-heating supply, the picture tube filament is supplied with heating power by the regular filament winding on the power transformer.

The circuit in Fig. 2 shows three 80-mfd electrolytics in the filter circuit. Actually, there is a difference of opinion among manufacturers as to what the filtering capacity should be. Some use filter capacitors with capacities as low as 40 to 50 mfd. capacity rating each. Others use capacitors with capacities ranging up to 200 mfd.

It can be seen that several values of voltages are available at the output of the power supply circuit. These range from a negative 15 volts to a positive voltage of 375 volts.

The exact manner in which those voltages are used differ from one manufacturer to another, and often differ from one model to another built by the same manufacturer. However, that is of relatively little importance to us at this time.

Probably the most common practice is to use the highest voltage, which is also the least filtered voltage, as a source of power for the audio amplifier and audio output tubes. That voltage is also used quite often as a source of power for the horizontal amplifier tube, or tubes.

There is no regular uniformity in the manner in which the other voltages are used. The higher B plus voltage is usually applied to the anodes of amplifier tubes where maximum amplification is desired. The lower B plus is reserved for application to screen grid circuits, and for the anodes of those tubes where a high B plus voltage is not desirable.

When using a circuit of this type the "ground", or zero voltage, is connected directly to B minus.

That leaves the negative voltage tap. The negative voltage is usually reserved for use as a fixed bias on those tubes where a fixed bias is necessary. But that is not a universal practice.

Sometimes the negative voltage is applied to cathodes of certain tubes where it is desirable to have the anode at zero potential. Such an arrangement will cause the tube to conduct just as though the cathode were at zero voltage and the anode at a positive voltage.

Many power supply circuits do not make provision for a negative voltage tap.

Section 3. TWO-LEVEL LOW-VOLTAGE SUPPLY

A modification of the circuit shown in Fig. 2 is shown in the power supply circuit of Fig. 3. In this latter circuit only one 5U4 rectifier tube is required for the power supply circuit, instead of the two shown in Fig. 2.

The differences between the two circuits goes further than the power supply circuits themselves. The biggest difference is in the way the voltage from the power supply circuit is used.

To better appreciate the differences in the way these two circuits are used it is well to return to Fig. 2 for a few moments. The various amplifier tubes in the TV receiver circuits are supplied with power in the conventional manner. The cathodes of all amplifier tubes, or the majority of them, are connected to B minus in the normal manner. Then the various B plus voltages — 150 volts, 340 volts, or 375 volts — are applied to the anodes of the amplifier tubes as is best suited to the needs of each.

Power is supplied to the various amplifier tubes in a somewhat different manner in Fig. 3. There we find that some amplifier tubes may be connected between B minus and 300 volts, while others are connected differently.

The amplifier tubes shown at the right side of the diagram in Fig. 3 are not intended to show any special or particular application. We merely show the manner in which B plus voltages are applied to them.

Some are connected between the 150-volt tap on the output of the power supply and the 300-volt tap. Since the anode is 150 volts more positive than the cathode the tube will work in the normal manner as a normal amplifier.

At the same time, other amplifier tubes are connected between the 15-volt tap and the 150-volt tap. This manner of connecting those ampli-

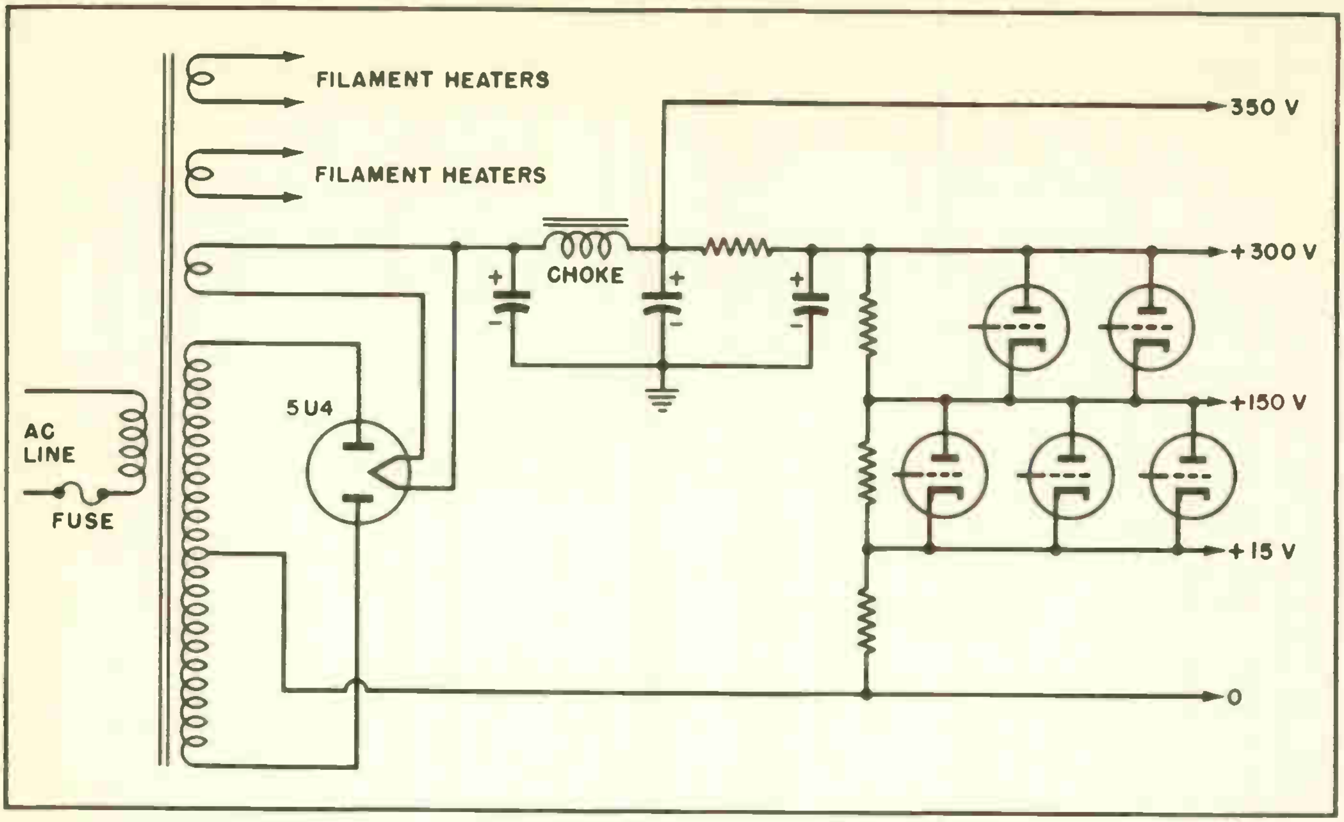

Figure 3. Modified Low-Voltage Power Supply using one Rectifier Tube.

fier tubes places approximately 135 volts of positive voltage on the anodes of those tubes. Thus, they too perform their normal duties as amplifiers.

The advantage of this method of supplying voltage to the amplifier tubes is that less current is drawn through the rectifier tube. The reason is that current which flows through those tubes connected between the 15-volt tap and the 150-volt tap also flows through the other tubes which are connected between the 150-volt tap and the 300-volt tap.

The individual B plus voltages applied to the amplifier tubes is not nearly so great in Fig. 3 as in Fig. 2. But that is often not important. While some amplifier tubes used in TV receivers require relatively high anode voltages, others do not need such high voltages. Instead of dropping the voltages to the individual amplifier tubes through resistors, as would be necessary in the circuit in Fig. 2, the circuit arrangement in Fig. 3 permits one group of tubes to drop the voltages for the other group of tubes.

Some of the largest TV receiver manufacturers have recently adopted the power supply circuit shown in Fig. 3, or modifications of that circuit.

Many of the older television receivers, particularly those in the higher price ranges which use a large number of amplifier tubes, have a power supply circuit similar to that shown in Fig. 2.

There is a growing tendency to reduce the number of tubes used in TV receivers. This tendency has reduced the drain on the power supply circuit, and has resulted in an increasing number of receivers which use only one rectifier tube.

Furthermore, many of the newer amplifier tubes use less current than older types. Reduced current demands of such tubes reduce the drain on the power supply.

Section 4. TV POWER SUPPLY FOR AC-DC OPERATION

Radio manufacturers have found it less expensive to use transformerless AC-DC power supplies in their less expensive radio receivers. Within limitations, they have found much the same thing to be true in TV receivers.

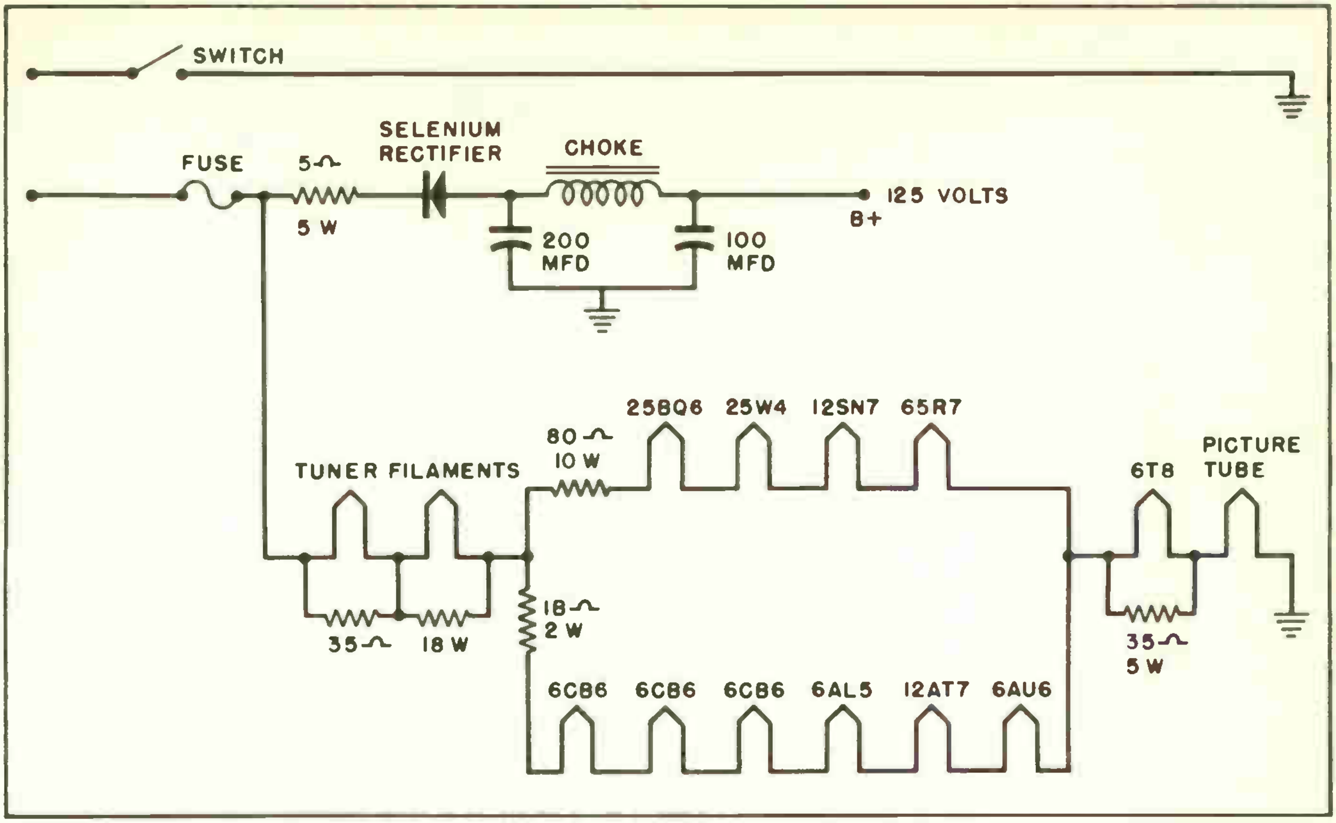

Figure 4. AC-DC Power Supply circuit for TV receiver.

A basic TV circuit employing an AC-DC power supply is shown in Fig. 4.

The circuit shown in Fig. 4 shows one side of the line tied directly to B minus. Whether this practice is always followed depends largely on the ideas of the designer. In most cases the line is *not* tied directly to the metal "ground" of the chassis. Instead, it is tied to a special B minus circuit which is not electrically connected to the metal of the chassis.

Electrically, it makes no difference whether the metal of the chassis is used for B minus. From a practical point of view it is safer to provide a special B minus circuit rather than tie the line to the chassis. There is little difference in the matter of cost when B minus is isolated from the chassis.

The B plus power supply section of the circuit shown in Fig. 4 consists of the selenium rectifier and the filter circuit. A surge-limiting resistor with a resistance of 5 ohms is connected in series with the selenium rectifier. It is merely a protective device to prevent too much current surging through the selenium rectifier to charge the high-capacity capacitors in the filter circuit when the power is first turned on. While that resistor is scarcely a part of the rectifier it should be taken into consideration when studying the power supply circuit.

This AC-DC power supply circuit is not a voltage-doubling circuit. But the high capacity of the input capacitor of the filter circuit maintains the output voltage at a level approximating 125 volts. In some cases this output voltage may be some 5 or 10 volts higher than this, in other cases it may be a little lower. But in most cases it will be on the order of 125 volts.

Most of the amplifier tubes used in a receiver using this type of power supply circuit will operate with reasonable efficiency on 125 volts. That voltage is applied directly to the anodes and screen grid circuits of such tubes.

However, somewhat higher voltages are often needed on the anodes or screen grids of some of the other tubes, such as the horizontal and vertical deflection tubes. The higher voltage needed for those tubes is secured by using a "booster" circuit in connection with the horizontal deflec-

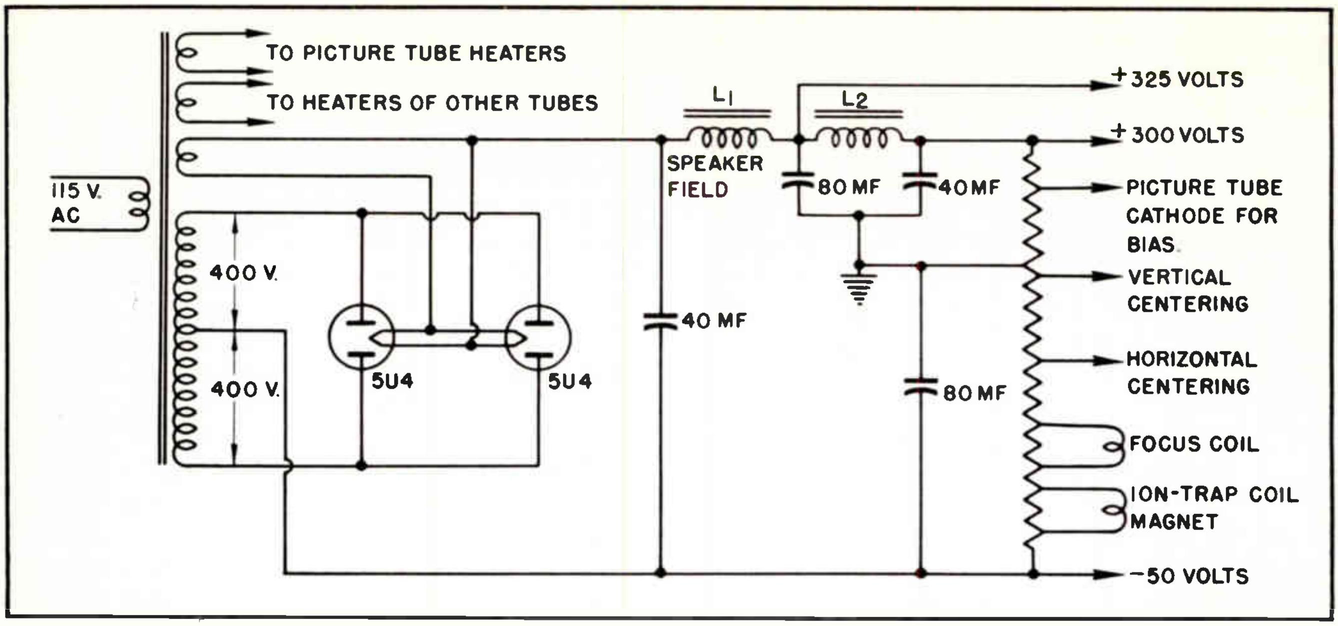

Figure 5. Power Supply with taps for Ion Trap Coil and Focus Coil.

tion system. Such a voltage booster, technically known as a "boosted B plus circuit", is also commonly known as a "boot-strap" circuit.

The "boot-strap" circuit will be explained in a later section of this lesson. It will also be discussed in other lessons which follow.

The filaments of the amplifier tubes are connected together in a complex series and parallel arrangement. The exact arrangement can be better understood by studying the filament circuit string in Fig. 4. Those tubes which operate on one value of filament heating current are connected together in one string. Those requiring a different amount of heating current are connected in another string.

Filaments are not always connected as in Fig. 4, but that is a typical AC-DC circuit.

The picture tube filament usually requires more heating current than the amplifier tubes. For that reason the current which passes through both strings of amplifier tube filaments is then passed through the picture tube filament.

The 6T8 filament is directly in series with that of the picture tube. But the 6T8 filament does not require so much heating current as the picture tube filament. To get around that situation a resistor is connected in parallel with the 6T8 filament to shunt some of the filament current for the picture tube around the 6T8 filament.

All the refinements necessary to make a circuit of this type operate properly have not been included in the diagram in Fig. 4. Special RF choke coils are inserted in the circuit between the filaments for the several 6CB6 tubes, and for some of the others. Presence of those choke coils prevents RF signals from one tube getting into the other tubes where such RF signals may not be wanted.

Additional filtering to prevent interference from unwanted RF signals is provided by means of RF by-pass capacitors from various parts of the filament circuit to B minus.

Use of an AC-DC power supply circuit, such as the one described in Fig. 4, reduces cost of the receiver by eliminating the power transformer. Power transformers for TV receivers are relatively expensive, being one of the most expensive items in the entire cost of the chassis.

Savings in the cost of the transformer is partially offset by the necessity of having to use larger electrolytic capacitors in the B plus circuit. It will be seen that the electrolytics in the filter circuit in Fig. 4 have capacities of 200 mfd and 100 mfd, respectively. That is a lot of capacity, and naturally runs up the cost of the electrolytics.

The cost of the 5-ohm surge-limiting resistor must also be offset against the saving in cost of eliminating the transformer. But that is not a major item.

There is not much savings one way or the other in using a selenium rectifier over a vacuum tube rectifier. Considering the cost of the tube socket, the tube itself, and the various connections to it, the actual cost of installing the selenium rectifier is probably slightly lower than using a tube.

Section 5. LOW-VOLTAGE SUPPLY FOR EARLIER MODELS

At this time there is a strong tendency to use permanent magnets as ion traps for electromagnetic deflection tubes. But such was not always true.

During the early days of television, and especially during the years of the Korean War, there were heavy restrictions on the use of cobalt. Cobalt is a necessary ingredient of alnico magnets which are used as ion traps.

Such restrictions forced manufacturers to use substitutes. This meant that many television receivers used electromagnets for ion traps rather than permanent magnets.

The use of electromagnetic coils as ion traps meant that those coils required a source of power to energize the coils, and create the necessary magnetism. The normal practice was to tap the bleeder resistors of the low-voltage power supply.

Much the same was true of focus magnets. Manufacturers prefer to use permanent magnets to focus the electron beam inside the picture tube. But the same restrictions applied to the use of alnico magnets for focusing as applied to the use of permanent magnet ion traps.

Those restrictions forced manufacturers to use electromagnetic coils for focusing. And like the ion trap coils, the focusing coils required a source of power to energize them.

Fig. 5 shows how the bleeder circuit of the power supply is tapped to supply the necessary power for energizing the coils for the ion trap magnet and the focus magnet. Other taps to aid in centering the picture are also shown. There is a growing tendency among manufacturers to depend on other means to center the picture. Such centering taps are not used so widely at the present time as formerly.

In Fig. 5 the field winding of the loudspeaker is used as the first section of the power supply filter choke. That was a fairly regular practice in the earlier days of television.

The present tendency is to use permanent magnet fields in the loudspeakers, thus doing away with the field winding. A regular iron-core filter choke is substituted for the speaker field. Instead of having two chokes, a resistor is frequently substituted for the second choke.

However, it must be kept in mind that each manufacturer, and each designer, has his own ideas. Minor details of power supply filter circuits often differ widely; in some cases differ radically.

Section 6. TYPICAL BLEEDER CIRCUITS

We have shown bleeder circuits in connection with the power supply circuit in Figs. 2, 3 and 5. We have touched on the use of bleeder circuits many times in previous lessons, since they are widely used in radio receivers, especially the older models.

But experience tells us that many have a difficult time understanding bleeder circuits, especially the voltage relationships involved when B minus is not connected to the most negative part of the bleeder circuit. For that reason we will pause here briefly to explain such voltage-divider networks a little more carefully.

A bleeder circuit is nothing more nor less than a resistor of some kind connected between the most positive output of the power supply circuit and the most negative part. It may be a single resistor, and often is.

More often the bleeder consists of two or more resistors. Usually they are connected in series across the output of the power supply circuit, as shown in Figs. 2, 3 and 5. Also as shown in Fig. 6.

When two or more bleeder resistors are connected in series, then connected across the output of the power supply circuit, they serve as a

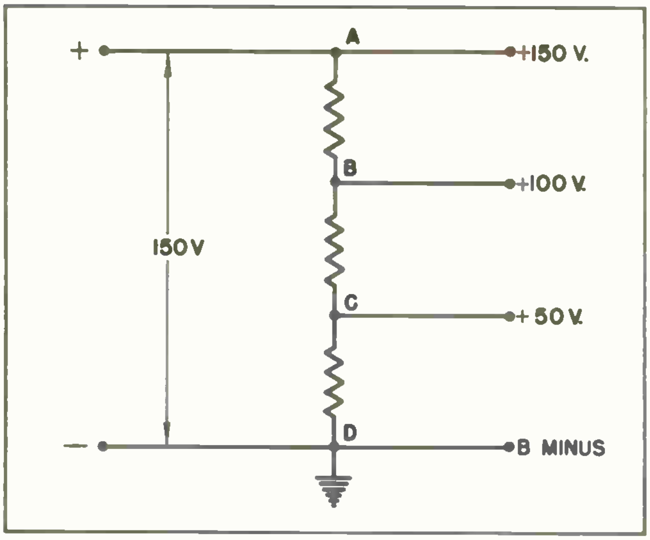

Figure 6. Voltage-Divider with B minus and Ground at most negative part.

voltage-divider circuit. The reason can be better understood by studying Fig. 6.

When resistors are connected in series, as shown in Fig. 6, and a current caused to flow through them as a result of a voltage, there is a definite voltage present across *each* of those resistors. The voltage across each resistor can be looked upon as a "voltage drop" because the voltage that appears across each of them is directly proportional to the amount of resistance in the resistor, and the current flowing through it. As you know from your study of Ohm's Law, voltage is equal to resistance multiplied by current.

In Fig. 6 three resistors are connected in series. The value of the resistors is not given; that is not a matter of immediate concern to us at this time. Since the voltage across the three resistors amounts to 150 volts, and the drop across each resistor amounts to 50 volts, it becomes immediately obvious that each of the three resistors has the same resistance as each of the others. Let us repeat, the value of the resistors is not important to us at this time.

The important fact is that the presence of the three resistors connected in series divides the voltage among them equally.

This means that voltages can be tapped off the divider network at each of the junctions between the resistors. If the voltages are measured with reference to ground, or B minus, the voltage at the first junction of the resistors will be 50 volts positive with reference to ground. The voltage at the second junction of the resistors is 100 volts positive with reference to ground.

And, of course, the voltage across the entire bleeder circuit, or across the output of the power supply circuit, is 150 volts.

It should be kept clearly in mind that the conditions we have described in connection with Fig. 6 apply only when those conditions are present. When all the resistors are connected in series, all resistors have the same resistance, and B minus is the most negative part of the bleeder network.

Conditions would be different if the values of the resistors differed.

A somewhat different set of voltages can be set up by connecting a different part of the bleeder network to ground, and then measuring all the voltages with reference to ground. In this case we can think of "ground" and B minus as being the same thing.

Instead of connecting the most negative part of the bleeder network to ground, as in Fig. 6, suppose we connect point *C* to ground. That situation is shown in Fig. 7.

Now keep in mind that we are still measuring

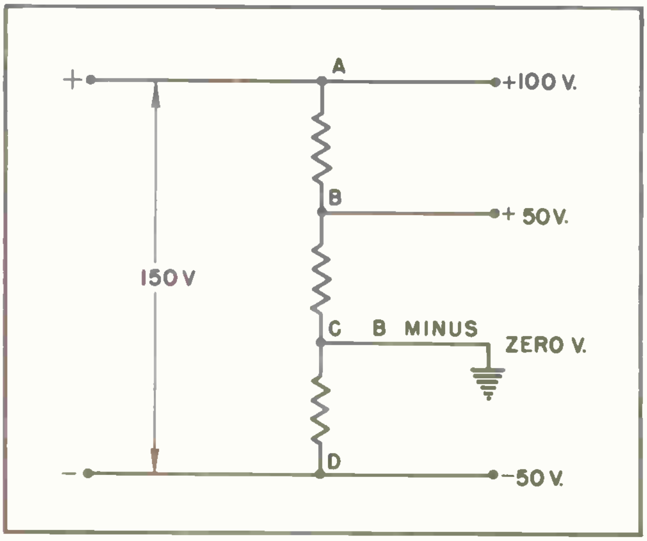

Figure 7. Voltage relationships on Voltage-Divider with B Minus connected at one of voltage taps.

the voltages at all the taps on the bleeder network with reference to ground, or B minus. But in this case B minus is *not* the most negative position on the bleeder network. Therefore, the voltage readings between B minus and the various taps will not be the same as we found them in the circuit of Fig. 6.

Point *C* is more positive than point *D*. That fact is clearly evident in both Figs. 6 and 7.

That can be said another way. Point *D* is more negative than point *C*. That fact is equally evident.

If we connect point *C* to ground, or B minus, then make all measurements with reference to B minus, it becomes quite clear that the voltage at point *D* is going to read negative. This is in contrast to the situation we found in Fig. 6, where all voltages read positive.

If we take the voltage at point *C* to be zero voltage, as is always true of the reference point, the voltage at point *D* is negative with respect to ground, or B minus. Point *D* is 50 volts negative with respect to B minus.

Measuring the voltages in the other direction is equally interesting. Since we are measuring those voltages from a different voltage base than we were using before, the voltages read differently.

The voltage between point *B* and B minus (point *C*) is 50 volts. This means point *B* is 50 volts positive with respect to B minus. Contrast this voltage reading with that at point *B* in Fig. 6.

The differences in the voltage readings in the two illustrations results from the fact that B minus is connected to the voltage-divider network at different places in the two circuits.

When working with voltage divider networks you must always keep in mind that voltages are *relative* matters, not necessarily absolute values. By this we mean voltages are different electrical pressure levels between two points. The difference in potential between one set of two points is not necessarily the same as the difference in potential between two other points.

In the situations presented here we can read the voltages at the various taps on the voltage divider by measuring them against the most negative part of the network. That will give us one set of voltage readings.

Or, we can read the voltages on the divider by measuring them against one of the taps. The voltage readings in this latter instance will be different.

This matter of relative voltages in a voltage divider network can be carried much further. In Fig. 8 we have connected point *B* on the network to B minus, or ground. This provides us with still a different set of voltage readings, when those voltages are measured with reference to ground, or B minus.

Note that in this situation we have two positions on the voltage divider network which are more negative than B minus, or ground. Point *C* is 50 volts negative with respect to ground, or B minus. Point *D* is 100 volts negative with respect to ground, or B minus.

In plain words, we find that when we tie point *B* to ground, or B minus, most of the network then becomes negative with respect to ground. Only one point on the voltage divider is more positive than the ground connection. That is point *A*, which is 50 volts positive.

Contrast the voltage at point A in Fig. 8 with the voltages at that location in Figs. 6 and 7.

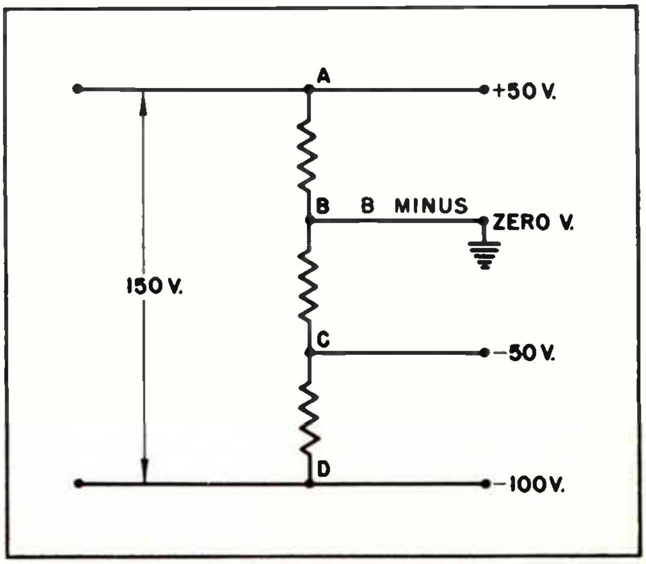

Figure 8. Voltage relationships when Point B *is connected to B Minus.*

The differences in the voltages are due entirely to the locations where the voltage divider is connected to ground, or B minus.

There are a few rare instances in electronic work where the most positive part of the voltage divider network is connected to ground, or the chassis. Some oscilloscopes are so designed that the highest voltages are applied to the cathode — in this case a high negative voltage. Applying a high negative voltage to the cathode is the same, electrically, as applying a high positive voltage to the final anodes.

A safety factor is involved in such an arrangement. It is safer to apply the high voltages to connections in the rear of the tube rather than in the front. The front of the tube is at, or near, ground voltage.

Fig. 9 shows the voltage relationships which result when the most positive part of the voltage divider network is connected to ground. All the other parts of the network then become negative with respect to ground.

It can be noted that voltages in Fig. 9 are much the same as those in Fig. 6 except that they are reversed, and all are negative instead of being positive.

These illustrations should give you a good idea of voltage relationships which exist in and

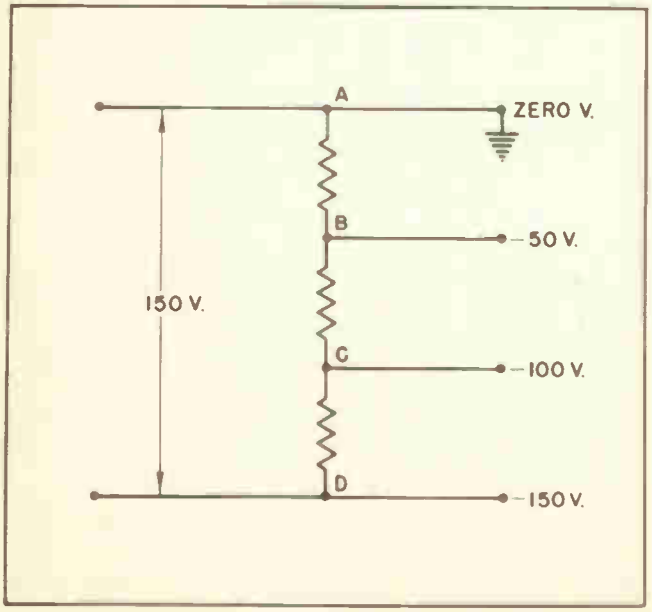

Figure 9. Voltage relationships when most Positive part of Network is connected to Ground.

around a voltage divider network when the network is grounded at various locations. It should make the technical references to voltages somewhat more clear and understandable.

One interesting thing about the voltage relationships shown in Fig. 9 is the fact that such a manner of grounding the voltage divider network is referred to as an *inverted power supply.*

Section 7. BLEEDER CIRCUIT FOR ELECTROSTATIC TUBES

Since all the operating forces applied to an electrostatic picture tube involve voltages, there is always the possibility the voltage relationship among the various circuits might become upset. For that reason it is usually desirable to provide variable controls across the voltage divider network so the voltages on the various elements can be adjusted until the picture is properly reproduced.

A circuit which was once used quite widely with electrostatic picture tubes is shown in Fig. 10. It is still used to some extent, but you are not nearly so likely to run into such a circuit as some of the others we introduce to you.

Note that the control grid on the picture tube is the most negative part of the circuit. The signal is fed to the control grid by causing a current to flow through the video input signal resistor. As the video current flows through that resistor a voltage is developed across it, and is then applied to the control grid to control the intensity of the electron beam inside the tube.

Note how the cathode of the picture tube is connected to the voltage divider network. It is connected at a position which is more positive than the control grid. This has the effect of making the control grid more negative than the cathode; the normal method of operation.

The focusing anode is an electrostatic gadget. The positive voltage applied to it is considerably greater than that applied to the cathode.

The manner of applying voltage to the deflection plates is shown quite clearly. Also the manner of controlling these voltages so the picture can be properly positioned.

This circuit is rarely used on new receivers,

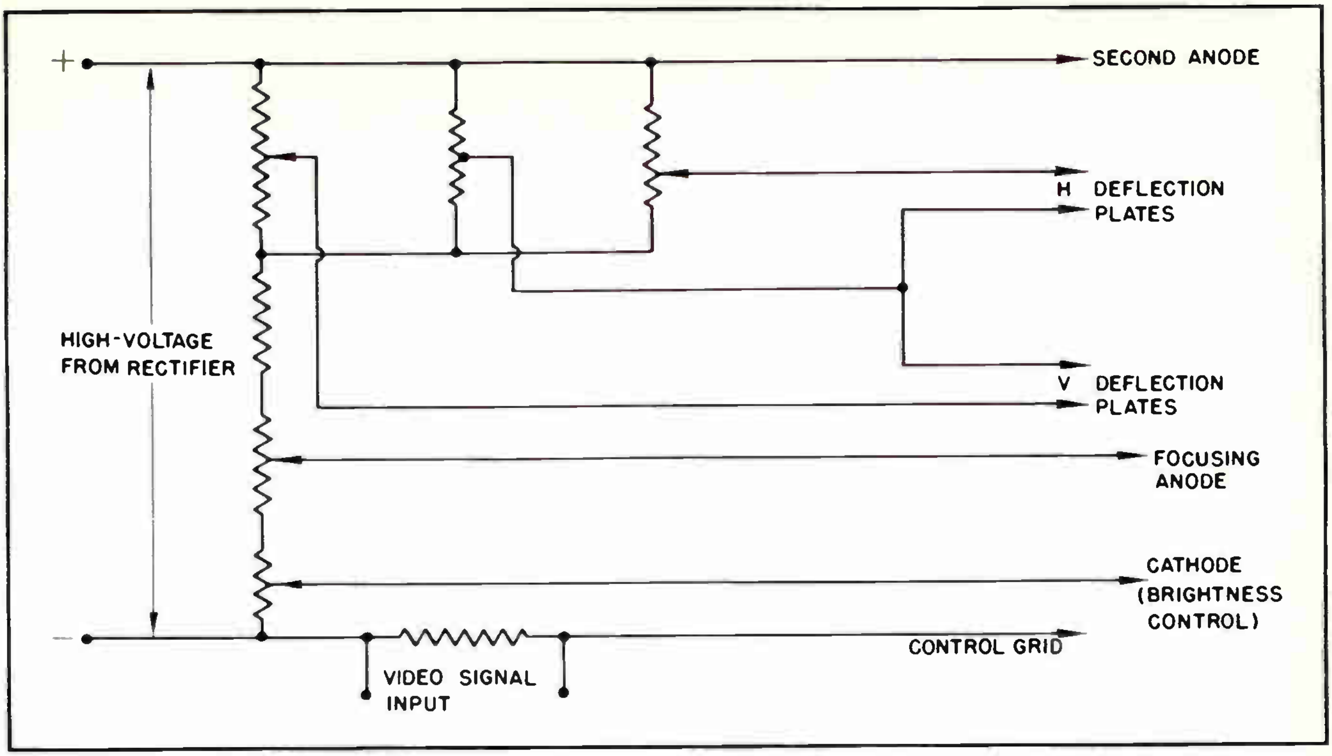

Figure 10.

but you are likely to find it on some of the old receivers.

Section 8. HIGH-VOLTAGE POWER SUPPLY

Although there are no major differences between the low-voltage power supply in a TV receiver and those used in radio receivers there is another power supply system in television receivers which is radically different. That is the *high-voltage* power supply.

There is no counterpart in a radio receiver which corresponds to the high-voltage power supply in a TV receiver.

The need for a high-voltage power supply system in a TV receiver stems from the peculiar requirements of the picture tube. The high voltage is needed to accelerate the movement of the electrons in the electron beam inside the picture tube. The electrons in the beam must be accelerated to a high velocity so they can acquire a high degree of kinetic energy.

If you have grown hazy as to the exact meaning of *kinetic energy* we suggest you review your lesson on POWER. That was one of your earliest lessons in this course.

There is a direct relationship between kinetic energy in the electrons of the beam and the amount of fluorescence they create when they strike the screen of the picture tube. The greater the velocity of the electrons in the beam the greater the kinetic energy stored in the individual electrons; the greater the kinetic energy acquired by the individual electrons the brighter the phosphors of the screen will fluoresce when struck by the electrons.

A strange thing about the high-voltage requirements of a picture tube is the fact that the current which flows as a result of that high voltage is extremely small. This fact simplifies the design of the circuits used to create the high voltage.

High-voltage requirements vary somewhat from one type of receiver to another. Projection-type receivers, for example, require much higher voltages than those which use direct-view picture tubes. This means that high-voltage circuits found in projection receivers frequently differ quite radically from those regularly employed in direct-view receivers.

Time has brought about many changes in the design of high-voltage power supplies. Those used in TV receivers built recently bear little resemblance to those used in the earlier days of television.

Section 9. SAFEGUARDS AROUND HIGH-VOLTAGE CIRCUITS

The high-voltage power supply circuits in almost any television receiver easily develop 6000 to 8000 volts. Such voltages are developed even though relatively small picture tubes are used.

Where larger tubes are used the voltages delivered by the high-voltage circuits range progressively higher. It is not at all uncommon for TV receivers using 17-inch to 21-inch picture tubes to demand 10,000 to 14,000 volts from the high-voltage power supply circuits.

Several of the larger TV receiver manufacturers advertise that their receivers develop 18,000 volts and more. The higher voltages definitely create brighter and sharper pictures. Moreover, when the newer aluminized tubes are used it is quite essential that the final anode voltage on the picture tube be as high as is obtainable.

That is the reason the receiver manufacturers boast of the high voltages generated in their receivers.

Presence of such high voltages in a TV receiver is not an unmixed blessing. Such voltages present clear and definite hazards, and precautions must be taken to see they cause no damage or injury. Unless safeguards are observed the high voltage can arc across into low-voltage circuits and cause damage.

Such high voltages are definitely dangerous to life unless great care is used to guard against them.

One definite danger which should never be forgotten, nor neglected when high voltages are present, is the possibility of creating X-rays. This is a subject which is not widely discussed in TV circles; it is something many would like to ignore as though it did not exist.

Yet, the truth is that creation of X-rays in the high-voltage circuits of a TV receiver is a very serious matter. It is very real. It becomes progressively more important as the voltages used in TV receivers become progressively higher.

Section 10. GENERATION OF X-RAYS

X-ray radiation in TV picture tubes is not considered to be serious so long as the final anode voltage remains under 16,000 volts. But X-rays are generated when the final anode voltages exceed 16,000 volts, and all picture tube manufacturers regularly warn of the necessity for providing special X-ray shielding around the picture tube when final anode voltages are that high or higher.

There is little purpose here in attempting to explain how X-rays are created. Despite the fact X-rays have been known and used more than half a century there are many things about them which are still unknown.

It is known, however, that when a stream of fast-moving electrons are permitted to strike a *target*, X-rays are generated as a result of that impact. The faster the electrons are moving when they strike the target, the more X-rays are generated. Fig. 11 gives a general idea how X-rays are generated in a TV picture tube.

Similarity of the conditions inside a TV picture tube to those inside a regular X-ray tube can be better visualized by comparing Fig. 11 with Fig. 12. Fig. 12 is a rough outline of the construction and action of an X-ray tube.

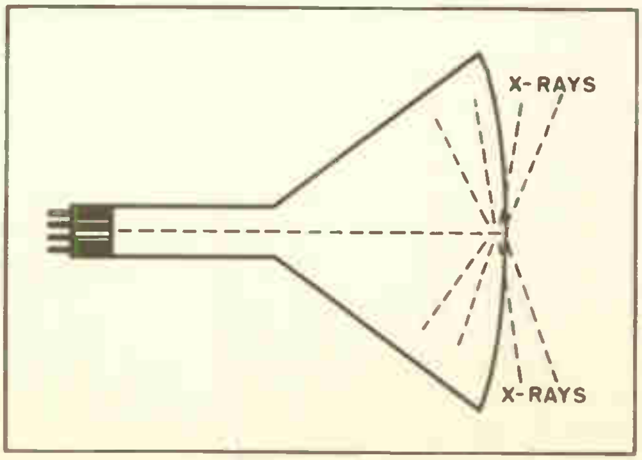

Figure 11. X-Rays are generated when fast-moving electrons strike a target.

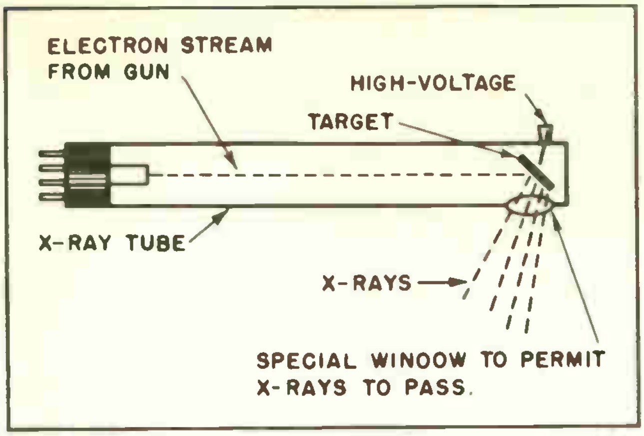

Figure 12. How X-Rays are generated in X-Ray tube.

In a regular X-ray tube streams of electrons are accelerated by applying high voltages to various accelerating anodes, and to the target, inside the tube. Voltages used in regular X-ray work are seldom lower than 50,000 to 75,000 volts. They range upward from there to more than a million volts.

X-rays are generated when the fast-moving stream of electrons strikes the target; the X-rays move away from the target area at an angle to the electron stream and to the face of the target. Usually the target face is set at an angle to the stream of electrons, as shown in Fig. 12, so the X-rays pass through the side of the tube. A special "window" is inserted in the side of the glass tube. The "window" is composed of some material which presents the least opposition to the passage of the X-rays.

In this connection it is worthy of note that X-rays will pass through all known materials. But they pass through some materials more readily than others.

A TV picture tube is not deliberately designed to create X-rays. Yet the same elements are present which cause X-rays to be created — a fast moving stream of electrons which strikes a target area.

Because a TV picture tube operates at much lower voltages than a regular X-ray tube it does not create nearly so many X-rays. Furthermore, the design of picture tubes does not permit them to create X-rays nearly so efficiently as an X-ray tube which is especially designed for that purpose.

But because a picture tube is often operated for long periods of time, such X-rays as it does produce are continuously generated for much longer periods than is true of X-ray tubes which are usually operated for short periods only. This means that over a period of a day, or a week, or longer a picture tube operated at high voltages can generate a quantity of X-rays roughly comparable to those generated during a short period by a regular X-ray tube.

Unless X-rays generated in a picture tube are prevented from reaching those who are viewing or servicing a TV receiver they can cause trouble due to their accumulation over a long period of time. This is because the effects of X-rays are a cumulative process. Radiation by weak X-rays over a long period is roughly comparable in effect to radiation by concentrated X-rays for a short period.

Experience has shown that few, if any, X-rays are generated in a picture tube when the final anode voltage is maintained at a level below 16,000 volts. Therefore, there is little danger from X-ray radiation from picture tubes when the final anode voltage is below that value.

But the picture tube should be carefully shielded to prevent X-ray radiation when final anode voltages exceed 16,000 volts. Fortunately, the radiation through the glass at the front of the picture tube is less than through some other parts of the tube. Use of heavy glass at that point further reduces the possibility of radiation, and when the glass is specially treated to reduce passage of radiation the danger in that direction is reduced to negligible values.

The kinescopes in projection-type TV receivers use far higher voltages than are required by direct-view picture tubes. Few, if any, projection tubes use less than 25,000 volts; most of them use voltages ranging from 50,000 to 100,000 volts.

Danger from X-ray radiation is materially greater in projection-type receivers than in direct-view types. Heavier, and more adequate, shielding must be employed. Greater care should be observed when servicing such receivers.

Section 11. PROTECTING AGAINST HIGH VOLTAGE

When the voltage applied to the final anode

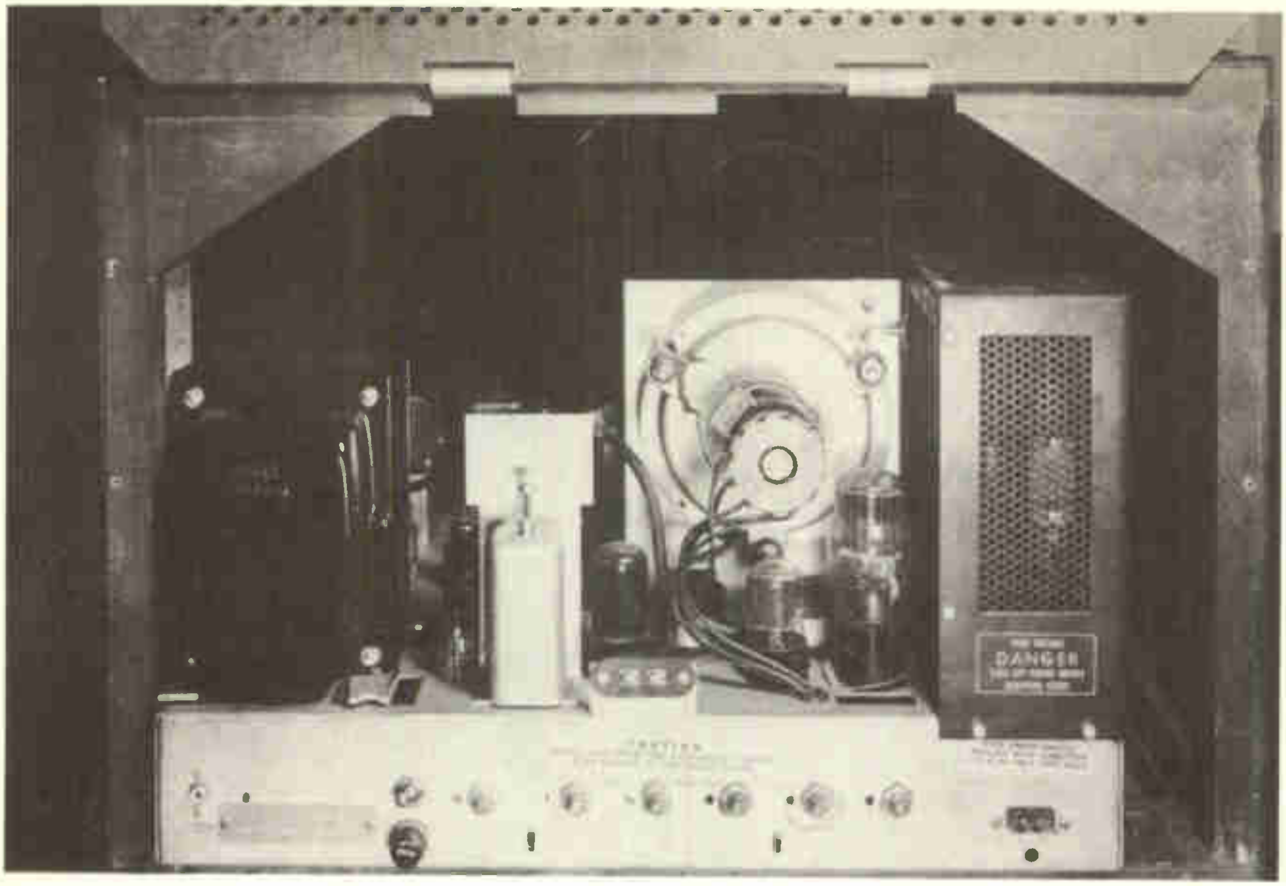

Figure 13. Metal enclosure around High-Voltage section shown at right.

of the picture tube is less than 16,000 volts there is little need for protection against X-ray radiation, but other kinds of safeguards against the effects of high-voltage must be observed.

The modern tendency in TV receiver design is to isolate the high-voltage section, then enclose it within some sort of metal enclosure. Fig. 13 shows one method of doing this which is widely used throughout the industry. Fig. 1 also shows the ventilated metal enclosure within which the high-voltage section is housed.

The metal enclosure around the high-voltage section is shown at the right side of the TV chassis in Fig. 13. This is a rear view of the chassis. It is a view with the back panel removed so the components on top of the chassis can be observed. The high-voltage section of the chassis in Fig. 1 is at the lower right side of the upright chassis.

The high-voltage section of most modern TV receivers is closely associated with the horizontal deflection circuits. Because of that it is a frequent practice to enclose some of the horizontal tubes and circuits within the metal enclosure with the high-voltage power supply circuits.

When the high-voltage circuits are enclosed as shown in Fig. 13 they are completely shielded so there is no danger of a serviceman or other person coming into contact with them accidentally. The only part of the high-voltage circuit which is outside the metal enclosure is the high-voltage lead which carries the high voltage to the final anode connection on the picture tube.

The high-voltage cable which carries the high voltage from the metal enclosure to the picture tube is heavily insulated to prevent leakage of the high voltage. The actual connection between the end of the high-voltage lead and the picture tube is usually covered with a wide-spreading rubber protective covering so there is very little chance of a person accidentally coming into contact with the high-voltage.

A peculiar electrical phenomenon called "corona action" surrounds a conductor carrying high voltage. This electrical phenomenon is present in the high-voltage ignition cables used in automobiles, the high tension power lines which link our cities and industries, and other places where high voltages are present.

Electrical *corona* can be observed as a faint glow surrounding the conductors if the metal is examined in the dark. The glow becomes brighter as the voltage is increased.

Corona becomes a factor to be considered when the voltage exceeds 10,000 volts. It becomes more important as the voltage increases.

Corona is destructive of rubber insulation. It causes rubber to become hard and brittle with the passage of time, and the rubber loses much of its insulating qualities.

All of which means that the heavily insulated cable which carries the high voltage from the metal-enclosed high-voltage section of a TV receiver to the picture tube often loses some of its insulating ability with the passage of time. One direct result of this action is that arcing then occasionally occurs between the conductor inside the high-voltage cable and the metal of the enclosure. Sometimes arcing occurs through the insulation to some other metal part of the chassis, but most frequently it occurs to the metal of the enclosure.

When such arcing develops the high-voltage cable should be removed and a new one installed. There is little use trying to do anything with the old one. Replacing such a cable is a simple job.

Additional protection against the high voltage which is developed in a TV chassis is provided by using some sort of "interlock" in the power wiring. Such interlocking circuit may take any of several forms; but the most common is that used with the chassis in Fig. 13.

If the photograph in Fig. 13 is studied quite carefully a plug connection can be seen on the back panel of the chassis directly below the metal enclosure of the high-voltage section. That plug connection on the back of the chassis fits into a socket connection mounted on the back panel of the cabinet which covers the entire back of the receiver.

When the back panel of the cabinet is fitted into place the socket fits into the plug on the back panel of the chassis. This makes a direct electrical connection between the plug and the socket.

The main AC power from the power cord passes through this plug-and-socket connection. When the covering panel of the receiver cabinet is fitted into place a good electrical connection is made for the AC power to reach the chassis. When the covering panel is removed the electrical connection is broken and no electrical power can reach the power circuit of the receiver.

This is a safety device to prevent electrical power reaching the TV electrical circuits when the back cabinet panel covering the rear of the receiver is removed. This prevents unauthorized persons removing the back panel of the receiver cabinet, then working on the TV circuits while the power is on.

Qualified TV servicemen carry special line cords which can be fitted into the plug on the rear of the chassis during their service operations. This will be discussed in another lesson.

There is always the possibility a service technician may accidentally come into contact with the high-voltage circuits. To prevent such an accident causing serious injury an additional safeguard is provided in the circuits. This safeguard is in the form of a low-capacity filter capacitor for the high-voltage circuit.

Section 12. HIGH-VOLTAGE FILTER CAPACITOR

Many persons have strange ideas about what makes electrical currents and voltages dangerous. Some have the idea current alone is the determining factor. Others believe high voltage alone, without regard to the amount of current, is the controlling factor which determines whether or not an electrical circuit is dangerous.

Actually, it is neither the voltage alone nor the current alone which determines what is dangerous to human life. It is the *power* which is applied. And power, as you well know by this time, is a product of both current and voltage.

In TV receiver work high voltages are necessary. Therefore high voltages must be available in order for the receiver to work properly. At the same time the *power* requirements, the need for current, is quite low.

This makes it possible to store the high voltage required by the TV circuits in a filter capacitor so it can be applied where it is needed, and as it is needed. Because the power, or current, requirements are low it is readily possible to keep the capacity of the filter capacitor low. Recharging the filter capacitor at frequencies far higher than ordinary power frequencies also aids in keeping the capacity low.

It has been determined through experience and experimentation that a capacitor which stores no more than one *joule* of electrical energy is not dangerous to human life. This knowledge enables engineers to design high-voltage filter circuits so they can supply the high voltage needed by the picture tube, yet not store sufficient electrical energy to be dangerous to those who might accidentally come into contact with it.

A *joule* of electrical energy is equivalent to 1 watt-second of electrical energy. This means that it is equivalent to 1 watt of electrical power released continuously during the period of 1 second of time.

There is little use going into all the details through which engineers have acquired the experience which has taught them these things. But it can be demonstrated that a *joule* of electrical energy has a direct relationship to the capacity of the capacitor in which the electrical energy is stored and to the voltage impressed on the capacitor.

Such relationship has been worked out mathematically, and has been determined to be equal to the capacity in *farads* multiplied by the square of the voltage, and then divided in half. By representing the capacity by the letter C, as is customary, and the voltage by the letter V, this situation can be set up in the form of an equation.

In equation form it would look like this:

$$\text{joule} = \frac{CV^2}{2}$$

The exact size of the capacitor which would be safe in any particular receiver would depend on the voltage impressed across it.

For purposes of explanation suppose we take a situation where it is known that 7000 volts are needed for the high-voltage supply. The question, then, is what value of capacity should the high-voltage filter capacitor have if the energy stored in it is to be considered reasonably safe?

This can be worked out in this manner:

$$1 \text{ joule} = \frac{CV^2}{2}$$

$$2 \text{ joule} = CV^2$$

$$\frac{2}{V^2} = C$$

Since the voltage is known it is only necessary to substitute the value of the voltage in place of the letter V. That would be done in this manner by substituting 7000 for V:

$$V = 7000$$
$$V^2 = 49{,}000{,}000$$

We now have a problem which looks something like this:

$$\frac{2}{49{,}000{,}000} = C$$

We have the numerical value of the capacitor in the form of a fraction. All that remains is to divide 49,000,000 into 2. That comes out something like this:

$$\frac{2}{49{,}000{,}000} = .000{,}000{,}04 \text{ farads.}$$

Keep in mind that our answer now is in the form of *farads*. It is very simple to convert this into microfarads (millionths of a farad). The most simple way to do that is to start at the decimal point and mark off six zeros. When that is done we come up with the value of .04, which is the capacity of the capacitor in microfarads (.04 mfd.).

In the earlier days of television various types of high-voltage generating circuits were used. Some of these will be discussed briefly in this lesson.

Some such H-V power supplies operated at 60 cycles per second, the same as the AC power frequency. When high-voltage was developed from such low frequencies it was necessary to use relatively large capacitors to filter the high-voltage power supply. At such low frequencies a capacitor as small as .04 mfd. did not have much filtering action. But because of the safety considerations which had to be kept in mind it was not possible to use capacitors materially larger.

Later developments in television brought newer designs of high-voltage generating circuits. Much higher frequencies were used with rectifiers to create the high voltages. Therefore smaller capacitors could be used.

With the development, and wide-spread use of the "flyback" transformer method of creating high voltages in the horizontal deflection circuits it is entirely practical to use relatively small filter capacitors in the high-voltage section. The industry has pretty well standardized on a .0005 mfd capacitor for that purpose.

A capacity of .0005 mfd is equivalent, of course, to 500 mmfd. A special type high-voltage capacitor has been developed for this specific purpose. It is widely used throughout the television industry.

The most commonly used high-voltage filter capacitor has a capacity of 500 mmfd, with a voltage rating of 10,000 volts. Similar capacitors have higher voltage ratings for use in those receivers where the final anode voltage is higher than 10,000 volts.

Such capacitors have proven highly satisfactory and dependable. Despite that, one occasionally breaks down and permits leakage between the two plates. When such breakdown occurs there is only one solution. The capacitor must be replaced with a new one.

Section 13. HIGH VOLTAGE DIRECTLY FROM AC POWER

When television receivers were first introduced to the public the high-voltage for the picture tube was developed by stepping up the AC power voltage then rectifying it. That method is still used in some projection type receivers.

Various types of circuits were tried for stepping up the high voltage. One that was adopted quite widely is that shown in Fig. 14. This type

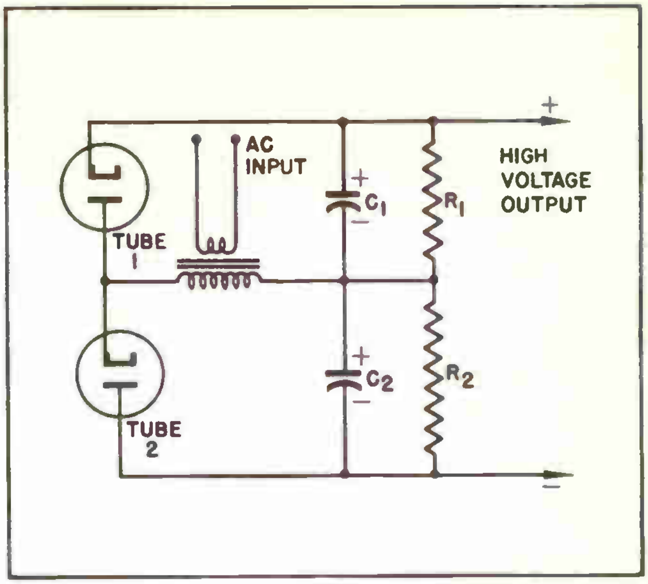

Figure 14. High-Voltage can be developed by Step-Up Transformer and Voltage Doubling.

of circuit was favored in those cases where extremely high voltages were required.

The big advantage of such a circuit is that the output voltage across the two resistors is approximately 2.83 times as great as the RMS (root mean square) voltage across the secondary terminals of the transformer. This means the insulation requirements of the windings of the transformer are much lower than would be necessary where the entire voltage is developed across a single secondary winding of a transformer.

The most objectionable feature of a high-voltage power supply circuit which obtains its high voltage directly from the AC power is the danger in such a circuit. The transformer must be designed to have very poor regulation so the voltage drops instantly when a load is placed across it which draws a sizeable amount of current. Even so, much electrical energy is stored in the magnetic fields of the transformer and the various capacities in the circuit. The circuit is definitely dangerous.

Fortunately, circuits similar to that shown in Fig. 14 have long since been discarded from TV receiver design, at least from those which use direct-view picture tubes. Other types of high-voltage circuits have been developed which have proven much more satisfactory; at least they are much less dangerous.

Section 14. RF POWER SUPPLY CIRCUITS

A high-voltage power supply circuit which uses an RF oscillator and high-voltage rectifier tube is shown in schematic form in Fig. 15. The circuit is fairly straight-forward, and easily understandable.

The oscillator tube, V-1, is a simple Armstrong oscillator, although any other type oscillator circuit could be used. Coils in the oscillator circuit, especially L-2, are closely coupled to a secondary winding having many turns. The secondary coil with a large number of turns is indicated as L-5 in the diagram in Fig. 15.

The oscillator is designed to have a relatively high frequency, although it does not necessarily need to have a frequency in the RF frequency spectrum. There is a high ratio of voltage step-up between the oscillator coils and secondary coil L-5.

Voltage developed across the coil is rectified by the V-2 rectifier tube. The output of the rectifier is filtered by the action of the resistor and capacitor combination shown in the lower right hand corner of the diagram in Fig. 15.

The RF power supply for providing high voltage for television receivers has much to recommend it over the method described in connection with the circuit shown in Fig. 14. The frequency is high enough so the filtering capacitors can have a relatively low capacity. The filter capacitors in the filter circuit in Fig. 15 are shown to be .0005 mfd, as was mentioned in section 12 of this lesson. This means the electrical energy stored in these filter capacitors is so low it cannot become dangerous to life.

Furthermore, there is no direct connection between the high-voltage circuits and those of the AC line. Thus there is little danger from that source.

Despite all these advantages, the RF power supply never came into widespread use. The drawbacks to it were the fact it required additional tubes, and additional coils, and other electronic components which ran the cost higher than seemed desirable. It never came into widespread use.

It has found some favor in some quarters, and is used in some of the older TV receivers. It is also used in some types of projection receivers. But its use is definitely limited at this time.

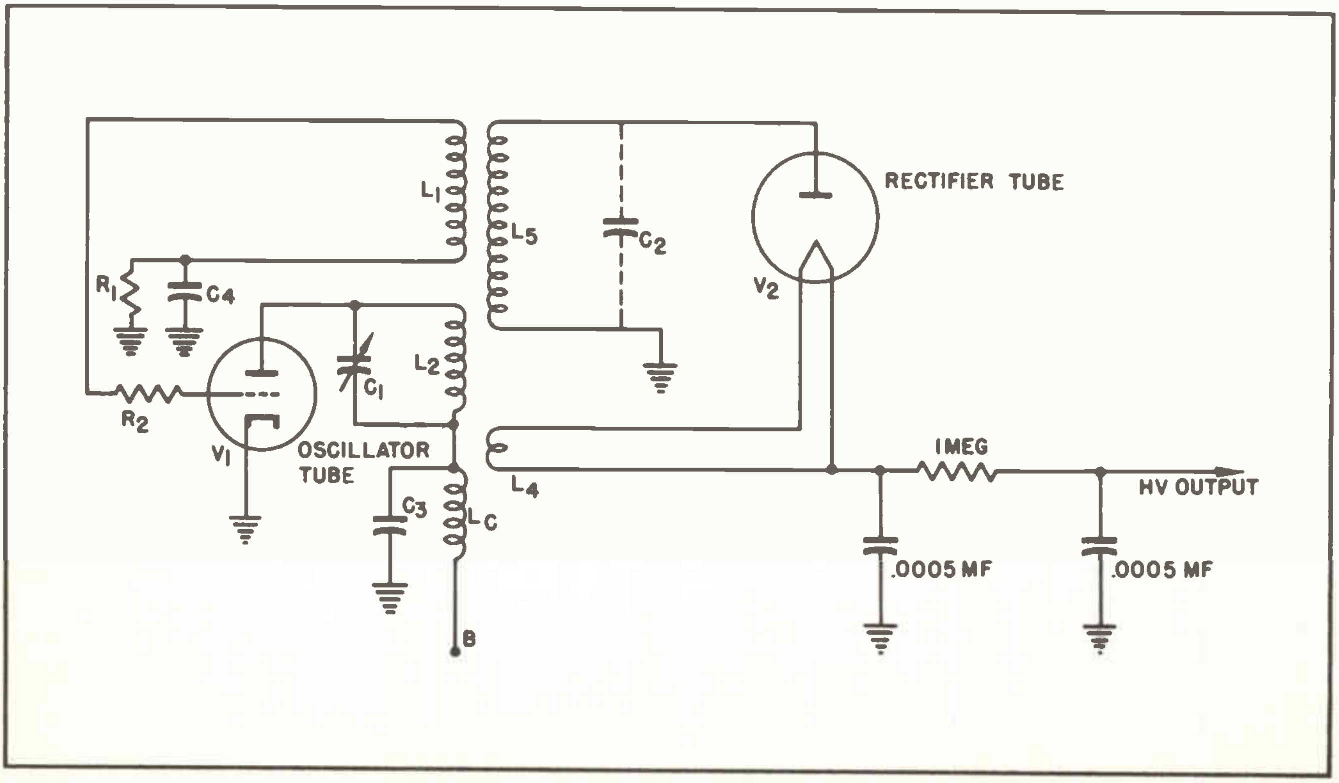

Figure 15. R.F. Power Supply Circuit.

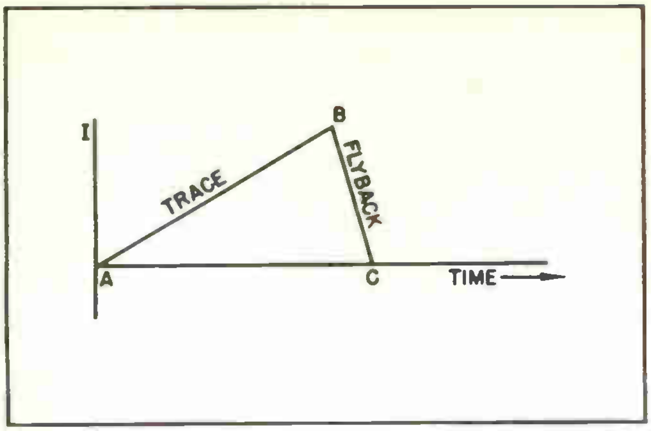

Figure 16. Graph of the rise and fall of current in Horizontal Output transformer.

Section 15. HIGH VOLTAGE FROM FLYBACK TRANSFORMER IN HORIZONTAL CIRCUITS

With the passage of time television engineers have constantly improved the circuits in the receivers. They have simplified the circuits, reduced the number of tubes, taken advantage of power previously wasted, and done other things which seem almost incredible at first glance.

Not the least of the things they have done is the development of a circuit which makes use of the tremendous energy created in the horizontal transformer during the retrace of the horizontal sweep. This is a great pool of energy which was formerly wasted.

To better understand the situation which exists in the horizontal deflection circuit we will describe briefly the action which occurs there. Fig. 16 shows, in graphical form, the manner in which the current rises and falls in the horizontal output transformer.

The current rises at a relatively gradual rate during the trace period. This is the period during which the electron beam is being moved from the left side of the screen to the right side. Then the current abruptly reverses itself in the secondary to move the beam rapidly back to the left side from the right side.

The abrupt reversal of the current in the secondary results from the sudden stopping of current flow in the primary.

During the trace period the current flow increases gradually in the primary winding between point *A* and point *B* in Fig. 17. That increasing current flow in the primary induces a gradually increasing voltage and current in the secondary winding.

At the end of the trace period — at the exact instant of the retrace — the current through the primary of the transformer suddenly ceases because it is cut off by the action of the horizontal amplifier tube. When that occurs the magnetic field built up around the iron core of the transformer suddenly collapses.

Collapsing of the magnetic field generates a sudden voltage in the secondary which causes the current in the secondary to reverse itself, and thus return the electron beam to the left side of the screen. That is the normal action of the currents in the horizontal output transformer.

But the sudden collapse of that current through the primary, and the sudden collapse of the magnetic field around the windings of the transformer, also affects another winding on it. That is the winding which lies between points *A* and *C* in Fig. 17.

The winding between points *A* and *C* is connected in series with the primary winding between *A* and *B*. This is a point worth remembering.

When the current through the primary sud-

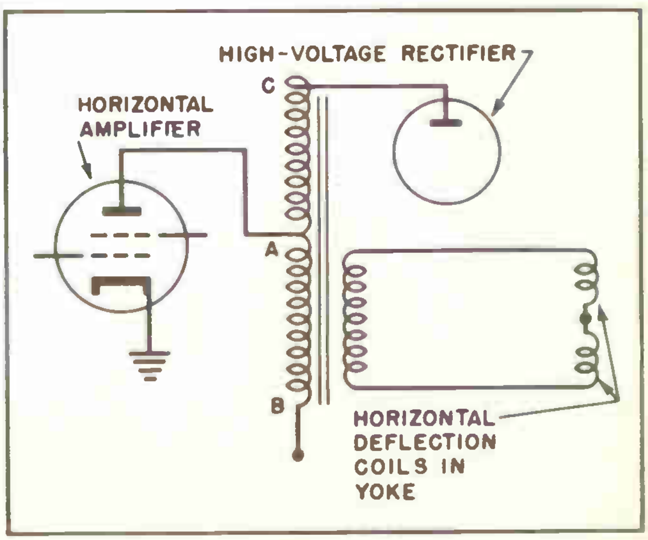

Figure 17. Horizontal Output Transformer Circuits.

denly ceases to flow, and the magnetic field suddenly collapses, the collapsing field induces a voltage in every conductor within the immediate vicinity of the field. It induces a voltage in every turn of the windings of the transformer core. All the turns in the windings between points *C* and *B* are in series with each other. Therefore all the voltages induced in all those turns are added together.

The net result is that the suddenly collapsing magnetic field induces a very high voltage in the winding between points *C* and *B*. That voltage — positive at *C* with respect to *B* — is applied to the anode of the high-voltage rectifier.

That voltage lasts for only a very small fraction of a second, in most cases not more than three or four microseconds, but it is sufficient to make the high-voltage rectifier conduct, thus attracting electrons from the cathode of that rectifier tube. Attracting electrons from the cathode of the high-voltage rectifier makes the cathode highly positive, even during those periods when no current is flowing through the tube.

A more complete diagram of the combined horizontal-high-voltage circuits is shown in Fig. 18.

It is interesting to note the high-voltage filter circuit in Fig. 18 and that with the RF high-voltage circuit in Fig. 15. Both are quite similar. Each uses a 1-megohm resistor as the filter resistor. Both use a .0005 mfd capacitor as the input to the filter circuit.

One interesting item in connection with this high-voltage filter circuit which is definitely worth mentioning is the manner in which the second filter capacitor is arranged. Fig. 15 shows an actual capacitor, while it is omitted in Fig. 18.

In most receivers there is no actual capacitor at the output of the filter circuit. At least none which can be seen.

The output of the high-voltage filter circuit is connected directly to the aquadag on the inside of the glass envelope of the picture tube. On the outside of the same glass envelope of the tube is a second conductive covering which is grounded. Fig. 19 makes this a little more clear.

The insulation of the glass of the picture tube acts as a dielectric between plates of a capacitor. The conductive covering on the inside

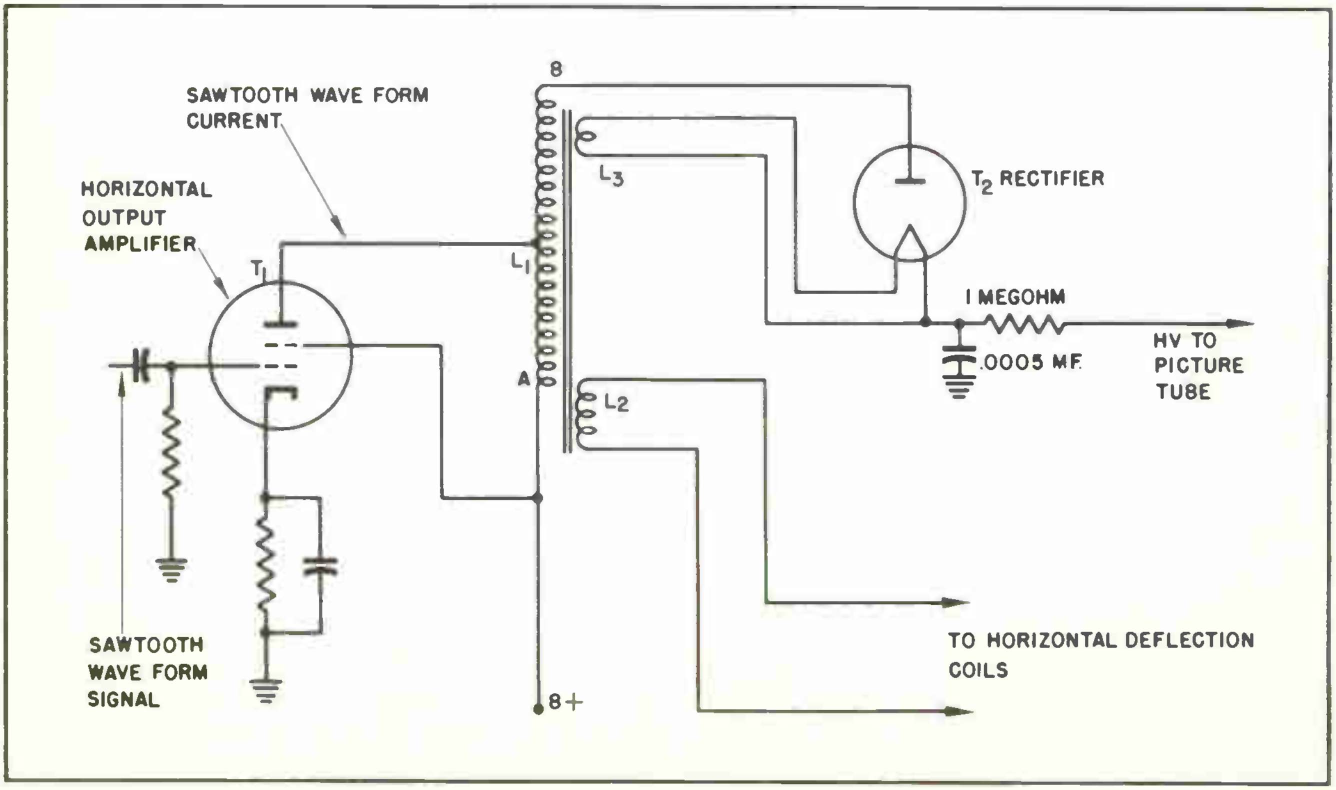

Figure 18. High-Voltage Circuits connected to Horizontal Output Circuit.

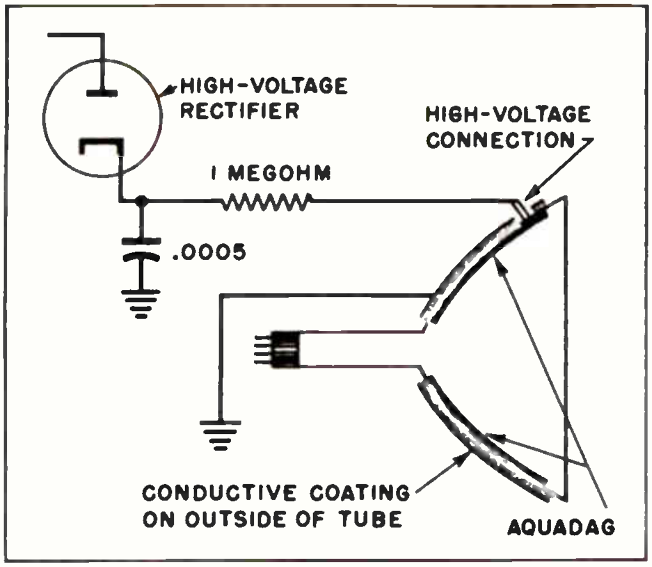

Figure 19. Conductive covering on outside of picture tube acts as Output Filter Capacitor.

of the glass acts as one plate of a filter capacitor. The conductive covering on the outside of the glass acts as the other plate of the filter capacitor.

When the conductive covering on the outside of the picture tube is grounded we have what amounts to an output filter capacitor in the high-voltage circuit.

Several types of high-voltage rectifier tubes can be used with a circuit of this kind. In practice the ones most frequently used are the 1X2 and the 1B3. The 1B3 has a higher voltage rating than the 1X2, and is capable of handling the heavier loads. It has a much higher "arc-back" voltage, meaning that a higher reverse voltage can be placed across the elements inside the tube without arcing occurring.

The heart of a "flyback" high-voltage power supply is the horizontal output transformer. It is called the *flyback transformer* even more frequently than by its more proper name of horizontal output transformer. In fact, TV supply houses are tending to list it in their catalogs as a flyback transformer.

Flyback transformers assume a variety of shapes and forms. It is impossible to show what all of them look like. Any attempt to do so would undoubtedly fail to list at least some of the more obscure types.

Despite that, most resemble the one shown in Fig. 20 to some extent. The main frame of the transformer consists of the heavy iron core. The iron frame is clearly visible in Fig. 20.

The wafer-like coil inside the iron core is the main high-voltage winding. That is the portion of the winding in Fig. 17 which is shown as being between points *C* and *A*. The high-voltage winding is wound outside the other portion of the primary winding so the winding itself provides some degree of insulation for the high-voltages induced within the coil.

The secondary winding is usually wound immediately around the iron of the core. The voltages in the secondary winding are all relatively low, therefore the insulation over that winding need not be so elaborate as that which protects the high-voltage winding.

Several types of tubes are used in the horizontal output amplifier circuits of television receivers. Two types, however, seem to be used in more receivers than any other tubes. Those are the 6BG6 and the 6BQ6, together with newer modifications of these types.

The frequency of the voltage applied to the high-voltage rectifier in this type of circuit is not necessarily as high as that used in the RF power supply circuit. But it is plenty high.

The frequency of the horizontal deflection sweep is 15,750 cycles per second. Therefore, that is the frequency applied to the anode of the high-voltage rectifier tube. This means that a peak positive voltage pulse is applied to the anode of the high-voltage rectifier tube 15,750 times each second.

Because of this relatively high frequency the filtering capacitors can be quite low in capacity. The .0005 mfd capacitors, which have been previously mentioned in this lesson, are entirely adequate for filtering; and because of their small capacity they are not capable of storing dangerous amounts of electrical energy.

The horizontal sweep frequency is within the hearing range, and is audible to the ears of many persons. Sometimes the coils or the laminations of the flyback transformer have a tendency to sing. This is due to minor physical movements

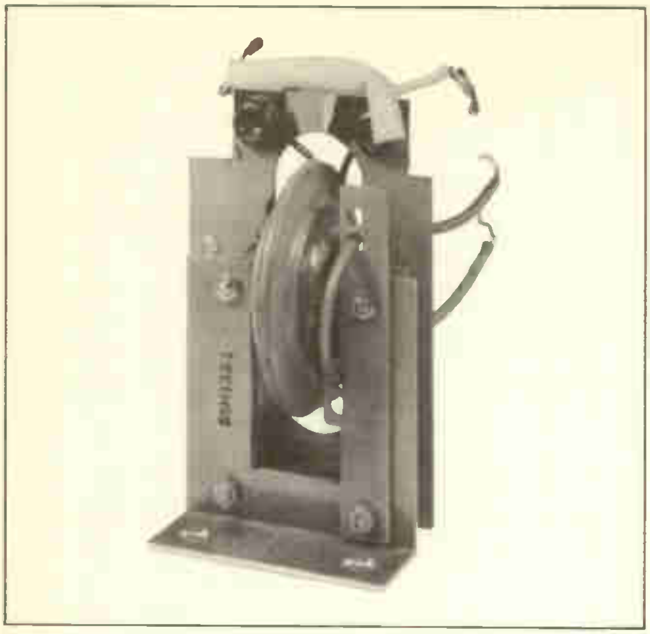

Figure 20. Flyback Transformer.

the parts are sometimes able to make.

Normally that tendency to *sing* is not objectionable — many persons cannot hear it at all. On other occasions it becomes quite pronounced. When that occurs it is sometimes necessary to replace the transformer to get away from the noise.

Because of the extremely sharp voltage surges to which the windings of the flyback transformer are subjected the insulation sometimes breaks down. This was an especially frequent occurrence with the earlier models of flyback transformers.

When such insulation breakdowns occur it is sometimes very difficult to discover where the defect is occurring, and even more difficult to repair the break.

In most cases the only satisfactory solution for a partially defective flyback transformer is to remove the old one and replace it with a new one. Sometimes minor defects in such a transformer can be repaired by an experienced serviceman. In most cases there is danger of spending more time on the transformer than it is worth. Furthermore, there is no assurance such repairs will stand up under the strain of regular use.

Few experienced service technicians make any attempt to repair a damaged or defective flyback. It can usually be replaced more quickly than it can be repaired.

An even more urgent reason for replacing it is the fact that all too often a repaired transformer has a tendency to break down again. If the transformer is replaced when it first becomes defective there is a better chance the same trouble will not recur — provided, the cause of the defect is not some unusual operating condition which imposes excessive voltage on the circuits of the flyback.

Newer types of flyback transformers are more ruggedly built than earlier models. They stand up better under heavier strains, and are more dependable. There is less trouble with their windings short-circuiting to other windings, or to ground.

There are many types of flyback transformers in regular use. Some manufacturers prefer one type, others prefer another. But most of them can be replaced by using a relatively small number of "universal replacement" transformers.

Once you understand the purpose for which the transformers are used, the performance expected of them, and the general characteristics of the various types it is usually rather simple to select a universal replacement transformer, and use it to replace almost any kind of transformer you are likely to run into. Physical shapes and sizes often make the matter of replacement more difficult than the matter of electrical characteristics.

The matter of the flyback transformer will be taken up again in a later lesson, and the subject of its replacement gone into more extensively.

Section 16. THE "BOOT-STRAP CIRCUIT"

The B plus voltage in some TV receivers using an AC-DC power supply is often not so high as is considered desirable in some of the working stages. In this connection it should be kept in mind the normal B plus voltage in such receivers seldom exceeds 125 volts, and in some cases is even less. This is especially true in those cases where the power supply is a straight AC-DC circuit and does not employ voltage doubling.

Sometimes it is desirable to supply the audio output tube with higher voltages than are available in the AC-DC power supply circuit.

It is even more desirable to supply higher B plus voltages to the screen grid and anodes of the horizontal output amplifier tubes, and also the horizontal oscillator tube. Higher voltages are also often desirable for application to the vertical deflection tubes, especially the output amplifier tube.

Most of the other tubes in a television receiver operate satisfactorily on the voltages available in a normal AC-DC power supply circuit. But that does nothing about the need for higher voltages on the tubes in the circuits we have mentioned.

While TV engineers were puzzling their heads about this need, and wondering how they could come up with higher voltages for those tubes that needed them in AC-DC receivers, they chanced to turn their attention to the *damper tube*. The damper tube is used across the windings of the deflection yoke — across the *horizontal* windings of the deflection yoke — to prevent an undesirable condition called "shock oscillations" distorting the left side of the picture.

While television was still young it was discovered that the fast retrace of the beam from the right side of the screen to the left created special electrical problems in the various circuits of the receiver. The fast retrace had a "shocking" effect on some of the circuits, and tended to set up short-lived "shock oscillations".

These shock oscillations affected the left side of the picture more than any other because that is the part of the picture scanned by the beam immediately after the retrace action.

One way to prevent shock oscillations forming is to "damp" them out. Such damping action is designed to permit a large amount of current to flow in one direction as the result of the shock conditions, but prevent it flowing in the other.

Several types of electronic circuits can provide that damping action, but the most satisfactory for the horizontal circuits is a diode vacuum tube. The diode permits current to flow in one direction, but blocks its movement in the other. Thus the oscillations are damped out before they can really get going. Fig. 21 shows

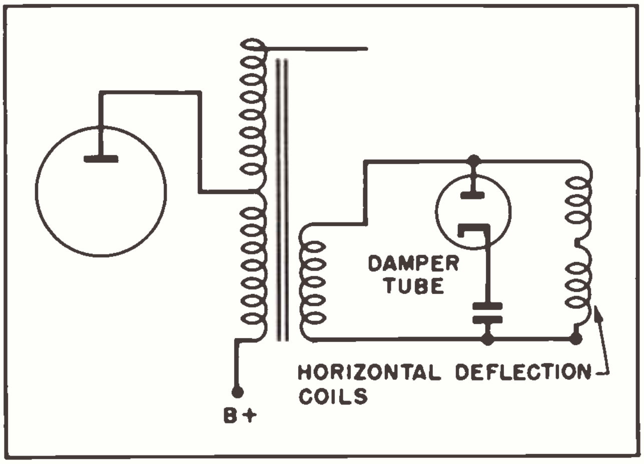

Figure 21. Damper Tube is connected across Deflection Coils.

how such a damper tube is often connected across a horizontal deflection coil.

The subject of damper tubes, and damper circuits, will be examined more thoroughly in lessons to come. Our interest at this time is how that damper tube can be utilized to boost the B plus voltage.

The damper tube can be connected directly across the deflection coils, or a capacitor can be connected in series with the cathode of the tube. Insofar as the damper action is concerned it makes little difference.

When the tube is connected as shown in Fig. 21 it acts to boost the voltage of the B plus in those parts which are supplied with power through the damper tube. A better explanation of the circuit is contained in Fig. 22.

Keep in mind that the voltage and current applied to the anode of the damper tube — and to the deflection coils — rises gradually during the *trace* period of the horizontal cycle. Suddenly the current and voltage are reversed. That is the *retrace* period.

During the short interval in which the current and voltage are reversed a very high positive voltage is applied to the anode of the damper tube. That short-interval voltage may rise to values of 500 to 1000 volts. Sometimes even more. Much depends on the actual circuits involved.

That sudden, high positive voltage on the anode of the damper tube causes the tube to

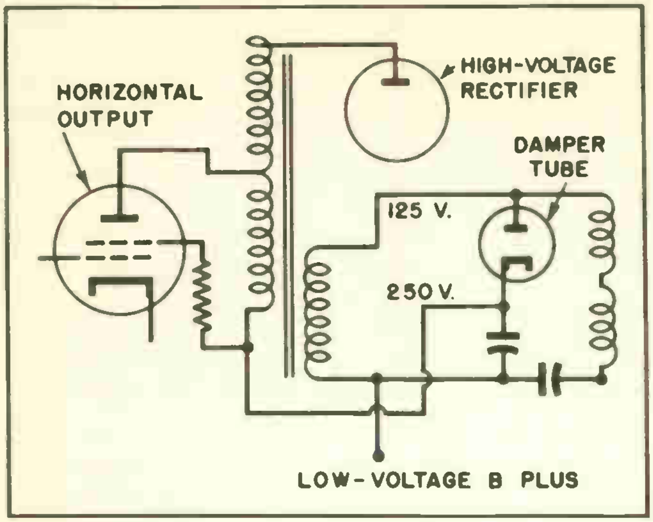

Figure 22. Damper Tube connected to provide Boosted B plus Voltage.

conduct. It attracts electrons from the cathode, and incidentally from the capacitor in the cathode circuit of the tube. The action charges the capacitor.

After that high voltage on the anode has passed the effects remain. Those electrons attracted from the cathode circuit during that short interval cannot return through the tube. The cathode retains the high positive voltage created on it by the removal of the electrons through the tube during the short interval in which the anode was so highly positive. The capacitor in the cathode circuit retains its charge.

If a meter is used to measure the voltages on the anode and cathode of the damper tube they will be something like those shown in Fig. 22. That would appear, at first glance, as being contrary to all the tube theory you have learned. But the explanation is quite simple. The meter registers only the normal, or average, voltage on the anode. That is the normal voltage of the regular AC-DC B plus power supply. The high-voltage pulse on the anode is so short in duration the meter needle cannot register it.

Despite the fact the meter does not register those short-interval high-voltage pulses, they are definitely present. And, during the short interval in which they are present they cause the tube to conduct. When the tube conducts it extracts electrons from the cathode circuit, and thus raises the positive voltage at the cathode. In most cases the average voltage on the cathode is raised to a value approximately twice that of the B plus which is normally present on the anode of the damper tube.

You might be interested in just how this circuit goes into operation when the power is first on to the receiver. Perhaps a few words of explanation will make the action reasonably clear.

The normal B plus voltage from the AC-DC power supply is applied to the anode of the damper tube through the secondary winding of the flyback transformer. It is usually on the order of 125 volts, although it may be slightly higher or slightly lower in individual cases.

That positive voltage applied to the anode of the damper tube causes electrons to flow through the tube, and thus causes the cathode to become somewhat positive. That positive voltage from the cathode — which at this instant is still somewhat lower than that applied to the anode — is applied to the anode and screen grid of the horizontal output amplifier. And probably other tubes as well.

That is sufficient voltage to cause the horizontal output amplifier to conduct, but it is not enough to operate at full efficiency.

Simultaneously, an oscillator signal will be applied to the grid of the horizontal output amplifier from the horizontal oscillator. That is a saw-tooth voltage.

When the saw-tooth current from the amplifier is applied to the primary winding of the flyback transformer it induces a saw-tooth voltage in the secondary of that transformer. That saw-tooth voltage is also applied to the anode of the damper tube.

Because of its nature the retrace voltage of the saw-tooth wave-form voltage is always greater than the normal voltage. That excessive voltage is also applied to the anode of the damper tube. The excessive voltage causes the damper tube to conduct, and the positive voltage on the cathode of the damper tube is gradually increased.

As the positive voltage on the cathode of the damper tube becomes progressively greater it is applied to the anode and screen grid of the horizontal output amplifier. The increased voltage causes the horizontal amplifier tube to work harder, and deliver increasingly greater current pulses into the flyback transformer.

The increasing current through the transformer causes the saw-tooth voltage at the secondary to grow progressively greater. And so it goes. Each passing cycle causes an increase in the voltage in various parts of the circuit until the normal operating voltage of the circuit is eventually reached.

The net effect of a circuit of this kind is that it raises its own B plus voltage. Thus the name by which it is most widely known — the "bootstrap circuit". The technical name for the circuit is a *boosted B plus*, but that name is usually reserved for strictly technical discussions.

While this circuit was originated for the purpose of raising the voltages to the operating elements of a few important tubes in AC-DC types of TV receivers, it will also be found in some receivers which use conventional full-wave AC power supplies. Modifications of this circuit have also been used for other purposes in TV receivers, but the one mentioned here is that in which it is most widely used.

Section 17. DISCHARGING CHARGED CAPACITORS

Capacitors are deliberately constructed for the purpose of storing electricity. Some such capacitors retain their charge longer than others, the exact length of time depending on the condition of the capacitor.

The amount of electricity which can be stored in a capacitor depends on its capacity, and the amount of voltage it can withstand.

Most of the capacitors used in radio and television receivers have relatively little capacity. Therefore, they are capable of storing relatively little electricity, and there is little danger of receiving a shock from them after the power has been turned off. Other capacitors are operated across circuits where there is relatively little voltage. There is little inherent danger in them.

On the other hand there are some capacitors in a radio or television receiver which are capable of accepting, and holding, a large charge of electricity. Others are charged with a very high voltage.

Some of these capacitors are able to hold their charge for relatively long periods of time after the power to the receiver has been turned off. These charges can often be held for thirty minutes, and even longer if the capacitor is in excellent condition.

If a technician comes into contact with one of these charged capacitors, even though the power has been shut off, he can receive a very uncomfortable shock. Under some conditions the shock can be downright dangerous.

Electrolytic capacitors in the power supply of radio and television receivers always have a high capacity, and the voltage across them is high enough to be definitely a hazard. The better quality A-C receivers frequently store voltages ranging up to several hundred volts.

The high-voltage filter capacitors in the high-voltage power supply in a television receiver must be treated with respect. Those capacitors are deliberately designed to be as safe as possible, just as was explained earlier in this lesson. But the voltage across them runs up into many thousands of volts. Even though the capacity is low, that high voltage can give an unwary person a severe jolt.

Common sense dictates that a wise technician will discharge all such capacitors before beginning any tests on a receiver. The steps necessary to discharge them are so simple that most technicians perform them as an act of habitual routine, almost without thinking.

All that is necessary is to provide a momentary short-circuit across the two terminals of the charged capacitors. The capacitors can be discharged in a second or two with a screwdriver which has an *insulated* handle.

Since most such dangerously charged capacitors have one terminal connected to B— or ground the technician usually rests the point of the screwdriver on the metal of the chassis, or against the B— circuit. The metal shank of the screwdriver is then brought into contact with the B+ circuit. This can be done at the "hot" terminal of the electrolytic filter capacitor, or to any other point which may be more convenient.

Discharging the high-voltage filter capacitors in the high-voltage power supply of a television receiver is equally easy. Usually the best place to discharge the high-voltage filter capacitors is at the point where the high-voltage lead is connected to the picture tube. But if some other location is more convenient it can be used.

The action is the same as that used to discharge the electrolytics in a low-voltage filter circuit. The metal shank of a screwdriver is used to provide a momentary short-circuit between the high-voltage power supply circuit and B−, or ground.

The voltages stored in the charged capacitors of a radio or television receiver are seldom dangerous in the newer models, at least they are not dangerous to a person in good health. But the sudden shock they can give is often most unpleasant. The best practice is to discharge the circuit before beginning any experimental tests.

NOTES FOR REFERENCE

Use of a conventional step-up transformer and rectifier to obtain high-voltage for TV receivers involves dangerous hazards which must be guarded against.

TV receivers use two types of power supplies. For want of better names they are referred to as the *low-voltage* power supply and the *high-voltage* power supply.

The low-voltage power supply used in television receivers closely resembles similar supplies used in radio receivers and other electronic devices.

Most television receivers use AC power supply circuits involving the use of full-wave rectifiers.

Because of the heavy demand for B-plus power many TV receivers use a pair of full-wave rectifier tubes rather than a single one.

AC-DC power supply circuits are employed to some extent in TV receivers, but not so frequently as is true of radio receivers.

There is an increasing tendency to use two-level power supplies, with many of the amplifier tubes operating at lower anode voltages but with one voltage level in series with the other.

When an AC-DC power supply is used for television receivers it is usually necessary to connect the tube filaments in two or more series strings, then connect them in parallel across the line.

It is usually desirable to connect a low-resistance surge-limiting resistor in series with the rectifier in an AC-DC power supply to protect the rectifier against sudden surges of current as the high-capacity capacitors charge up.

Bleeder circuits are regularly used with power supply circuits to assist in regulating the stability of the voltage.

Bleeder circuits are frequently used as voltage-divider networks across the output of the power supply circuit so various voltages can be tapped off for various purposes.

High-voltage is needed in the picture tube so a strong electric field can be created which acts to accelerate the velocity of the electrons in the beam.

The electrons in the beam in a picture tube must have a high velocity at the instant they strike the phosphors of the screen. The high kinetic energy of the electrons is converted into light energy at the instant of impact.

X-rays represent an ever-present, yet little known, danger in the use of TV picture tubes.

X-rays are created when a high-velocity stream of electrons strikes some type of target.

When voltages exceeding 16,000 volts are applied to the electron stream in a picture tube the electrons strike the fluorescent phosphors of the screen with sufficient velocity to create X-rays.

When voltages on a picture tube exceed 16,000 volts users of the equipment should be shielded against X-ray exposure.

The modern tendency in TV receiver design is to enclose the high-voltage section within a metallically shielded compartment. This provides protection to the circuits, and to those who use the receiver.

Automatic interlocks are provided on most television receivers so the AC power is turned off whenever the back of the receiver is opened to gain access to the chassis.

Capacitors in the high-voltage filter circuits should be limited in capacity to such values as will prevent storage of electrical energy dangerous to human life.

Using high-frequency currents and voltages as the input to the high-voltage power supply makes it possible to use very small filter capacitors in that circuit.

Filter capacitors in the high-voltage section of modern TV receivers have been pretty well standardized at .0005 mfd., with a voltage rating of 10kv or higher.

It is now a regular practice to use a flyback transformer as the source of power for the high-voltage section of TV receivers.

Boosted B plus circuits, better known as "boot-strap circuits", are widely used in AC-DC receivers to boost the B plus voltage.

"Boot-strap circuits" operate from the boosted voltage present at the cathode of the damper tube, a source of power which would otherwise be wasted.

Since some capacitors, especially those in the high-voltage circuits, can store large amounts of electricity for rather long periods of time they can be troublesome. It is important that a serviceman knows how to discharge these to render them harmless. The metal shank of a screwdriver, having an insulated handle, can be used to provide a momentary short-circuit across the two terminals of a charged capacitor — or by touching the B+ and the chassis simultaneously.

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PARALLEL A-C CIRCUITS

Contents: Introduction — Similarity of A-C and D-C in Resistive Circuits — Why A-C Parallel Circuits Often Differ from D-C Circuits — Problems Presented by Parallel A-C Circuits — Resistances in Parallel — Parallel Circuits Containing Capacity — How Capacity in an A-C Circuit Affects Its Action — Current Action in Parallel Circuits — Current Through Resistance in Parallel — Mathematical Methods for Calculating Impedance — Current in Parallel Circuits Having Capacitance or Inductance — Limitations on the Usefulness of the Current Method for Calculating Impedance — Notes for Reference.

Section 1. INTRODUCTION

We have discussed electrical circuits many times in these lessons. Electrical circuits are the pathways along which electrical impulses travel, and through which electrical current flows.

By this time you are well aware that A-C voltages and currents play an important part in radio and television work. As a matter of fact, A-C voltages and currents are important in all kinds of electrical work, and are not confined to radio and television alone.

The electrical power which lights our homes and powers our industry is almost always delivered by the power company in the form of alternating current. This can come as no surprise since we have already devoted several lessons to the matter of power supplies, much of which were occupied with explanations of the manner in which alternating current from power lines is changed into other forms for use in radio and television receivers.

The very existence of radio and television depends upon the peculiar phenomena which surround the passage of alternating currents through a conductor. Were it not for high-frequency alternating currents and voltages, and our ability to produce them, there would be no radio or television.

The truth is that the usefulness of electrical power was at one time severely limited because engineers had not yet learned how to create and handle alternating current. Were it not for the fact that engineers learned to deal with the peculiar effects which surround the flow of alternating currents through conductors it is doubtful we would enjoy our present benefits from electrical power. Certainly, the usefulness of electrical power would be much more limited than it is now.

In previous lessons we discussed many kinds of circuits. We first introduced you to the most simple kinds of series circuits. After we felt you were sufficiently well acquainted with them we explained the more difficult problems which occur when it is necessary to calculate, or predict, the action of voltages and currents in parallel circuits.

While we have never dodged discussions connected with parallel circuits, we have always tried to restrict them to circuits involving direct current. We have touched on the action of alternating currents in parallel circuits in a few lessons, but in none of our discussions was it necessary to inquire into the manner in which parallel reactances and impedances are calculated. We thought it best to defer such discussion until you had a reasonably good understanding of the basic principles involved in the action of alternating current in parallel circuits.

We believe the time has arrived for you to learn something about the more precise relationships involved when it is necessary to calculate the actions which take place in such circuits.

Section 2. SIMILARITY OF A-C AND D-C IN RESISTIVE CIRCUITS

In the past most of our discussions have revolved around the actions which take place in resistive circuits. This practice has made it possible to simplify explanations of electrical circuits. By using resistances in our discussions and explanations we have been able to explain actions which occur in both D-C circuits and A-C circuits.

The reason this was possible is that A-C currents and D-C currents behave alike when the load is purely resistive. All the rules of Ohm's Law which apply to D-C in a circuit apply exactly the same to A-C when the load is some form of resistance.

Resistive loads are common in our daily lives. Incandescent lamps, which most of us use in our homes and offices as a source of light, represent the most common type of resistive load.

Electric toasters, hot plates, sandwich makers, soldering irons, and all kinds of electrical heating apparatus represent other types of resistive loads. All these things work equally well on either A-C or D-C, provided there is not some kind of auxiliary control which works on only one kind of current or the other. Some types of pressing irons and roasters have temperature controls which operate only on A-C or only on D-C.

In radio and television work we find even more kinds of resistive loads. Definite resistive loads, in the form of carbon resistors or wire-wound resistors, are deliberately introduced into many electronic circuits to accomplish certain specific purposes. Filaments of vacuum tubes are resistive; some are connected in series, others in parallel. Filaments in some TV receivers are connected in series-parallel.

Other examples of resistors in radio and television circuits are those used as loads in anode

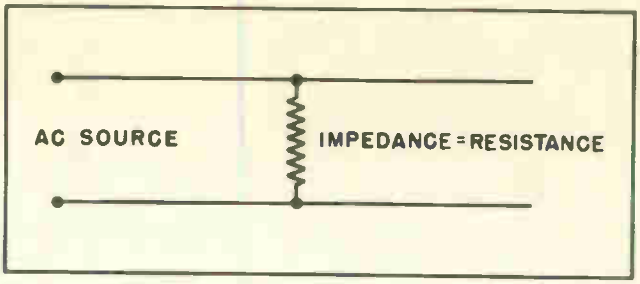


Fig. 1. When the load is resistive, total impedance is limited to the resistance.

circuits and those used to develop grid bias in cathode circuits. Of course, there are many other resistors in vacuum tube circuits. Grid-return resistors, screen-grid dropping resistors, isolating resistors, and many others are all important.

The point we are trying to make is that resistive loads are commonplace in all kinds of electronic circuits, including those with which we work regularly in radio and television receivers.

In earlier lessons you learned that only resistance presents an opposition to direct current. You have also learned that opposition to alternating current may be reactive as well as resistive. Or it may be a combination of resistance and reactance. When these two types of opposition are combined in an A-C circuit it is commonly referred to as *impedance*.

However, when the load is resistive only, the impedance is equal to the resistance. This is the fact we demonstrate in Fig. 1.

When the load is resistive, as shown in Fig. 1, the circuit presents exactly the same opposition to either A-C or D-C. Both A-C and D-C affect such a circuit in the same way.

In a resistive circuit all the rules which apply to D-C current flow, such as the rules of Ohm's Law, apply equally to A-C current flow.

Section 3. WHY A-C PARALLEL CIRCUITS OFTEN DIFFER FROM D-C CIRCUITS

Resistive loads, as we have previously mentioned, are common in our daily lives; but loads which contain some form of reactance as well as resistance are even more common.

It is no exaggeration to say the overwhelming majority of the electrical circuits with which we work regularly in radio and television contain some form of reactive opposition in addition to resistive opposition. Probably 90% of all practical electrical circuits possess some degree of reactance.

In ordinary electrical circuits reactive opposition is presented by every type of electrical motor, by neon signs, by fluorescent lights, by transformers, and an almost endless list of other electrical apparatus. In our radio and television work every circuit which includes a coil presents some degree of inductive reactance, while those which include capacitors presents some amount of capacitive reactance.

All of which means that virtually every circuit in a radio or television receiver possesses some degree of reactive opposition to the flow of electrical current. These include R-F and I-F transformers, choke coils, power transformers, coupling impedances and others, all of which are inductive in nature. Those circuits which present reactive opposition of a capacitive nature are the couplings between stages, by-passes to ground, and almost every other place where capacitors are used.

In addition to the circuits mentioned are those which consist of capacitors and inductances in parallel. The outstanding of these are the paralleled, tuned "tank circuits," but there are many others. Not the least are the various filter circuits so widely used in so many sections of radio and television receivers.

So long as nothing but D-C voltage is applied to circuits, and nothing but direct current flows within them, we can continue to view them as we have other D-C circuits in the past. But the very fact that coils and capacitors are used in a circuit insures, almost automatically, that the circuit has been deliberately designed for use with alternating current or voltage.

All of which leads to the inescapable fact that alternating current possesses some very peculiar properties when it flows through coils and capacitors. To take advantage of those peculiar properties engineers deliberately introduce definite values of capacitance and inductance to the circuits, and thus bring about specific actions.

Since A-C voltage and current play such important roles in radio and television, and since the circuits which include those components are so often connected in parallel with each other, it becomes important to know exactly what happens when A-C power is applied to a parallel circuit. It is our intention to search into mysteries surrounding the action which occurs when alternating current flows through parallel circuits, especially when those circuits include some degree of reactance in addition to the normal resistance.

Section 4. PROBLEMS PRESENTED BY PARALLEL A-C CIRCUITS

There is no disguising the fact that problems which occur in connection with the flow of alternating currents through parallel circuits are somewhat more difficult of solution than similar problems which involve current flowing only in one direction.

The problems arise from the fact that A-C current through a coil or a capacitor is never in phase with the impressed voltage. Electrical engineering students regularly devote as much as two years studying the problems arising from the complexities of parallel A-C circuits.

Early in this course we took up the explanation of the action which occurred when A-C current flows through an inductance. Among the things we mentioned was that current through an inductance always lagged behind the voltage.

At about the same time we explained that A-C voltage applied to a capacitor apparently caused current through the capacitor to lead the voltage.

From these two facts it becomes reasonable to expect that when A-C voltage is applied to a parallel circuit, which possesses various degrees of resistance, inductance and capacitance in its combined paths, somewhat different actions will occur than would be true in the case of uni-directional voltage. The currents which flow through the various paths, as a result of the impressed voltage, will vary quite widely.

In the case of a circuit similar to that illustrated in Fig. 2 we have one path which presents only resistive opposition to the flow of A-C current. In the other path current encounters capacitive reaction.

When A-C voltage is applied to a circuit of this

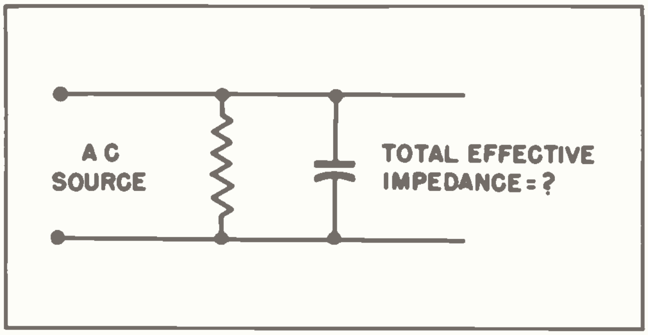


Fig. 2. Parallel paths for current; one reactive, the other resistive.

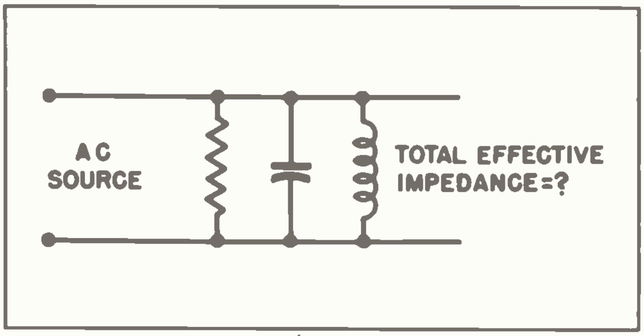


Fig. 3. Three parallel paths for current; two reactive and one resistive.

kind current will flow through the *resistive* path *in exact phase* with the applied voltage. By this we mean that when the voltage is rising in one direction the current will also be rising. At the instant the voltage reaches its peak the current will also reach its peak. And when the voltage declines and reverses, the current will also decline and reverse in exact unison.

But the same conditions will not prevail in the case of current through the *capacitive* path. The action of the capacitor causes the current to actually *lead* the voltage through that path.

The action in the two paths is such that at the instant the current through the capacitive path reaches its peak in one direction the current through the resistive path will be just starting to flow in that direction. By the time the current through the resistive path reaches its peak the current through the capacitive path will have declined to zero, and be ready to start flowing in the opposite direction.

All of which presents us with a very peculiar bit of electrical phenomenon. The same A-C voltage is applied to the two paths of the parallel circuit—but the current which flows through the two paths does not always flow through them in the same direction at the same time.

These actions of current in a parallel A-C circuit become even more complex and complicated when we add a third path, as shown in Fig. 3.

Application of the same A-C voltage from the same A-C source, to the three parallel paths causes current to flow through each of them in a different manner, and at a different time. That through the resistance will rise and fall and reverse in exact phase with the voltage. Each change in the magnitude or direction of the voltage instantly affects the current through the resistance.

But the current through the other two paths does not rise and fall in phase with the applied voltage. The current through the capacitor leads the voltage, just as we have explained. But the current through the coil *lags* behind the voltage.

Here we find an apparently confusing situation. We find an A-C voltage applied to three parallel paths. From our study of D-C circuits we would expect the currents through the three paths to rise and fall in unison with the applied voltage, yet from our other studies of inductance and capacitance we know that is not true.

When A-C voltage is applied to the three parallel paths the voltage causes current to flow through all three paths. That fact must not be forgotten nor neglected. But current through the three paths is not affected in the same manner.

It is well worth our time to study this a few minutes, and see just what actually happens in such a circuit. To understand the action best we will assume, for the sake of convenience, that the only opposition in one path is resistance, in the second it is capacitive reactance, and the third is inductive reactance.

In the resistive path the current is *in phase* with the applied voltage. Through the capacitive path the current is *ahead* of the voltage by 90°. That through the inductive path *lags* the voltage by 90°.

Keep in mind that the current through the resistive path is in phase with the voltage, while that through the capacitive path is 90° ahead of the voltage and through the inductive path is 90° behind the voltage. If you have taken the time to study this carefully you have probably been struck by the fact that the current through the capacitive path *is 180° out of phase* with that through the inductive path.

Reduced to everyday language this last statement means that at the instant current is flowing through the capacitive circuit in one direction the current through the inductive circuit is flowing in the opposite direction. If this statement is not entirely clear to you it would be worth the time to go back and read it again. Read it several times, if necessary. You will also probably find it profitable to go back and review your lesson on *Resonance*.

The same applied A-C voltage, when applied across three different types of circuits, causes current to flow through these circuits at different times with respect to the applied voltage. The times at which currents flow are so different that at the instant current is flowing in one direction in one circuit it is flowing in the opposite direction in another circuit.

The fact that currents in the various branches of a parallel circuit move in the ways they do complicates the problem of calculating impedance of a parallel A-C circuit. The problem of finding the impedance of a parallel circuit is one that confronts practical electronic men every day of their working lives.

The effective impedance of a parallel A-C circuit is equal to the voltage across the combined circuit divided by the current through it. This is similar to the situation we find in connection with finding the total effective resistance in a parallel resistive circuit, in which case the total effective resistance is equal to the voltage divided by the current.

It is merely a restatement of the basic form of Ohm's Law. The resistance is equal to the voltage divided by the current; or:

$$R = \frac{E}{I}$$

In the case of impedance we merely substitute the symbol for impedance (Z) for the symbol for resistance (R). The formula then becomes:

$$Z = \frac{E}{I}$$

This all seems simple enough. And, it is simple when we know the total voltage applied to the combined circuit, and the total current which is delivered to the combined parallel circuit from the line.

Unfortunately, when problems involving parallel A-C circuits arise we are often confronted with situations where we know the capacity or reactance of the capacitor, or the inductance or reactance of the coil, but do not know the voltages and currents involved. In many cases it is necessary to start with that kind of information, and from it determine the amount of impedance involved.

Very often it is necessary to figure out what will happen in a circuit before that circuit is actually created. It is only by applying the rules we explain in this lesson that such predictions can be made.

It is because situations like that occur quite regularly in radio and television work that it is so convenient—even necessary—to know how to calculate the various actions which take place in parallel A-C circuits.

Section 5. RESISTANCES IN PARALLEL

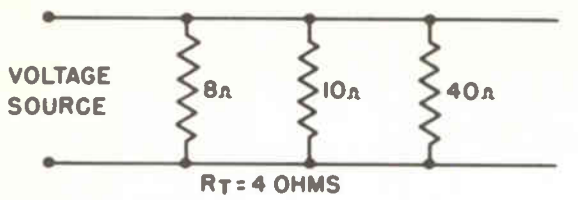
To better appreciate the exact nature of the problems involved in parallel A-C circuits it is well that we go back and review briefly the action which takes place in a parallel D-C circuit involving resistances. The parallel resistive circuit will perform the same whether A-C or D-C voltages are applied to it.

When a parallel circuit contains only resistance the total *effective resistance* can be found by finding the reciprocal of the sum of the reciprocals of the individual resistors. This is shown in Fig. 4.

These facts were discussed and explained in earlier lessons. We are repeating them now for the purpose of refreshing your memory before we go any deeper into parallel impedances.

The manner of finding the total effective resistance in a parallel circuit, where only resistance is involved, is a relatively simple job. It is merely necessary to find the reciprocals of the individual resistors, as shown in Fig. 4, then add them together. After the sum of the reciprocals has been figured out it is merely necessary to find the reciprocal of that sum.

In the case of the problem presented in Fig. 4



TOTAL EFFECTIVE RESISTANCE IS

$$\frac{1}{R_T} = \frac{1}{8} + \frac{1}{10} + \frac{1}{40}$$

$$= \frac{5}{40} + \frac{4}{40} + \frac{1}{40} = \frac{10}{40}$$

$$\frac{1}{R_T} = \frac{10}{40};\ R_T = \frac{40}{10} = 4 \text{ OHMS}$$

Fig. 4. Calculating total effective resistance of resistors in parallel.

the total effective resistance is 4 ohms. All the steps involved in finding the total effective resistance is shown in Fig. 4.

Our previous studies of parallel resistances explained that the total effective resistance is always *less* than the resistance of the smallest individual resistor. This fact enables a technician to quickly check his figures to see if he has made a gross error in his calculations. If his final figure on the total effective resistance is greater than that of the smallest of the paralleled resistors, he knows he has made a mistake, and should recheck his figures.

A good example of this is the situation where 5 ohms are across 20 volts. The 20 volts will force 4 amperes of current through the 5 ohms of resistance. All that is normal—and is exactly what we would expect. It is a simple application of Ohm's Law.

If a second resistor is then connected in parallel with the 5-ohm resistor across the same 20 volt source it will not necessarily reduce the amount of current through the 5-ohm resistor. So long as the voltage remains at 20 volts there will continue to be 4 amperes of current flowing through the 5-ohm resistor. However—when the second resistor is connected across the 20 volts of pressure, current is going to flow through that second resistor also. Current will flow through it despite the fact it is in parallel with a resistor which is already drawing current from the power source.

The amount of current which flows through the second resistor is entirely independent of that which flows through the first one. The exact amount is determined solely by the voltage of the source and the resistance in the resistor.

We now have a situation in which 4 amperes are already flowing from one side of the circuit to the other through the 5-ohm resistor. Adding the second resistor in parallel with the 5-ohm resistor permits additional current to flow from one side of the line to the other—provides an additional path.

The 20 volts of pressure from the source is now causing *more* than 4 amperes of current to flow from one side of the line to the other. For all practical purposes this means that the effective resistance between the two lines has now been reduced.

The exact amount of the reduction depends upon the value of the second resistor. But in any case the total effective resistance will be equal to the voltage divided by the *total amount of current* which flows from one side of the line to the other.

There is nothing new to you in what we have just said. It is merely a simple application of Ohm's Law. But we want to stress it again for the purpose of emphasizing new ideas we intend to explain in this lesson.

When the only opposition between the lines is resistance it affects both direct current and alternating current alike. But please remember this: opposition to the two types of current will be the same *only* when that opposition is resistive. If there is inductance or capacitance in any branch of the parallel circuits different conditions will exist.

In most practical electrical circuits—whether in ordinary electrical work or in electronics—some degree of inductance or capacitance is usually present. In many cases both inductance and capacitance are present.

Section 6. PARALLEL CIRCUITS CONTAINING CAPACITY

There are a number of methods by which parallel impedance can be determined. Some are more complicated than others, but in most cases any of the methods can be used, the exact method being determined by the convenience of the person who needs to solve the problem at hand.

You might even be tempted to ask just what is the necessity of learning the impedance of any particular circuit. Why not merely measure the impressed voltage and the total current flowing at any particular instant? From those values determination of the impedance is a very simple matter.

Unfortunately, the problems with which we are constantly confronted are not quite that simple. Instead of actually measuring the impedance of a particular circuit we must often determine the impedance of a *proposed* circuit, or must determine the impedance of an existing circuit at some particular frequency, or at several differing frequencies.

In the case of video amplifiers we are often confronted with the problem of calculating the impedance at some certain frequency, so as to decide which load resistor will give the best gain for the stage, yet allow the least distortion.

Selection of the load resistor for a video amplifier circuit is a very critical matter. If the value is too low we sacrifice badly needed gain. If the value is too high we run into the problem of distortion created by the parallel capacitive reactance of the *stray capacitance* in the circuit.

There is only one correct value for the load resistor. That value must usually be determined, at least partially, by calculation. It is essential that a properly trained service man be able to calculate such values if he is to do the things he is supposed to do, and is expected to do.

An ability to calculate parallel impedances is highly useful, even necessary, when working with antennas and transmission lines. Lack of ability to solve problems dealing with parallel A-C impedance places the television serviceman in the position of being severely handicapped when competing with other trained workers who can solve such problems. Employment examinations for technicians invariably include questions on A-C parallel circuits.

If a serviceman encountered such problems only on rare occasions, the matter of parallel impedance might be considered unimportant. It so happens, however, that he is constantly running into such things, and is being constantly called upon to solve problems connected with them. This is particularly true in fringe areas.

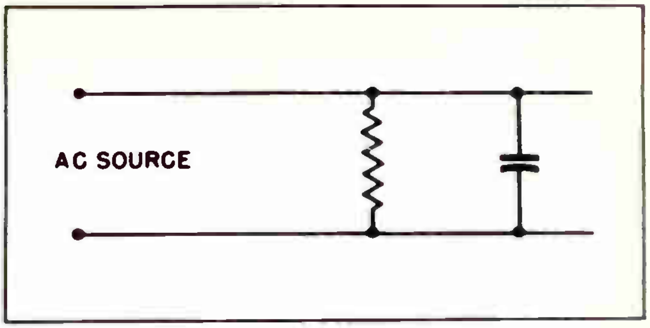


Fig. 5. Capacitor in parallel with resistor.

To get back to a comparison of circuits containing only resistance and those which also contain capacitance and inductance, let us look again at the diagram in Fig. 4. There we see three resistors connected across an A-C circuit in parallel with each other. When a voltage is impressed across the three resistors current flows through all of them.

An important thing to note is that current will flow through all the resistors at the same time. By this we mean that current will start to flow through each of them at exactly the same time it starts to flow through the others. It will reach the maximum amount of flow at the same time in one that it does in all the others. Furthermore, it ceases to flow in all of them at the same time.

However, suppose we have a resistor in parallel with a capacitor as in Fig. 5. Current flows through the resistor in the same manner, and at the same times, as in the resistors of Fig. 4. But what about the current through the capacitor?

Well, the situation with respect to the capacitor is somewhat different. We already know that when a voltage is applied to a capacitor the current first rushes in at a maximum rate, then rapidly slows down. The action is such that when alternating current is applied to a capacitor, the current through the capacitor actually leads the voltage.

Therefore, when an alternating current is applied to a circuit similar to that in Fig. 5, we find at each alternation the current rushes into and out of the capacitor long before the voltage has reached its maximum value. On the other hand, the current through the resistor depends upon the instantaneous voltage of the A-C wave. By this we mean that the current slowly begins flowing as the voltage changes, then builds up to the maximum value as the voltage approaches the maximum peak of the A-C wave.

The result of this action is that current flows through the capacitor at its maximum rate at the instant the voltage changes, but at the same instant there is very little or no current through the resistor.

This action is shown in Fig. 6 where the voltage is shown at its minimum value—just changing—with the current through the resistor at zero, but the current through the capacitor at its maximum amount of flow.

On the other hand, when the A-C voltage reaches its peak in either direction the current will reach its maximum value through the resistor, but will decrease to zero through the capacitor. This is indicated in Fig. 7.

This action of the various components in an A-C circuit is not new to you. We are repeating them here to refresh your memory, and to point out what happens when these two components are included in the same circuit—when they are in parallel with each other across the same AC voltage.

The important thing to note is that each of the two components in the circuit, the capacitor and the resistor, still pass the same amount of current as either of them would if in the circuit by itself.

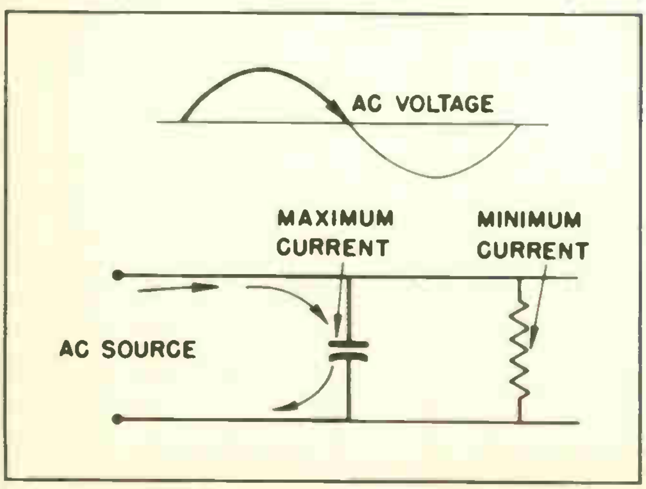


Fig. 6. A-C voltage condition for maximum current through capacitor.

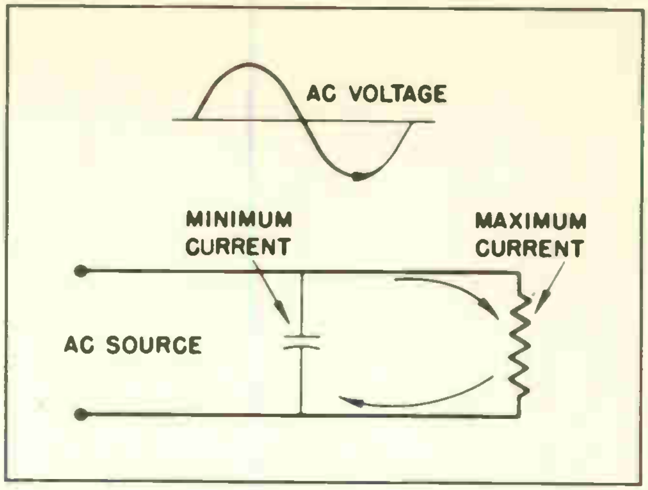


Fig. 7. Voltage condition which forces maximum current through resistor.

But—they do not pass current at the same *time*. In other words, the currents are *out of phase* with each other.

Section 7. HOW CAPACITY IN AN A-C CIRCUIT AFFECTS ITS ACTION

What difference does it make whether the two components pass current at different times—each of them still passes current?

Both pass the same amount of current as though it was in the circuit by itself. Why should it make any difference to the external circuit—the source, for example—whether current passes through them both at the same time or at different times?

To answer this question, let's take a look at Figs. 8, 9 and 10. In Fig. 8 we find the A-C voltage wave just completing the positive half-cycle and starting to go negative. At this instant there is no current through the resistor. This is the same condition we examined in Fig. 6.

But at that instant there is a maximum inrush of current into the capacitor.

The capacitor will continue to accept electrons—and pass current—until the A-C voltage wave reaches its maximum peak in the negative direction as shown in Fig. 9. As the A-C voltage continues to rise, more and more current passes through the resistor, but less and less passes through the capacitor.

By the time the A-C voltage reaches its max-

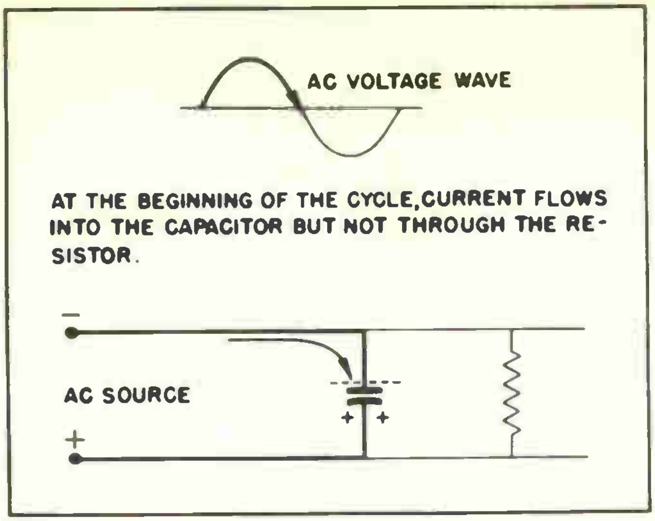


Fig. 8. Current conditions in parallel circuit at beginning of voltage cycle.

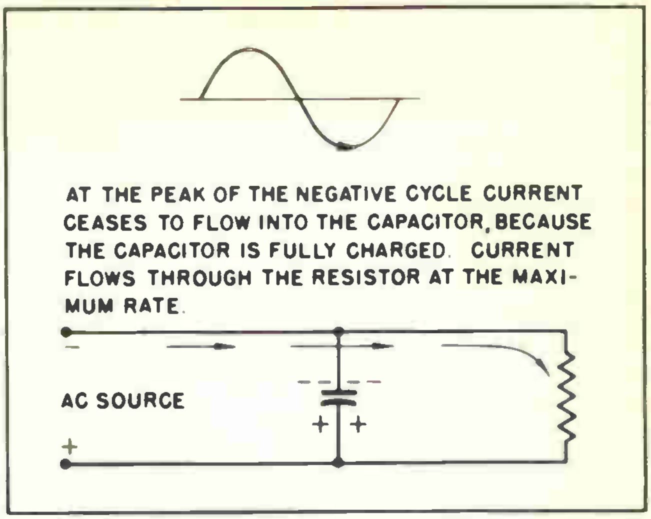


Fig. 9. No current flows in capacitor circuit when source voltage is maximum.

imum peak, as shown in Fig. 9, the current will have ceased to flow through the capacitor but will be flowing through the resistor at its maximum rate.

Now let's see what happens when the A-C voltage begins to decline from its peak value as shown in Fig. 10.

We find the capacitor has been charged to a voltage equal to the peak voltage of the A-C wave. But the source voltage is now less than peak—and *less than that of the charged capacitor.*

The capacitor begins to discharge. Since the upper side is highly negative with respect to the bottom, and there is a path between them provided by the resistor, the natural result, then, is for the capacitor to discharge through the resistor. And, that is what happens.

To review what has happened note this: the A-C source has furnished a certain amount of current to flow through the resistor, and a certain amount to flow through the capacitor. But, a part of the current that flowed into the capacitor, later flowed through the resistor.

It can be seen from this that we cannot add the total amount of current through the resistor to the total amount of current through the capacitor and thus find the total amount of current from the source. The reason is that we would be measuring part of the current twice — when it was in the capacitor circuit and again when it was in the resistor circuit.

If we had current measuring meters in the capacitor circuit, the resistor circuit and the source circuit, as shown in Fig. 11, we would find that we had considerably more total current through the meters in the capacitor circuit and the resistor circuit than in the source circuit. To make this clear: The *sum* of the current through the capacitor meter and that through the resistor meter would be greater than the current through the source meter.

Section 8. CURRENT ACTION IN PARALLEL CIRCUITS

From the foregoing section it becomes evident that determining the impedance through a paral-

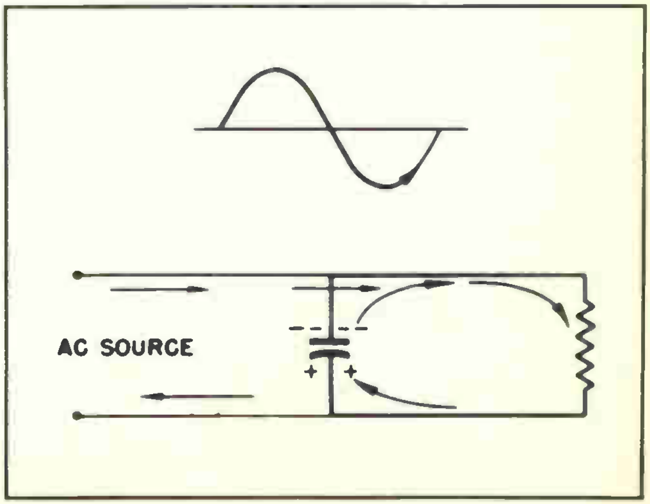


Fig. 10. Under this voltage condition voltage across capacitor is greater than line voltage. Capacitor begins disharging through resistor.

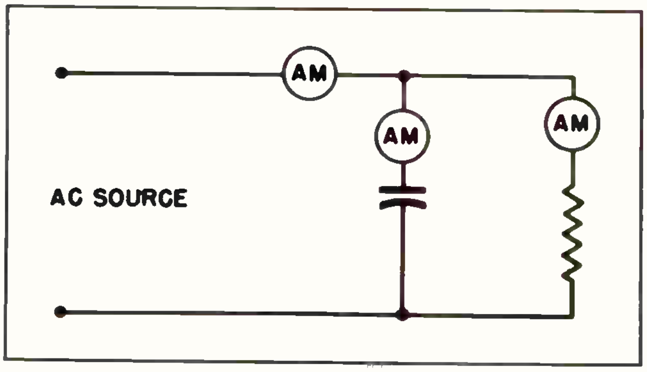


Fig. 11. Meters show current from source is not equal to sum of that through individual circuits.

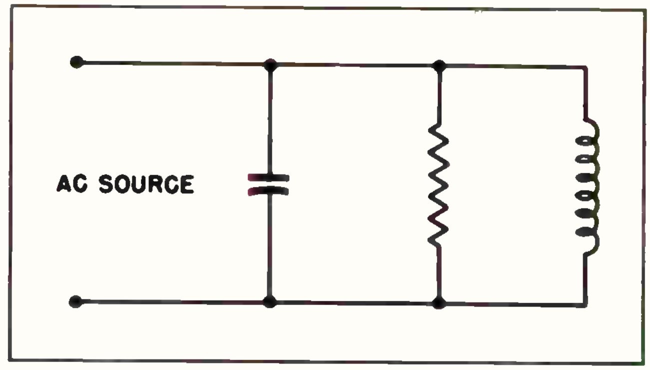


Fig. 12. Parallel circuit to which inductance has been added.

lel circuit containing capacitance and resistance is a bit more complicated than when only resistance is involved.

When only resistance is involved we can add the current through each branch of the parallel circuits, then divide the total current into the source voltage and thus find the total impedance of the circuit. Since the sum of the current through the individual branches, as shown in Fig. 11, is not the same as the current supplied by the source, we can easily understand that such procedure would give us the wrong value for the *total effective impedance.*

You might ask: Why not find the total amount of the current furnished by the source and then divide that into the source voltage? Wouldn't that give the total effective impedance?

Yes, of course.

Unfortunately, it is often difficult to measure the current from the source. Frequently the impedance of the circuit must be determined before the circuit is actually built. Often the presence of the meter would upset the circuit so badly the measurements would not be accurate. Very frequently the currents in the circuit are so small the measurements would not be accurate. Under these conditions we must do indirectly, by calculations, those things which we cannot do directly.

What we must do, then, is determine the value of the currents which *should* flow through the individual circuits under certain conditions, then combine those currents according to the rules we are about to discuss.

So far we have been discussing the combination of capacity in one circuit with resistance in a parallel one. There is still another element we must often consider, that of inductance. Such a circuit could be similar to that in Fig. 12.

In Fig. 12 we see three different circuit elements in parallel with each other: a capacitor, a resistor and an inductance. Each of these circuit elements affects the flow of alternating current in a different manner.

In previous studies we have learned that current through a resistor will rise and fall in phase with the value of the impressed voltage. When the voltage is at a low point on the A-C cycle, the current through the resistor will be low; when the voltage rises the current will rise, and when the voltage reaches its maximum value, the current will reach its maximum value.

We have also learned, and have reviewed in our previous studies, that the current through a capacitor located in an A-C circuit will tend to *lead* the voltage. By this we mean that the current through the capacitor will be greatest just as the voltage is changing but will be flowing at a minimum rate when the voltage reaches its maximum value.

Now, in the case of the inductance we have a condition which is almost opposite that which is present when we use the capacitor. The current through the inductance has a tendency to *lag* behind the impressed voltage from the A-C source.

We see how these things act in an actual circuit in Fig. 13. There we see the A-C voltage entering the negative half-cycle. The current starts to flow to the right along the upper wire of the circuit in that diagram.

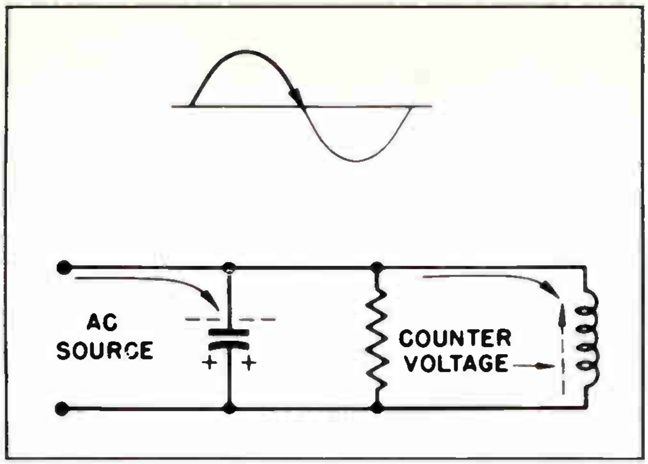


Fig. 13. Under this voltage condition current is at maximum through capacitor, but none flows in the other two sections.

The capacitor readily accepts the current, and the current in that section of the circuit is at the maximum rate at that instant. Little or no current flows through the resistor because the voltage is so low as to be unable to force any great amount of current through that section of the circuit. In the third leg of the circuit we find the inductance. There may or may not be some resistance in this leg of the circuit but, regardless of that, the inductance will immediately set up a counter voltage which tends to oppose the inrush of the current.

So, we find that at this instant heavy current flows in the first leg of the circuit, but no appreciable current flows through the other two legs.

As the A-C voltage wave continues to the point shown in Fig. 14, that is at the maximum point in the negative half-cycle, we find current has ceased to flow through the capacitor leg of the circuit. The voltage within the capacitor at this instant equals the impressed voltage, and the result is that no current can flow. But, there is a maximum flow of current through the resistive branch. These conditions are not much different from those we discussed a little earlier in this lesson.

Note that the full voltage is now impressed across the coil of the inductance. The impressed voltage is just about to overcome the counter voltage of the inductance so a current can flow through that branch of the circuit. However, no appreciable current is *yet* flowing in that branch.

In Fig. 15 we see the voltage decreasing from its negative peak. There is still some current flowing through the resistive branch of the circuit, but the current is somewhat less than it was at the voltage peak. The voltage within the capacitor is greater than the externally impressed voltage. The result is that the capacitor is now discharging. Some of the current from the discharging capacitor flows through the resistor.

However, another action is worthy of note.

The impressed voltage has now practically

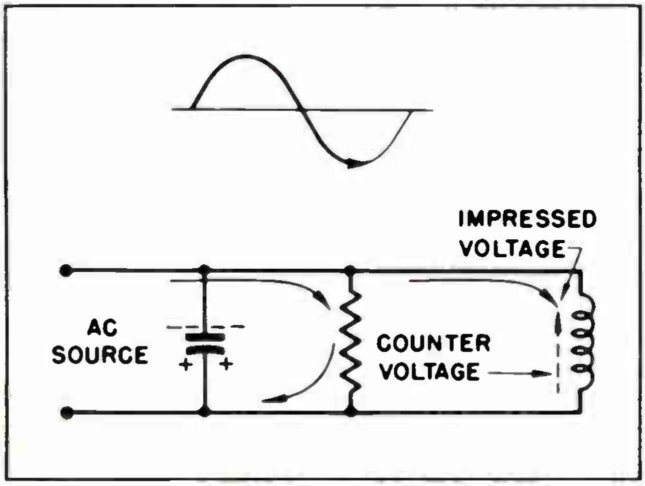


Fig. 14. Capacitor fully charged under these voltage conditions, preventing current in that circuit. Maximum current flows through resistor. Counter voltage in inductor prevents current through that circuit.

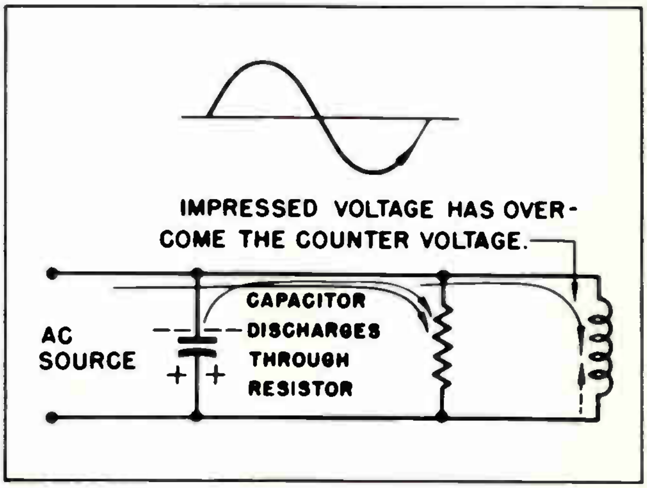


Fig. 15. Under these voltage conditions capacitor is discharging. Current from capacitor divides between resistor and inductor. Current flows through inductor because counter voltage has been overcome.

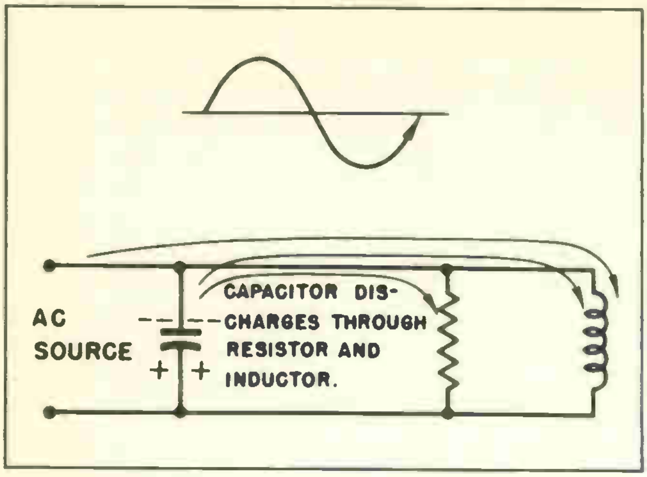


Fig. 16. Capacitor is discharging through resistor and inductor. Inductor counter voltage has been overcome; current flows freely. Very little current from source.

overcome the counter voltage of the inductance and current is beginning to flow in that branch of the circuit. There is some current flowing through that branch directly from the external source. Some of the current from the discharging capacitor is also beginning to flow through the inductance.

In Fig. 16 the external voltage of the source has dropped practically to zero. The external voltage is now causing very little current to flow within any part of the circuit; but the capacitor is still discharging. In fact the flow from the capacitor is just approaching its maximum in that direction. Current from the discharging capacitor is dividing, part of it flowing through the resistor and part through the inductor.

Now let us look at Fig. 17 for a moment. Polarity of the voltage at the source has just changed from the negative to the positive. It now causes current to flow into the capacitor in the direction shown by the arrow. And, note something else. The collapsing magnetic lines of force around the inductance coil is inducing a voltage in that coil which is keeping the current flowing through it in the same direction as it was a moment before.

The voltage induced in the coil by the collapsing lines of force causes current to move from the coil in the direction shown by the arrows, part of it going to the capacitor and part of it through the resistor. Note also that the current is still flowing out the upper side of the capacitor and that much of this current is flowing into the upper side of the inductance coil to replace that forced out the bottom of the coil.

As the A-C voltage source continues to go through one cycle after another this action continues over and over.

You might ask how much current, or electrical energy, is stored in the capacitor? How much current flows through the inductance? Also, how much flows through the resistor? You might ask if the sum of all the currents flowing in each of the several branches of the parallel circuit adds up to the total amount of current flowing from the source.

The answers to these questions depend upon many things. They depend upon the frequency of the applied voltage, the size of the capacitor, the amount of the inductance, the value of the resistor, the resistance of the connecting wires, and other things.

But one thing stands out clearly from these diagrams, that is, the *total current* flowing in the various branches of the circuit should *always exceed* the current supplied by the external source. For example, if we were able to insert current measuring meters into all the circuits as shown in Fig. 18, the total current through the main meter, AM total, would never be so much as the sum of all the currents through the other meters.

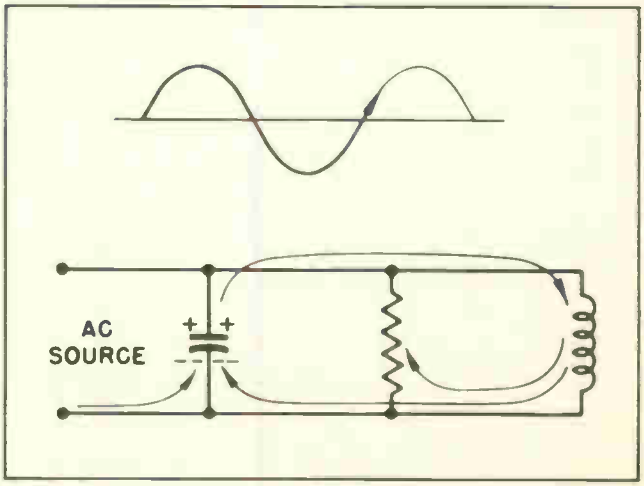


Fig. 17. Inductor's collapsing magnetic field keeps current moving in same direction despite reversal of voltage at source. Part of current from coil is forced through resistor, and part helps recharge capacitor.

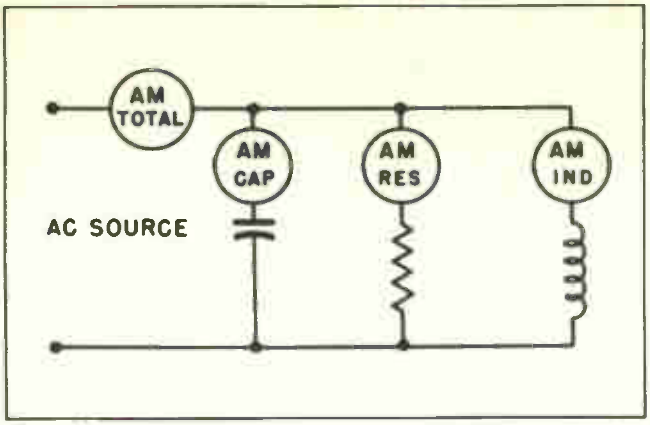


Fig. 18. Current through AM TOTAL meter is always less than the sum of that through other meters.

The reason for this is that the voltages across the various elements in the circuit are not in phase with each other, and the currents are greatly *out of phase* with each other.

When the capacitor has current flowing in one direction, the inductance has current flowing in the opposite. Thus, much of the current through the capacitor is supplied by the inductance without drawing from the external source. Then, a moment later, the current through the inductance is supplied by the capacitor without having to draw so much from the external source.

It is rather obvious that under these conditions there will be more current flowing in the individual legs of the circuit than is being supplied by the external source. In fact, what is happening is that the same electrons are being passed back and forth between the capacitor and the inductance, thus drawing less current from the source.

Since this condition is so different from what we found when two or more resistors were in parallel with each other, it becomes rather clear that we cannot use the same rules for determining impedance we used earlier. Since we cannot use the same rules, it becomes necessary to explain the rules — or physical laws — which govern the flow of electrical current under these new conditions.

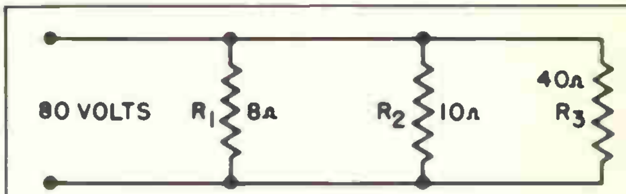
In the event you think this is quite interesting, but that it does not affect you in any way, it is only fair to mention that the conditions we have described exist in nearly every A-C circuit. It is all very well to use the rules of ordinary direct current, such as we obtain from batteries, to teach elementary rules of electrical current flow. The truth is that for every circuit in which we find direct current flowing there are twenty other circuits where we find alternating current. An employer will expect you to know how to deal with A-C problems.

Further than this, nearly every circuit we meet in practical electrical and radio work, as well as television, will be parallel circuits rather than the more simple series circuits. In other words, by far the greater number of circuits you will find in your everyday work will be just such circuits as we are discussing here. It will be well worth your time to study this lesson, and learn it well. Once you have mastered it you will know the principal actions of practical electrical circuits.

Section 9. CURRENT THROUGH RESISTANCE IN PARALLEL

In Fig. 4 we found three resistances in parallel. In that illustration we show the method for finding the effective resistance by use of the reciprocal method. You know, from your earlier studies, that you can also determine the effective resistance by using the current method and Ohm's Law.

In Fig. 19 we show how the total effective resistance of the current in Fig. 4 can be found by



CURRENT THROUGH $R_1 = \frac{80V}{8\Omega} = 10$ AMPS

CURRENT THROUGH $R = \frac{80V}{10\Omega} = 8$ AMPS

CURRENT THROUGH $R = \frac{80V}{40\Omega} = 2$ AMPS

TOTAL CURRENT FROM SOURCE = 20

TO FIND THE TOTAL EFFECTIVE RESISTANCE, DIVIDE THE SOURCE VOLTAGE BY THE SOURCE CURRENT, THUS;

$$\frac{80V}{20A} = 4\Omega$$

Fig. 19. Ohm's Law can be used to find total effective resistance of resistors in parallel.

the current method and using Ohm's Law. We first find the amount of current flowing through each branch of the circuit. To do that it is necessary to impress a voltage across the circuit.

We could take the actual voltage impressed there if it is known. But if the voltage is not known we can assume a voltage. It makes no difference what voltage we assume, the results will always be the same, so long as the same voltage is impressed across all branches of the circuit. We will show you in a moment why this is so.

For convenience we have chosen to impress a voltage of 80 volts across the circuit originally shown in Fig. 4, and which has been redrawn in Fig. 19. The 80 volts causes 10 amperes of current to flow in the first leg, 8 amperes to flow in the second leg and 2 amperes to flow in the third leg. Adding these currents we find a total of 20 amperes of current flowing in the circuit. All this current is flowing from the source.

If there are 20 amperes of current flowing in a circuit under the influence of 80 volts of pressure, it is evident, from Ohm's Law, that the effective resistance "seen" by that voltage must amount to the voltage divided by the current. This is 80 divided by 20.

Simple arithmetic tells us this amounts to 4 ohms of resistance. This is the same effective resistance we obtained by the reciprocal method in Fig. 4.

You may say that this is all well and good, but just where did we obtain the value of 80 volts? We did not have that value of voltage given to us.

As we have mentioned before, it makes no difference what voltage is impressed across the circuit; the different voltages are not going to change the resistances. The resistances stay the same regardless of what voltage is placed across them. The only difference will be that a different amount of current will flow.

CURRENT THROUGH R_1 WITH 120 VOLTS = 15 AMPS
CURRENT THROUGH R_2 WITH 120 VOLTS = 12 AMPS
CURRENT THROUGH R_3 WITH 120 VOLTS = 3 AMPS

TOTAL CURRENT FROM SOURCE = 30 AMPS

$$\text{EFFECTIVE RESISTANCE} = \frac{120 \text{ VOLTS}}{30 \text{ AMPS}} = 4 \text{ OHMS}$$

Fig. 20. Total effective resistance is independent of the applied voltage.

Which means that we can select such value of voltage as is most convenient.

Usually we try to choose a value of voltage that will make our calculations easy. Suppose that instead of choosing 80 volts across the circuit in Fig. 19 we had chosen 120 volts, a common power line value. Actually the results would have been similar, as we will show you.

In Fig. 20 we show 120 volts across the circuit.

Placing 120 volts across the 8 ohms in the first leg of the circuit would allow 15 amperes of current, 120 volts across 10 ohms would allow 12 amperes to flow, and 120 volts across 40 ohms would allow 3 amperes. Adding these together, as in Fig. 20, gives us a total of 30 amperes.

Dividing the 30 amperes into the 120 volts gives us 4 ohms of effective resistance, the same obtained by the other two methods. If you are still a little doubtful you can try using any value of impressed voltage you care to use, great or small.

It will always be to your advantage to use an assumed voltage with which it is easy to work, and thus avoid the use of fractions. However, this precaution is merely one of convenience, not of necessity. The fact is that your final calculated results will be always the same, regardless of the voltage you select.

Section 10. MATHEMATICAL METHODS FOR CALCULATING IMPEDANCE

There are several ways an electrical man can go about the problem of calculating impedance in a parallel A-C circuit. The impedance in such a circuit determines the total opposition of the combined circuit to the flow of alternating current. It takes into consideration such things as the capacitive and inductive reactances in the various branches of the circuit, as well as the resistances which are present.

Unfortunately, most mathematical approaches to the solution of such problems require that you have a better knowledge of mathematics than we can assume you have.

In all parts of this course we have carefully avoided any discussion which would involve use of algebra or trigonometry, or any other branch of mathematics other than ordinary, grade school arithmetic. We assume you can add and subtract and multiply and divide, but we do not expect you to have any knowledge of the higher branches of mathematics.

All of which means that if you remember the simple rules of ordinary grade school arithmetic you should have no trouble completing this course. No algebra and only one application of trigonometry is used anywhere in it.

In keeping with that policy, we show in this lesson how to solve electrical problems which involve impedance in parallel A-C circuits; but we show how they can be solved by using simple grade school arithmetic. The methods we show here are not widely used in the radio and television industry, but they are accurate methods, and are technically sound.

Principal objection to them is that they involve somewhat longer calculations than other methods in more common use.

Probably the most widely used method for solving electrical problems involving voltages and currents and impedances in parallel A-C circuits is a procedure familiarly known as "Operator-J."

Operator-J is merely a branch of algebra, and is usually known to most students who have graduated from high school, although some books on algebra refer to the subject under another name. It is often referred to as "complex notations," although there is really nothing especially complex about them.

One of the principal advantages of using Operator-J is that it is fast, and permits the use of certain trigonometric equations which are widely used in electrical work.

Because we cannot assume you know anything about either algebra or trigonometry, and because we have no intention of trying to teach a course in mathematics, we avoid the use of these more common, but more complicated, methods of solving electrical problems.

Yet many of you constantly seek our advice as to how they can best learn something about Operator-J, and the more complex methods for solving electrical circuit problems.

The reason so many want to learn something about these methods for solving electrical problems is that they are used so often in radio and TV magazines, and other technical publications. Some seem convinced a knowledge of these subjects would improve their ability to understand the technical articles they read.

It is always difficult to recommend any specific book, or course of study, in connection with these branches of mathematics. What may be suitable for one person is often not fitted for another. A book one person finds easy may prove quite difficult for another.

In general, we believe a radio and television technician is better served if he restricts his studies to a mathematical text prepared specifically for radio and electrical workers. Such books eliminate much of the unnecessary mathematical rules and material, and includes only that which applies directly to electrical work. There are a number of such mathematical texts available to radio and television technicians. Among the publishers who print such texts are Prentice-Hall Book Company, Van Nostrand Book Company, John Wiley & Company, and McGraw-Hill Book Company.

We hesitate very much to recommend any one of these books over another, yet the undeniable fact remains that one of them is more widely used than all the others put together. That is the one published by McGraw-Hill. It is entitled MATHEMATICS FOR ELECTRICIANS AND RADIOMEN, and written by Nelson M. Cooke. It is a standard text throughout the armed forces technical schools, and is widely used by technicians in all branches of radio, electronics and electricity. Almost every radio and television supply house in the country carries it in stock. It can be also obtained direct from the publisher. This book explains the algebraic operations which are regularly used in electrical and electronic work, yet leaves out other branches of algebra which are not so used. It also explains in simple language how to use certain parts of trigonometry in electrical work without bringing in all the rules and formulas most people find so hard to learn.

Before leaving this subject we want to make it very clear that you do not need to know any mathematics beyond simple grade school arithmetic to complete this course. At the same time we feel it is only fair to mention there are other mathematical methods through which parallel electrical circuit problems can be solved. The decision is entirely up to you if you want additional studies in electrical mathematics.

Section 11. CURRENT IN PARALLEL CIRCUITS HAVING CAPACITANCE OR INDUCTANCE

Let's get back to our study of parallel A-C circuits, and the determination of *impedance* such circuits offer to the flow of alternating current.

When solving problems dealing with such circuits there are two things which are usually of importance. One is the total amount of current which is able to flow from the source through the entire circuit and back to the source. The other is the *phase angle* of the current.

The phase angle refers to the displacement of the current with respect to the voltage.

You already know that when alternating current flows through a resistor the current will be *exactly in phase* with the voltage. By this we mean that as the voltage rises the current will rise, as the voltage reaches its peak value the current will likewise reach its peak value, and as the voltage declines from its maximum the current will also decline. Further than this, when the voltage reverses itself, the current will likewise reverse itself at the same time.

The same thing is *not* true with respect to current through capacitances or through inductances. In these latter two cases the current tends either to lead the voltage or to lag behind it.

When there is inductance or capacitance, or both, in a parallel circuit the current tends to lead or lag the voltage depending upon the values of the inductance or capacitance, and upon the frequency. The amount by which the current is displaced from the voltage is referred to as the *phase angle* of lead or lag. Since determination of the exact phase angle depends upon an ability to use trigonometry we will pass that by for the moment.

The other thing that is of importance to us, and this is really important, is the total opposition, or *impedance*, offered by the circuit to the flow of alternating current.

It is frequently necessary to know the total impedance. The total impedance is important even though we may not know the phase angle by which the current is displaced from the voltage.

One of the most simple methods for determining the total impedance in a parallel A-C circuit is to determine the total current flowing in each branch of the circuit, then add the currents *vectorially*, or *algebraically*.

Note the method by which these currents must be added. We explained earlier in this lesson why the currents through the several legs of the circuit could not be added together as we do the currents through resistive branches. But they can be added vectorially, or added algebraically, which is actually the same thing. Despite the fact we say they are added *algebraically*, it is not necessary to have a knowledge of algebra in order to do the figuring.

Fig. 17 shows how the current through one branch of the circuit might be flowing in one direction while the current through another branch would be flowing in the other. That illustration was used to explain why it was not possible to simply add the currents together to learn the total current.

In Fig. 21 we have redrawn a circuit similar to those we have shown in earlier illustrations in this lesson. Here we have a capacitor, a resistor and an inductance. We have not given the values in farads or henries for the capacitor or inductance. We are just going to assume that at some frequency the reactance of the capacitor is 10 ohms and the reactance of the inductance is 20 ohms. The resistance of the resistor will be the same regardless of the frequency.

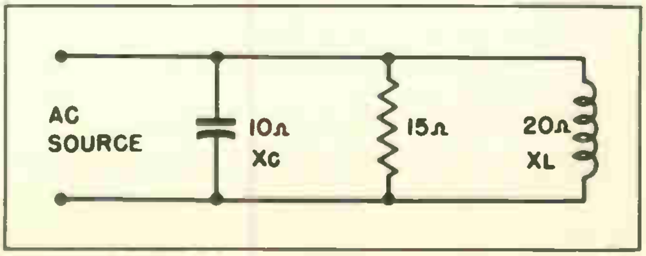


Fig. 21. Ohmic opposition in three branches of parallel circuit.

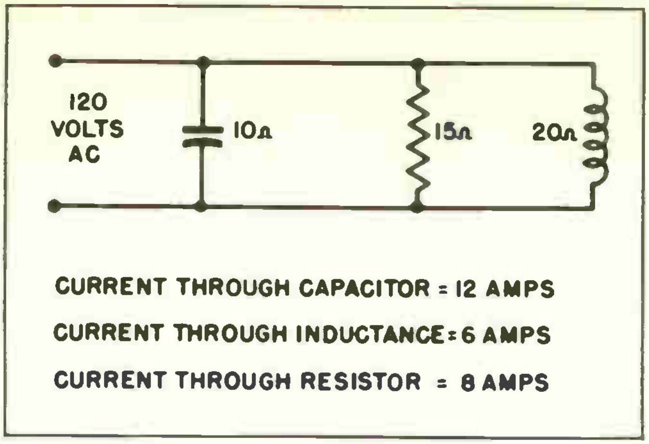


Fig. 22. How voltage forces current through each branch of parallel circuit.

If an A-C voltage is impressed across the circuit which has a frequency such that the reactances will be as we have shown, it is easy to understand that current will flow through each branch of the circuit. The exact amount of current through each branch, or leg, will depend upon the magnitude of the impressed voltage and the resistance or reactance of each individual branch.

In Fig. 22 we have redrawn the circuit and have impressed 120 volts of A-C across the circuit from the source. We see that 120 volts across the 10 ohms of reactance in the capacitor branch causes 12 amperes of current to flow in that branch. 120 volts across the 15 ohms of resistance causes 8 amperes to flow in that branch of the circuit, while the 120 volts causes 6 amperes to flow through the 20 ohms of reactance in the inductance branch of the circuit.

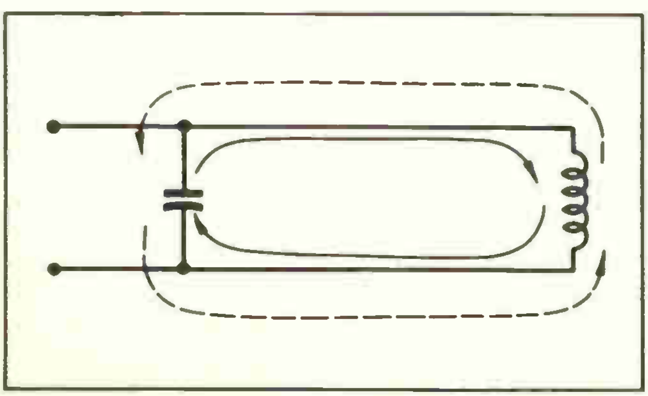


Fig. 23. During one half-cycle current flows as shown by solid arrows inside diagram. During next half-cycle it flows as indicated by broken arrows. Current between inductor and capacitor does not flow to or from the source.

Now if these currents could all be added together, as in resistive circuits, we would have a total of 26 amperes of current flowing from the source. But in this case that would be wrong—*very wrong.*

And by the same token *if* 26 amperes of current were flowing from the source it would mean the total effective impedance of the circuit would amount to 120 volts divided by 26 amperes, or approximately 4¾ ohms. Since the 26 amperes is incorrect, of course, the 4¾ ohms would be wrong also.

When calculating the impedance of a circuit of this kind the first step is to *subtract* the current flowing in one of the reactive branches from the current flowing in the other reactive branch. The custom is to subtract the smaller current from the larger. The reason is that the two currents are exactly 180° out of phase with each other. Every bit of the smaller current which flows through one branch will also flow in the other branch, and not through the external circuit.

CURRENT THROUGH CAPACITOR = 12 AMPS
CURRENT THROUGH INDUCTOR = 6 AMPS
CURRENT THROUGH C WHICH DOES NOT FLOW THROUGH L = 6 AMPS

Fig. 24. Calculating how much more current flows in one branch than the other.

In the case of the circuit shown in Fig. 22, all the current which flows in the inductive circuit also flows through the capacitive circuit. Since this is true, we can subtract the 6 amperes which flows through the inductive circuit from the current which flows through the capacitive circuit. This shows how much additional current flows through the capacitive circuit which does *not* flow in the inductive circuit.

Fig. 23 shows how this current flows back and forth between the capacitor and the reactor, or inductor. All the current in and out the inductive branch flows in this manner. But there is some current through the capacitor which does not flow through the inductor. Fig. 24 shows how there are 6 amperes more through the capacitor than through the inductor.

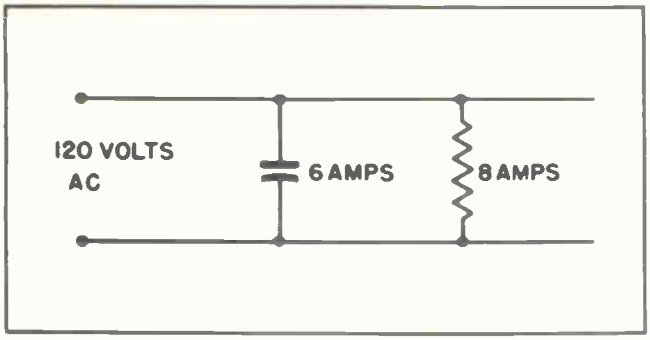


Fig. 25. Since inductor draws no current from source it can be eliminated from our calculations.

So far as the source is concerned, then, we could redraw our diagram as in Fig. 25.

There we show the currents through the capacitor branch and the resistor branch, but have omitted the inductive branch. The reason for omitting the inductive branch is that for all practical purposes it does not draw any current from the source, it draws only from the capacitor circuit. And since the capacitor branch draws only 6 amperes which could conceivably be drawn from the source, that is all we have shown on the diagram.

But this is still not all. The currents through the capacitor and through the resistor are still 90° out of phase with each other. These two currents do not completely cancel out one branch as in the case of the inductive and capacitive circuits. But neither do they add up arithmetically as would be the case of currents through two resistors—or through two capacitors.

They must be added according to the rules of Pythagoras' Theorem. Fig. 26 shows how that is done. The resistive current is always placed on the base of the triangle. In this case the resistive current amounts to 8 amperes. It is placed as shown. The reactive current is the difference between the capacitive branch and that of the inductive branch. In this case it is 6 amperes.

Since the reactive current in this case is a leading current, due to the fact there is more current through the capacitor than through the inductor, the reactive current is shown on a plane extending upwards at the right angles from the base of the tri-angle. Had the inductive current been predominant, the triangle would have been turned upside down with the reactive current being measured in a downward direction. We will discuss this condition in more detail a little later.

Now we come to the problem of finding just how much current is flowing from the source to the parallel circuit. All that is necessary now is to work it out by the rules we have previously given you for using Pythagoras' Theory. In this case, the total current would be 10 amperes as shown in Fig. 27.

This means that the total current flowing from the source in Fig. 22 amounts to 10 amperes instead of the 26 amperes we would have had if we had merely added the currents through the several branches according to the rules of arithmetic.

Now that we know the total current from the source, just what do we actually know? Well, for one thing we know how much current the source would be called upon to supply to the circuit. But

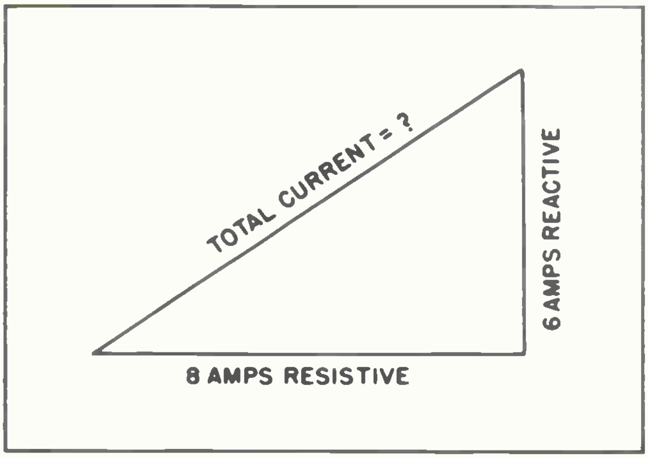


Fig. 26. Currents are added vectorially according to Pythagoras' Theorem.

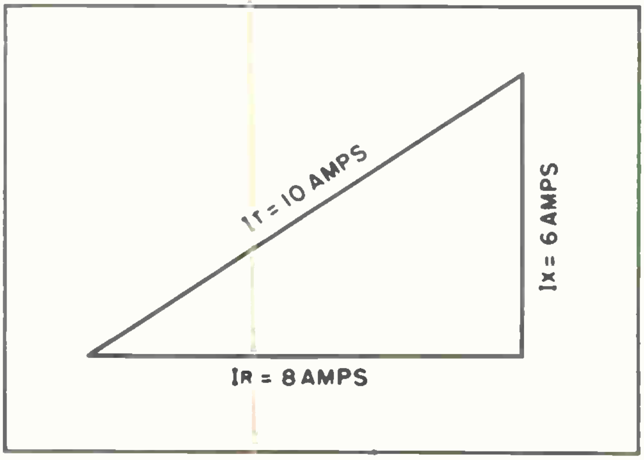


Fig. 27. Solving for total current drawn from source.

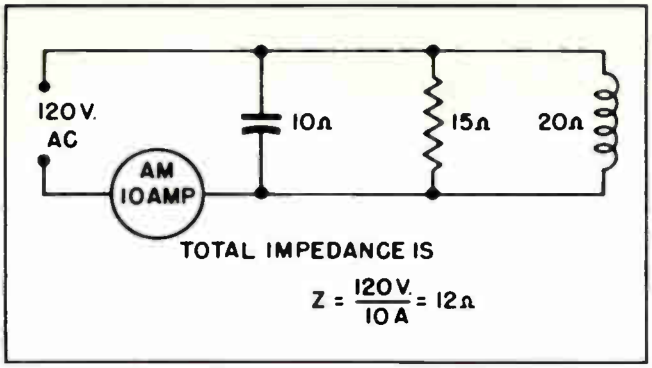


Fig. 28. How to find impedance when the other facts are known.

most important of all, we are now in position to determine the total *effective impedance* of the circuit.

And once we know the total effective impedance, we know how much current would flow under any condition of voltage. This is what we started out to learn.

Fig. 28 shows how to work out the final step in determining the total effective impedance of the circuit. The total effective impedance of the entire circuit amounts to the impressed voltage divided by the actual current which is supplied to the circuit by the source. In this case it amounts to 120 volts divided by 10 amperes, and this gives us an impedance of 12 ohms.

There are several points of importance worthy of notice in connection with this circuit. When working with resistive circuits we learned that the total effective resistance is always less than that of the lowest resistance. This does not necessarily hold true when capacitances and inductances are also included in the circuit.

Here we find the reactance of the capacitor alone amounts to 10 ohms, but when an inductor and a resistor are placed in parallel with it the total effective impedance is actually larger than that of the capacitor alone. In other words, if the capacitor were across the line by itself it would draw more current from the source than is drawn when the inductor is placed in parallel with it.

When first introduced to this situation it seems strange, but after you have worked with inductances and capacitances a while it all seems perfectly natural. Even so, it is not entirely new to you. This situation was discussed in the lesson on Resonance.

We have found now that the total effective impedance of the circuit in Fig. 22 is 12 ohms. This is the same impedance that would be presented to any impressed voltage. If a higher voltage is impressed across the circuit, more current would flow in all parts of the circuit, but it would be in direct proportion to the voltage and to the 12 ohms impedance.

It should be emphasized, however, that this particular impedance is true for only one frequency. Any change in frequency would also change the reactances of both the capacitor and the inductor.

One thing we have not yet determined is the phase angle of the total current with respect to the impressed voltage. One thing we can determine by casual observance is that the current would tend to lead the voltage, but just at this time we are not prepared to calculate the *exact* angle of lead in degrees.

Section 12. SIMPLIFIED IMPEDANCE CALCULATIONS

Our discussion in the preceding sections was for the purpose of showing you in detail exactly what goes on in a parallel circuit containing capacity and inductance. Actually, of course, it is not necessary to go through all those steps in working out an ordinary problem in trying to find the impedance of a parallel circuit.

Probably the easiest method is to merely follow these steps:

Step 1. Find the reactance of the capacitor.
Step 2. Find the reactance of the inductor.
Step 3. Assume some convenient voltage across the circuit.
Step 4. Find the current through the capacitive branch.
Step 5. Find the current through the inductive branch.
Step 6. Subtract the capacitive current from the inductive current, or the inductive current from the capacitive current. (Subtract the smaller from the larger).
Step 7. Determine the current through the resistive branch.
Step 8. Find the total current through the reactive branch and the resistive branch ac-

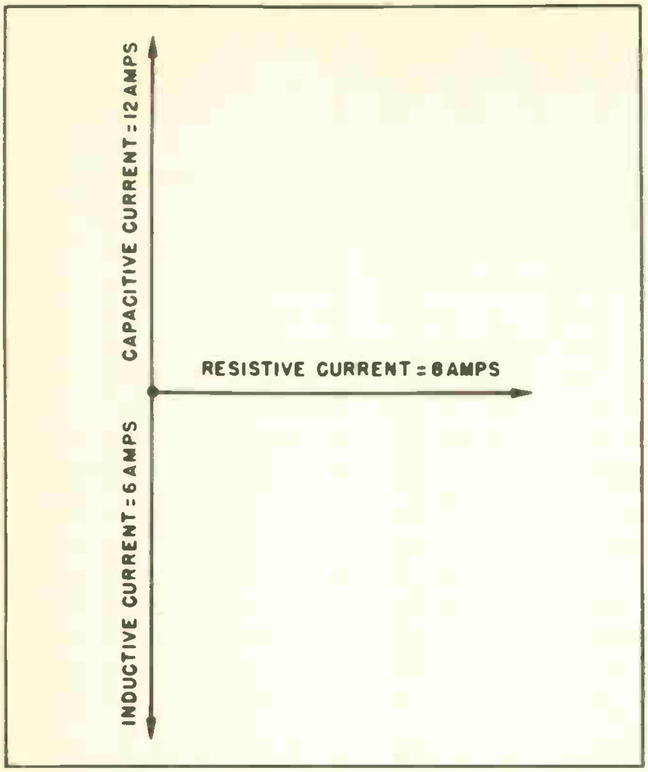


Fig. 29. A current vector.

cording to Pythagoras' Theorem.

Step 9. Now to find the total impedance—divide the impressed voltage by the total current. This gives you the impedance.

Remember, all this gives you the total impedance for any one definite frequency. You will have to determine the impedance all over again for any other frequency. The main point is that by using this method you will be able to calculate the total impedance for parallel A-C circuits.

In your actual work you will be constantly faced with the problem of calculating impedance. This is not the quickest way of finding impedance but it is a method that is easy to learn, and does not require the knowledge of any mathematics other than grade school arithmetic.

In working out a problem such as this, it is often convenient to set up a system of vectors to represent your various currents. Fig. 29 shows how this would be done for the circuit shown in Fig. 22, and in which we have just found the total impedance.

The capacitive current is shown above the center of the diagram, so it is leading the resistive current. The resistive current is shown on the main axis line and to the right of the intersection of the vector lines.

The inductive current is shown at right angles to the resistive current, just as is the capacitive current, but since the inductive current lags the resistive current its vector goes downward from the junction of the various current vectors. This puts the inductive current at right angles with the resistive current, and 180° out of phase with the capacitive current.

Then the smaller reactive current is subtracted from the larger reactive current. Since in this case the inductive current is smaller than the capacitive current, the inductive current is subtracted from the capacitive current. This is shown in Fig. 30.

Finally a line is drawn along the hypotenuse from the extreme end of the reactive current (in this case, 6 amperes of current in the leading direction) to the end of the resistive current. This is shown in Fig. 31.

The full usefulness of vectors becomes more evident as the number of branches in the parallel circuit increases. Suppose we take the circuit such as that shown in Fig. 32. There we see two capacitive branches, three inductive branches and three resistive branches.

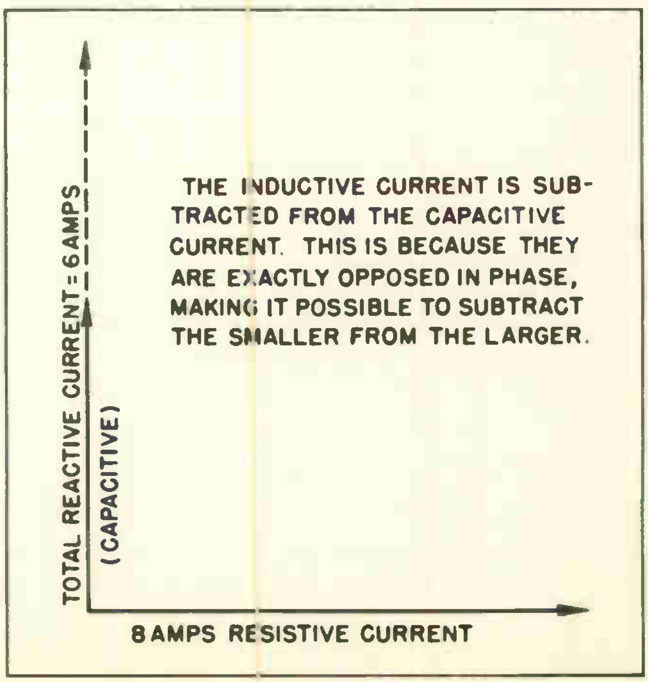


Fig. 30. Inductive current is subtracted from capacitive current to find total reactive current.

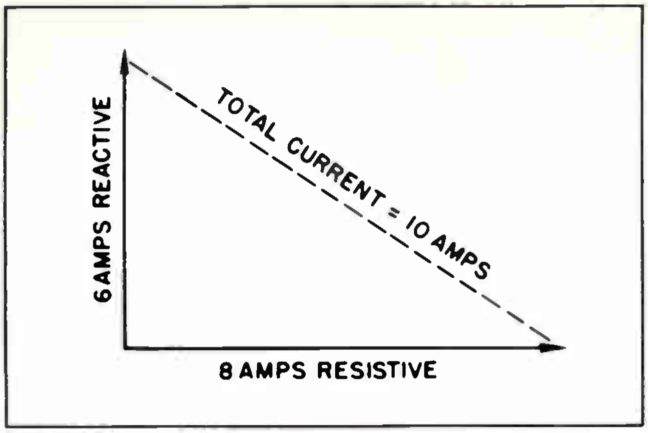


Fig. 31. Using Pythagoras' Theorem to find total current.

We have not shown how the reactances of each branch have been obtained. The matter of calculating inductive reactance and capacitive reactance has been discussed so many times in previous lessons it seems scarcely necessary at this time. But to refresh your memory we will repeat that inductive reactance is $X_L = 2\pi fL$, and capacitive reactance is equal to:

$$X_C = \frac{1}{2\pi fC}$$

The main point now is that the reactance of each branch of the circuit has been found to be as shown in Fig. 32. The next thing is figure out how much current flows through each branch, then draw a vector diagram showing the arrangement of the various currents.

This has been done in Fig. 33. There we find the current through the three resistive branches moving off to the right, going to the right in phase with the impressed voltage, going to the right along the reference axis. The current through the two capacitive branches is drawn in an upward direction from the reference axis because the capacitive current leads the current through the resistances. Finally the current through the various inductive branches is shown moving downward from the reference axis, in a direction which is diametrically opposite that taken by the current in the capacitive branches.

Adding up the totals for each of the three *kinds* of current we find there are 3 amperes of resistive current, 14 amperes of inductive current, and 10 amperes of capacitive current.

The next step is to subtract the smaller value of reactive current from the larger value.

In this case the inductive current is greater than the capacitive current. So we subtract the 10 amperes of capacitive current from the 14 amperes of inductive current and come up with a vector as shown in Fig. 34. There we have 3 amperes of resistive current and 4 amperes of reactive current, the reactive current being inductive. Note the inverted triangle. This is caused by the fact the inductive current is lagging, and thus is drawn in a downward direction.

The final step in finding the total amount of current flowing from the source to a circuit is found as in Fig. 35. There we find the total current amounts to 5 amperes.

Once the total *current* has been found we proceed to the final step in determining the total *effective impedance* presented by the circuit to the flow of alternating current. This is the simple matter of dividing the original impressed voltage of the source by the total current flowing in the circuit. This is done in Fig. 36, and we find that we have a total effective impedance presented by the circuit which amounts to 20 ohms.

Section 13. LIMITATIONS ON THE CURRENT METHOD OF FINDING IMPEDANCE

The current method for finding impedance has

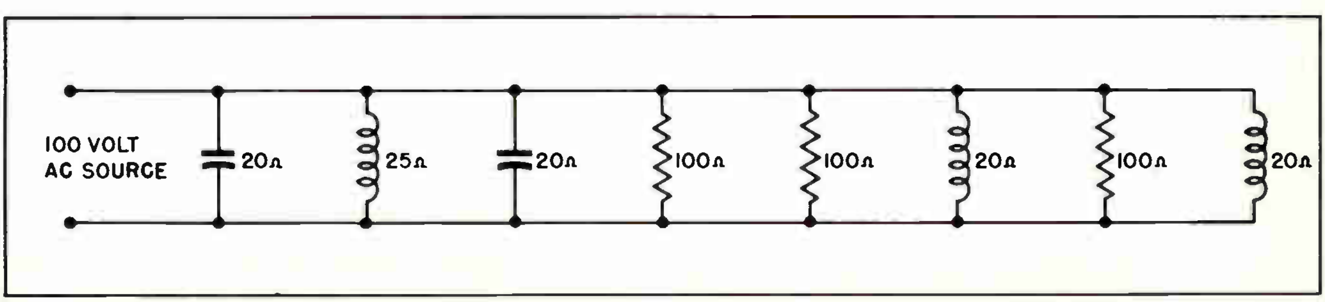


Fig. 32 Parallel circuit with many branches.

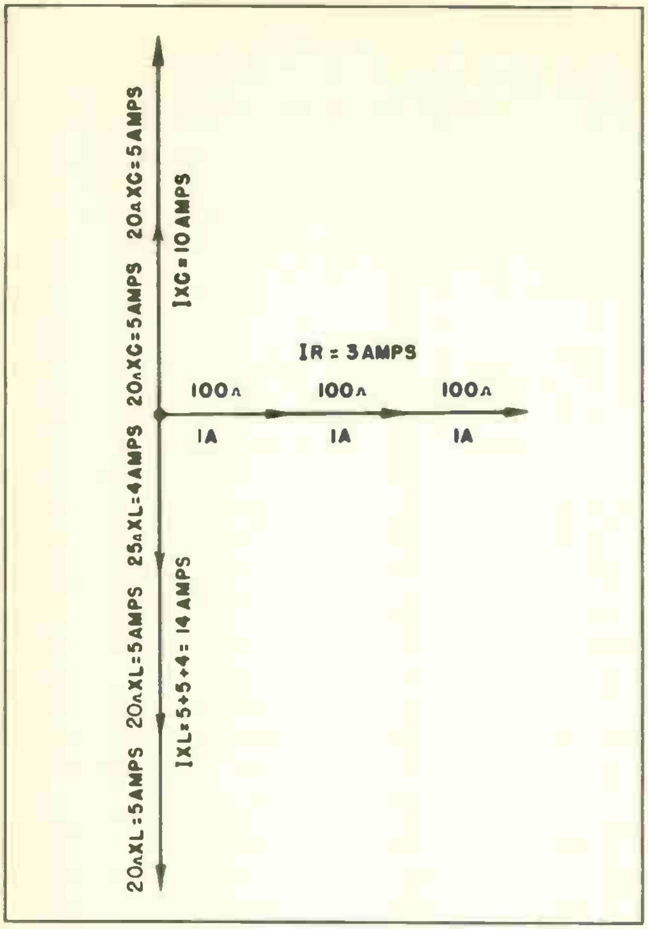


Fig. 33. Vector which shows current flow in many branches.

certain advantages over other methods which are more commonly used. It is ideally suited for a person who has a limited knowledge of mathematics.

It provides a convenient method for finding the total effective impedance of a complicated parallel A-C circuit without resorting to algebra or trigonometry. This is especially true when the predominant characteristics of each branch of a parallel circuit can be determined.

By the term "predominant characteristics" of a branch of a circuit we are referring to those characteristics of the circuit which determine if it is resistive, or capacitive or inductive. In Fig. 28 we have one circuit which is clearly capacitive, a second which is resistive and a third which is inductive. There is no mixing of resistance and reactance in any of the branches.

The same conditions hold true in the case of a circuit like that in Fig. 32. They hold true despite the fact there are many more branches than the circuit in Fig. 28. Each of the branches in Fig. 32 has a predominant characteristic, some are resistive, some capacitive and some inductive. None of the branches contain both resistance and reactance.

The usefulness of the current method for determining impedance is limited when the circuits become more complicated. This is especially true where one or more of the branches have resistance and reactance mixed together.

The parallel circuit shown in Fig. 37 is one type of circuit to which the current method for solving impedance cannot be readily applied. This is because the phase angles of the currents through the several branches are different from those cases where the individual branches consist only of resistance or reactance, but not combinations of them.

In Fig. 37 there are three branches. Each branch contains more than one of the elements which go to make up impedance. In the first branch, which is designated as branch *A*, there is both resistance and capacitance.

From our previous studies we know that current through a resistance is in phase with the voltage. We also know that current through a capacitor is 90° out of phase—it is leading the voltage.

Further than that, we know that when we combine resistance and capacitance in an A-C circuit the current through that circuit is neither in phase with the voltage, nor is it 90° out of phase with it. Instead, the current is out of phase by some phase angle between 0° and 90°, the exact

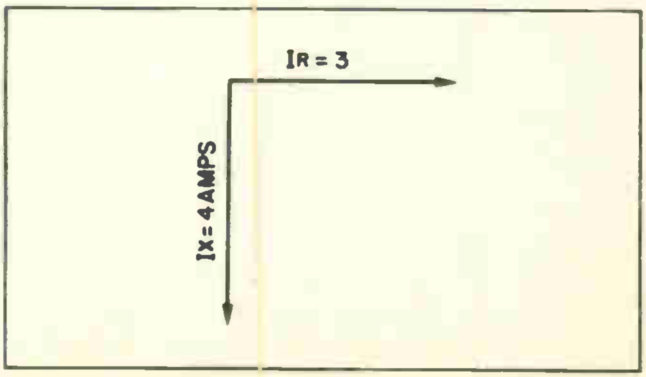


Fig. 34. Vector of total reactive current and total resistive current in parallel circuit of many branches.

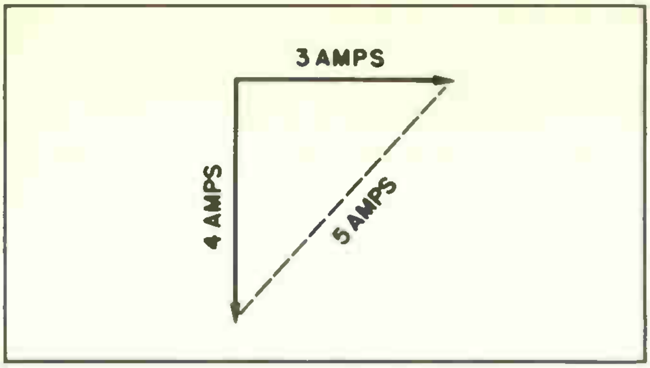


Fig. 35. Total current drawn from source in circuit of many branches.

IMPRESSED VOLTAGE = 100

TOTAL CURRENT = 5 AMPS

TOTAL IMPEDANCE $= \frac{100}{5}$

$= 20$ OHMS

Fig. 36. Calculating total effective impedance of parallel circuit with many branches.

phase angle being determined by the amount of resistance and capacity in the circuit.

Following the same line of reasoning, we know the phase angle of the current through branch *B* is also out of phase by some phase angle between 0° and 90°. The exact phase angle of the current, with reference to the voltage, would depend upon the amount of resistance and inductive reactance in the circuit.

In the case of the current through branch *B*, however, the current would be lagging the voltage by some phase angle between 0° and 90°, rather than leading the voltage as in the case of the current through branch *A*.

The current method for finding the total impedance depends for its usefulness upon our ability to apply the principles of Pythagoras' theorem. This means that the phase angle of the currents through the individual branches must be at right angles to each other. If the phase angles of the currents through the individual branches happen to be some angle besides 0°, or 90° out-of-phase, the principles of Pythagoras' theorem cannot be applied.

Fortunately for men working in radio and television, most circuits are so constructed that currents in the various branches differ from each other by 90°, or close approximations to it. Thus, it happens that the current method can often be used.

For the person who plans to make radio and television his life work, and who wants to learn everything it is possible to learn about it, it would be well to give some thought to learning how to use the "Operator-J." That is a highly accurate method, and can solve virtually every circuit problem involving A-C impedance. It is not especially difficult to learn, but does require some elementary knowledge of algebra and trigonometry.

Another useful, but very inexpensive, book of electrical and electronic formulas and data is available if you want to learn more about the mathematics of electrical impedance. It has been prepared by Allied Radio Corporation, 100 North Western Avenue, Chicago. It is called RADIO DATA HANDBOOK, and sells for 25c.

We do not necessarily recommend that you send for the book, and under no circumstances should you order it through the school. We have nothing to do with its publication nor distribution.

Yet, the book does contain a wealth of electrical formulas, RMA standards, mathematical tables, and other useful information most radio technicians like to carry with them. The book is small enough so it can be slipped into a worker's pocket.

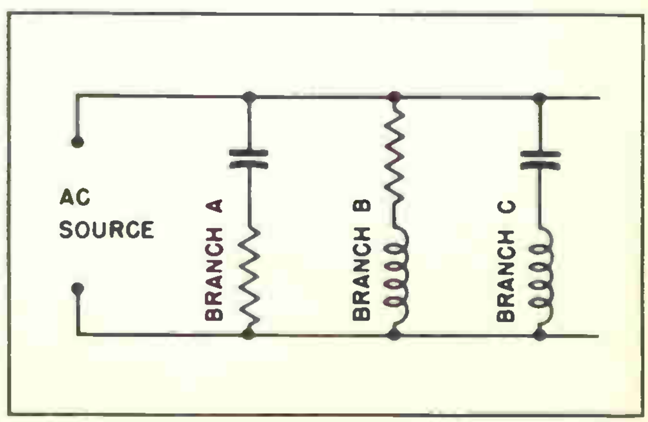


Fig. 37. A type of circuit where current method cannot be used to find total impedance.

NOTES FOR REFERENCE

Impedance in an A-C parallel circuit with only resistance in each branch is calculated exactly the same as effective resistance in a D-C parallel circuit.

A-C current through a resistance is 90° out of phase with current through a capacitor or inductor.

The current through an inductance is 180° electrical degrees out of phase with that through a capacitance.

When an inductance is in parallel with a resistance the total impedance cannot be calculated by the method used to calculate parallel resistances.

Neither can the impedance of a capacitor in parallel with a resistor be calculated by the method followed when resistors are in parallel.

When there is capacitance in one branch of a parallel circuit, and inductance in another branch, some current flows back and forth between the capacitor and inductor. This results from the fact that currents through the two types of load are 180° out of phase with each other.

Current which flows between a capacitor and inductor in parallel branches does not flow in the circuit from the source.

Impedance in a parallel A-C circuit is equal to the voltage of the source divided by the current which flows from the source to the parallel load.

When using the current method for calculating impedance it is necessary to subtract the smaller *reactive* current from the larger reactive current to learn the net reactive current.

Once the net reactive current through the parallel branches of an A-C circuit is known, that current is then combined with the current through the resistive branches. They are combined according to the rules of Pythagoras' theorem.

Total impedance of a parallel A-C circuit can be calculated by dividing the voltage by the current, but that does not tell the phase angle by which the current is out of phase with the voltage.

The current method for calculating impedance cannot be used in those cases where any of the branches contains a combination of reactance and resistance.

The current method for calculating impedance can be used only when the currents in the various branches are in phase with the voltage, or are exactly 90° out of phase.

If any of the branches of a parallel circuit contains both reactance and resistance the phase angle of the current through that branch is neither in phase with the voltage, nor is it exactly 90° out of phase.

Most circuit branches in radio and television work consist of only resistance, or of only reactance.

When a purely inductive circuit is in parallel with a purely capacitive circuit the combined branches will take *less* current from the source than would be true if either were in the circuit alone.

In practical electrical work there are many times as many parallel circuits as series circuits.

A-C voltage and current are present in more electrical circuits than direct current.

There are more parallel A-C circuits in electrical work than any other kind.

Employers of electronic technicians and television Servicemen expect them to know how to solve problems involving parallel A-C circuits. Employment examinations always include questions about parallel A-C circuits.

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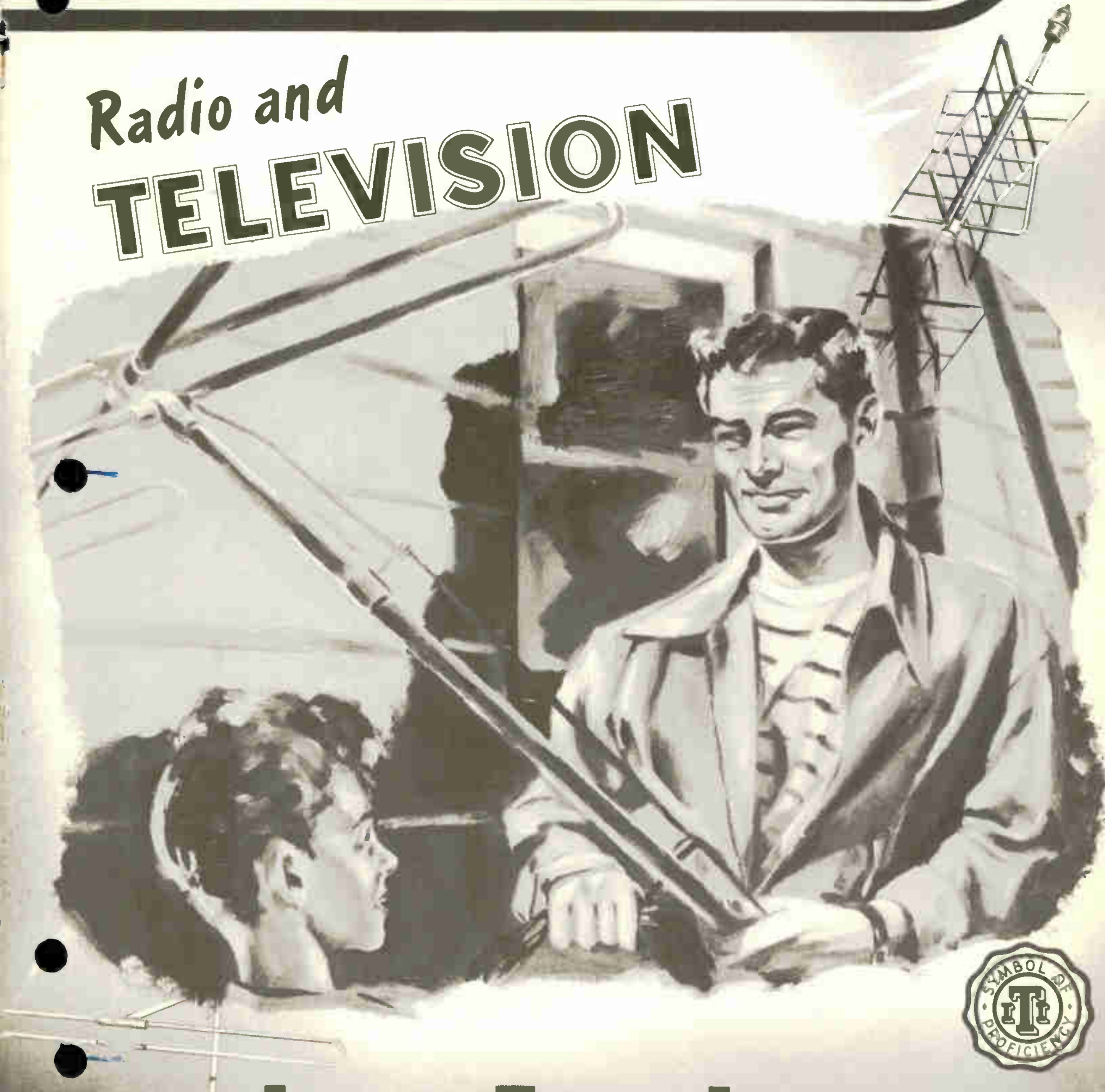

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TECHNICAL TRAINING SERVICE

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RADIO TELEVISION

D-C REINSERTION AND CATHODE MODULATION

Contents: Introduction — How the Level of Composite Video Signal Varies — Problems Created by Varying Composite Signal Voltage — Biasing the Picture Tube — Function of the Brightness Control — The D-C Component — Effect of Capacitive Coupling — Average Amplitude Level in Video Signal — D-C Reinsertion — Using Grid-Leak Bias as D-C Restorer — Diode Restoration — Reinsertion Voltage and Brightness Control — Restorer Circuit Using Grid-Leak Bias — Diode Restorer Circuit — D-C Restorer Combined With Sync Separator Circuit — Video Signal Voltages After Inversion — Applying Inverted Video Signal to Picture Tube — D-C Reinsertion not Needed With Cathode Modulation — Practical Circuit Employing Cathode Modulation of Picture Tube — Notes for Reference.

Section 1. INTRODUCTION

Most radio signals, whether RF or audio, consist of sine waves, or combinations of sine waves. Since that is true, such signals are reasonably symmetrical in nature.

At least they are sufficiently symmetrical so the voltage above a given "zero line" is equal to, and balanced by, the voltage below that line. The sine wave drawn in Fig. 1 demonstrates the symmetrical character (regular form) of most A-C voltages found in radio and other electrical circuits.

When it comes to the *composite video signal,* however, we are dealing with varying voltages which are not symmetrical. This fact was brought home to you at the time we were discussing the nature of the composite video signal; if you did not recognize it then, it should not be difficult for you to recognize it now since we are again pointing it out to you.

The composite video signal, as you already well know, consists of the camera video signal, upon which has been superimposed the blanking and synchronizing pulses needed to maintain synchronism between the receiver sweep circuits and the transmitter sweep circuits. The blanking and sync pulses are evenly spaced, and their intervals closely controlled; but the pulses are certainly not symmetrical.

There is even less symmetry in the voltages which compose the camera video signal. They vary from instant to instant as the camera beam passes, in turn, over light and dark areas of the scene being scanned. The result is that the voltage level of the signal swings over relatively wide degrees of amplitude.

The amplitude of the blanking pulses and that of the sync pulses is carefully established at the

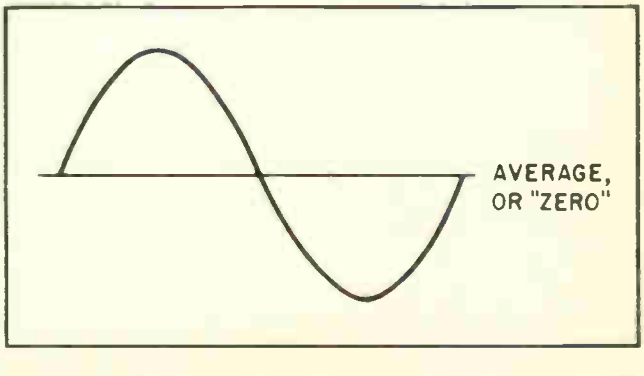

Fig. 1. A sine wave voltage is symmetrical because it is equally divided above and below the zero line.

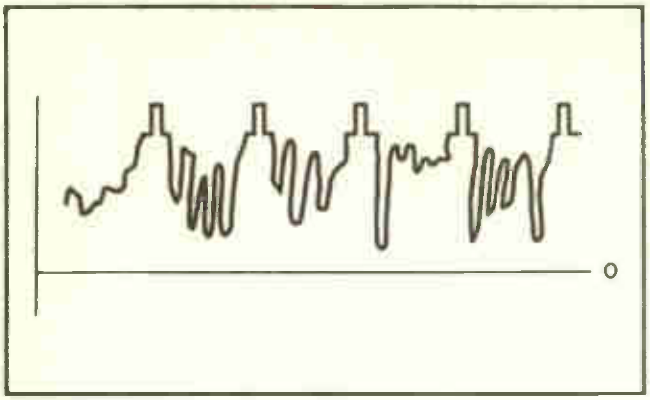

Fig. 2. Diagram of Composite Video Signal which demonstrates its lack of Symmetry.

transmitter. The level of the blanking pulses is held at 75% of full amplitude by the circuits at the transmitter, while the peak level of the sync pulses is equal to 100% of the peak signal. That has all been explained in previous lessons, and is repeated here merely for the purpose of emphasis before proceeding with our discussion.

A graph of a composite video signal would follow the general pattern of that shown in Fig. 2. A given signal would undoubtedly differ from it in detail, but that graph represents the general pattern.

The peak level of all the sync pulses in the graph are shown to have the same level. Each has a peak amplitude equal to that of all the others.

The same is true of the blanking pulses. All have the same level, and each is equal in every way to each of the others.

But the camera video signal varies over wide ranges. In Fig. 2 there are some relatively wide swings during the passage of each cycle.

The fact that the composite video signal is not a symmetrical signal, and the additional fact that the *average* level of the composite video signal tends to vary over relatively wide ranges, creates a peculiar problem for television engineers and technicians. That problem stems from the difficulty of passing a composite video signal through a coupling capacitor, through which a reference D-C voltage cannot pass, then continuing to maintain the *average* level of the signal at the same level it had before passing through the capacitor.

This lesson deals with that problem, and the methods used by engineers to solve it.

Section 2. HOW THE COMPOSITE VIDEO SIGNAL LEVEL VARIES

To better understand *how* a composite video signal average level varies from instant to instant it is desirable to first understand what causes it to vary.

Variations in the *average* level of the composite video signal stems from the fact there are often expanses of white picture areas which are not immediately balanced — electrically — by equal areas of black. Other variations stem from the opposite condition when large areas of black are not balanced by equal areas of white.

It has already been established in previous lessons that when the amplitude of the composite video signal is low the effect on the picture tube screen is to produce a white area. The graph in Fig. 3 represents such a condition.

When a composite video signal, similar to the one graphed in Fig. 3, is applied to the control grid of a picture tube, it acts upon the electron beam in the tube in such manner that the beam is permitted to strike the screen with nearly full strength. The strong beam produces strong luminescence, and thus a bright picture area.

On the other hand, a composite video signal which has a high amplitude camera signal acts differently. We have shown a graph of such a composite video signal in Fig. 4.

When the level of the camera signal portion of the composite video signal is high, as in Fig. 4, it acts upon the control grid of the picture tube to restrict the passage of electrons comprising the electron beam. This results from the fact that when the signal is applied to the control grid of the picture tube the composite video signal is always negative.

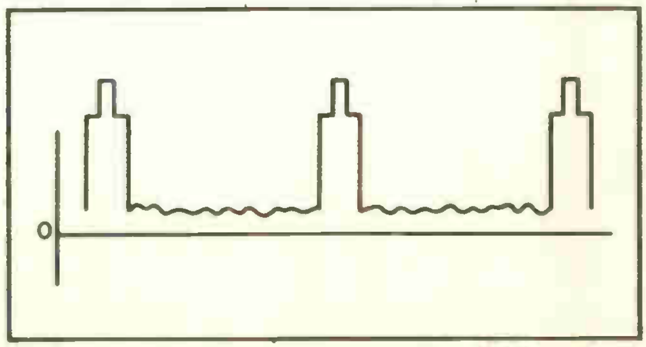

Fig. 3. Video signal for a bright scene.

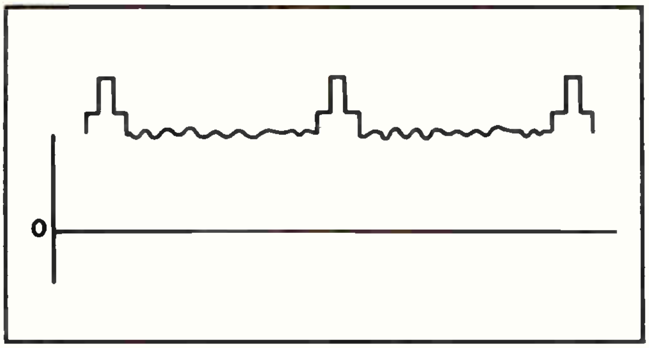

Fig. 4. Video signal for a dark scene.

You may wonder why this is true, but reflection will quickly show you why it must be true. The blanking pulses are negative. They must be negative to blank out the electron beam during the horizontal retrace period. Only a negative voltage on the control grid can possibly cut off the passage of electrons.

Further than this, the sync pulses are superimposed on the blanking pulses. The sync pulses are driven into the *infra-black* region, and are thus more negative than is necessary for signal blanking purposes.

The blanking and sync pulses are located at higher amplitude levels of the composite video signal. Since this has been clearly established it follows as a natural result that other high amplitude signals from the camera — though they may have a lower amplitude than the blanking pulses — reduce the strength of the electron beam, and thus darken the area where the beam strikes the screen.

A close study of the graphs in Figs. 3 and 4 discloses a significant condition. There is a distinct difference in the *average* levels of the signals in the two graphs.

The degree of this difference is emphasized in the graphs in Fig. 5. It can be seen that the average level of the composite signal is significantly lower in the case of the signal for a light scene than that of a signal for a dark scene.

What all this adds up to is the fact that the average level — the average amplitude — of the composite video signal varies constantly. It varies as the signal carries electrical information, needed to reproduce varying levels of light, from the scene being viewed by the camera.

So long as there is a voltage reference base of some kind, against which the video signal can be compared, it makes little difference if the average signal level tends to vary. The instantaneous changes in the composite video signal voltage are always maintained at the correct degree of amplitude with respect to the reference voltage. There is no distortion of the signal voltage, and it acts upon the picture tube control grid so as to reproduce the original scene with reasonable fidelity.

In most cases the reference voltage is some type of D-C voltage which is maintained at a given amplitude. This is necessarily so, because only a D-C voltage can provide those stable conditions against which a varying voltage can be compared.

Section 3. PROBLEMS CREATED BY VARYING COMPOSITE SIGNAL

A little study of this problem would probably make you well aware of the task which confronts a television engineer or technician. That is the one of coupling the composite video signal from one stage of a video amplifier to another without distorting the signal.

There is little problem in coupling the *varying*

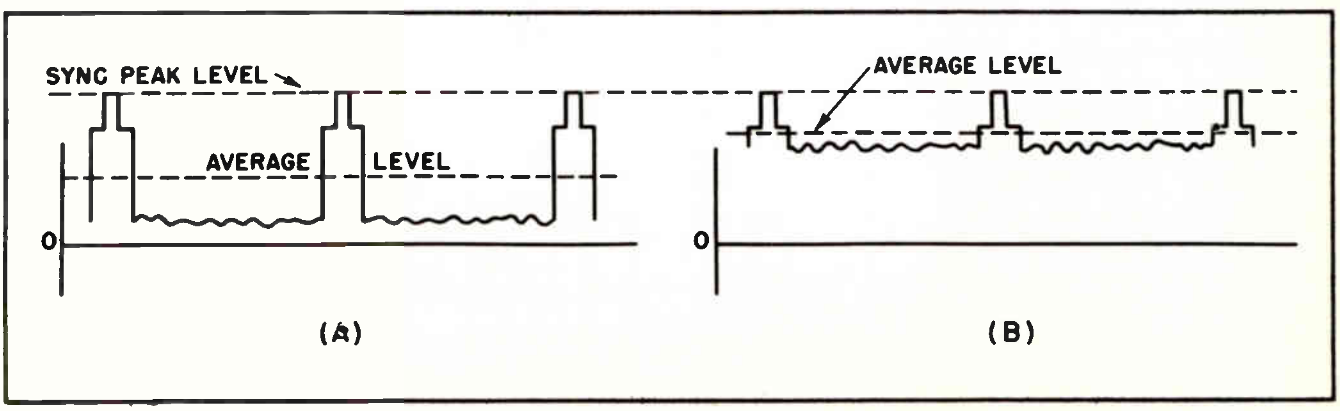

Fig. 5. Comparison of Average Signal Levels for Light and Dark Scenes.

voltage in the composite video signal from one stage to another. That can be done by using capacitors or transformers. For technical reasons, it is usually more satisfactory to couple the composite video signal from one stage to another by using capacitors.

But that is only a part of the problem. The big headache arises from the fact that when the composite video signal is coupled from one stage to another through a coupling capacitor the D-C component of the video signal is lost. The D-C reference voltage cannot pass through a capacitor.

All of which means there remains nothing against which the amplitudes of the various parts of the composite video signal can be compared, and there is a tendency for the various amplitudes to vary in accordance with the *average* level of the composite video signal.

The net effect of this is during low amplitude intervals, when the composite signal is carrying information of light areas, the amplitudes of the blanking and sync pulses will not be so high as when the signal is carrying information for dark areas. This condition affects the *peak* amplitude of the sync pulses. It can affect them to such an extent as to interfere with synchronization.

Further than this, it affects the blanking pulses. For proper reproduction of the original scene, and to provide a proper pedestal for the sync pulses, it is necessary for the blanking pulses always to have the same amplitude. The amplitude of the blanking pulses should be equivalent to 75% of peak amplitude of the composite video signal.

Since the varying *average* signal can affect the amplitude of the blanking pulses it can create varying situations. It can create the situation where the amplitude of the blanking signal is not great enough to blank the electron beam; and it can create the opposite condition where it may raise the amplitude of the blanking pulse to such high level that it trips the horizontal oscillator. In this latter case it affects the oscillator much the same as a sync pulse, but at a different time.

All of which means that absence of the D-C component in the composite video signal deprives the composite signal of a reference voltage against which it can be stabilized. This, then, results in distortion of the picture on the receiver screen.

Section 4. BIASING THE PICTURE TUBE

To provide true fidelity in the reproduction of the scene viewed by the camera it is necesary to maintain the peak amplitude of the synchronizing pulses at an even level. This means all must have the same amplitude regardless of any variations in the average signal amplitude.

Further than this, it is also necesary to maintain the amplitude of the blanking pulses at an even level. The graphs in Figs. 3, 4, and 5 show the blanking and sync pulses maintained at constant amplitudes.

One way to accomplish this action is to restore the D-C component of the composite video signal by placing a D-C bias on the control grid of the picture tube. Such D-C bias would necessarily have to vary uniformly with variations of the *average* level of the composite video signal.

What such a D-C bias would have to do is increase the negative bias voltage whenever the *average* amplitude of the composite signal tended to decrease, and to decrease the negative bias whenever the average amplitude of the composite signal tended to increase. In plain words, the action of the varying D-C bias should be such as to counteract the normally varying levels of the composite video signal, and establish a stabilized reference level for them.

The matter of varying the D-C bias on the control grid of the picture tube to counteract the varying level of the composite signal is not a particularly difficult condition to correct. But the conditions are complicated by the fact the picture tube, like all other vacuum tubes, must be operated with a bias voltage to provide linear operation. This means that a stable D-C voltage must be placed on the grid to provide normal operating conditions, then a varying D-C bias superimposed on that stable bias to compensate for the varying level of the composite signal.

These bias voltages are separate from, and largely independent of, the varying video camera voltage. The varying camera voltage, used to modulate the electron beam, is superimposed on both the regular voltage, and the varying bias voltage used to compensate for the varying *average* level of the composite signal.

The presence of so many voltages around the control grid of the picture tube — all of which are acting upon the electron beam in some manner, — becomes rather complicated. It becomes somewhat difficult to keep them all in mind, and continue to follow their actions.

A study of the circuits immediately surrounding the cathode and control grid of a picture tube, should make these conditions somewhat easier to understand. A simplified diagram of the circuits connected to the cathode and control grid of a picture tube is shown in Fig. 6.

The composite video signal is injected on the control grid of the picture tube through the coupling capacitor. That signal comes from the video amplifier, or directly from the video detector.

The circuit in Fig. 6 also shows the regular biasing arrangement, although the details of the biasing differ considerably from those with which you have become acquainted while working with vacuum amplifier tubes. The regular biasing in the circuit in Fig. 6 is created by making the cathode of the picture tube positive with reference to the control grid. The cathode is made positive by placing a definite amount of B+ voltage on it.

Making the cathode *positive* with reference to the control grid is precisely the same as making the control grid *negative* with respect to the cathode. The voltage relationships between the two elements of the tube are exactly the same in either case.

The exact amount of normal bias on the control grid can be regulated by the "brightness control," as shown in Fig. 6. Its purpose is to increase or decrease the average brightness of the entire picture on the screen. By adjusting the setting of the slider on the potentiometer the positive voltage applied to the cathode can be raised or lowered, thus changing the amount of negative bias voltage applied to the control grid.

From a study of the circuits in Fig. 6 it becomes clear that biasing voltage is applied to the cathode rather than applying it directly to the control grid. The composite video signal, including the camera signal, is applied directly to the control grid. All of which is not radically different from conditions we have encountered in the operations of ordinary-amplifier tubes.

But the varying D-C bias, which represents the restoration of the D-C component in the composite video signal, has not yet been applied to the picture tube circuits. The diagram in Fig. 6 does not show that circuit. It has been deliberately left out to avoid complicating the diagram at this time.

However, the varying D-C bias voltage needed to compensate for the varying average of the composite signal would normally be applied directly to the control grid. Since that voltage is D-C it is necessary to apply it *directly* to the grid because the D-C voltage cannot pass through a capacitor.

Section 5. FUNCTION OF THE BRIGHTNESS CONTROL

Almost every person who has had contact with a television receiver, even as a viewer only, is aware of the presence of the "brightness" control. The exact position of the brightness control varies from one receiver to another, but it is usually placed so it is convenient to the viewer — in case it needs to be adjusted to raise or lower the general level of brightness on the screen.

Most receivers have the brightness control positioned on the front panel. There is a strong trend toward mechanically combining the brightnes control with the "contrast" control, so both can be adjusted through the medium of concentric shafts. This trend has been aided by several component manufacturers who have designed special concentric controls which can be used for that purpose.

Some receivers have the brightness control positioned in some other location. A few receivers

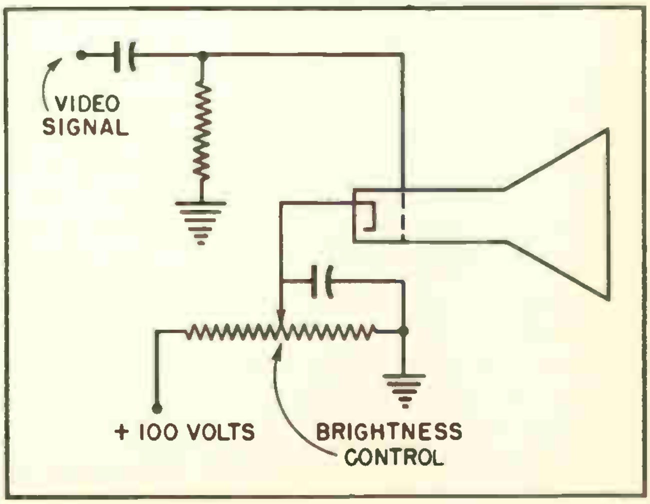

Fig. 6. Cathode and Control Grid Circuits of Picture Tube.

have the brightness control mounted on the rear panel of the chassis, and some have it mounted on the side panel.

Regardless of whether the brightness control is mounted on the front panel, or elsewhere, it is always variable. The fact it is variable makes it possible to adjust the average level of brightness on the screen of the receiver.

The correct adjustment of the brightness control is that which causes the "black level" to reach an amplitude of 75% coincident with the peak level of the blanking pulse. In most receivers this is the level at which the diagonal lines of the vertical retrace just disappear from the screen.

For all practical purposes the correct setting of the brightness control is reached when the brightness level is reduced from a high level to that at which the vertical retrace lines just disappear. A higher level setting of the control permits the vertical retrace lines to be visible on the screen. That is often annoying. A lower level makes the darker picture elements black instead of some shade of gray.

The vertical retrace lines are those which can often be seen — especially with the brightness control turned up — slanting from the lower left-hand corner of the screen toward the upper right-hand corner. They are bright lines which cut diagonally across the face of the screen.

Most modern television receivers have special circuits which place damping pulses on the picture tube to prevent the vertical retrace lines from showing, but they can usually be made visible if the brightness control is turned too high.

Action of the brightness control is relatively simple. This is revealed by a study of the circuit in Fig. 6.

The brightness control consists of a simple potentiometer. One side of the resistance element is tied directly to "ground," or to B−. The other side of the resistance element is connected to a positive voltage, very often being connected directly to the B+ power supply. Sometimes it is connected to the B+ power supply through a fixed resistor.

Such resistance circuit is actually a voltage divider, since the resistance is connected between a positive voltage and a negative one. The voltage varies constantly from one end of the resistance element to the other. Then, as the slider of the potentiometer is moved from one position to another on the resistance element, it is possible to tap off almost any amount of voltage. That voltage can then be applied directly to the cathode of the picture tube.

It can be seen that almost any degree of voltage, between zero volts and some 100 or more positive volts, can be applied to the cathode merely by moving the slider of the potentiometer from one position to another. If the slider is moved to the extreme right end in Fig. 6 the cathode is placed at ground potential, which is the same as that applied to the grid. When the slider is in that position there is no negative bias on the grid of the picture tube.

When the slider is moved in the other direction — to the left — the voltage applied to the cathode becomes progressively more positive. This has the practical effect of making the grid progressively more negative with respect to the cathode. Making the grid progressively more negative makes it progressively more effective in preventing the movement of electrons in the beam toward the screen, thus causing the pattern on the screen to become progressively darker.

The slider is connected with ground through a large capacity capacitor which serves as a by-pass capacitor around the resistance of the potentiometer. This provides a pathway for the A-C component of the signal current in the picture tube.

Section 6. THE D-C COMPONENT

When the transmitted signal has been properly adjusted at the transmitter, and we are usually justified in assuming that it is properly adjusted, all the pedestal voltages will be lined up at a constant level. This is true because the transmitter inserts sufficient D-C bias — the D-C component — to maintain the level of the pedestals at a value equivalent to 75% of the peak amplitude of the carrier signal.

It is worth mentioning that this perfect alignment of the pedestals at the blanking level is maintained throughout the R-F and I-F stages of the receiver because the R-F and I-F signals carry the video as a modulation of the sine wave carrier. The frequency is quite high in those stages, but the signal is a sine wave nevertheless. It is a sine wave signal until demodulated at the video detector.

After the carrier signal has been demodulated — or rectified — in the video detector stage we obtain the video signal output, a signal which is no longer a sine wave. In this form the D-C component of the composite signal is lost whenever an attempt is made to pass the composite signal through a capacitor. You are, of course well aware that a capacitor will readily pass an A-C signal, but it will block the passage of D-C.

It is interesting to note that at the output of the detector the height of the pedestals are all lined up so their voltage level is equal to 75% of the maximum amplitude of the signal. If the output of the detector stage could be applied directly to the grid of the picture tube it would be possible to adjust the manual brightness control so the correct bias could be applied to the grid, a bias of such value that the pedestal level would be just sufficient to drive the tube to cut-off.

It so happens, however, that the output of the detector stage is not always strong enough to be applied directly to the grid of the picture tube. Instead, it is passed through one or more stages of video amplification so as to raise the voltage amplitude to a value great enough to drive the picture tube.

Since capacitive coupling is normally employed between such amplifier stages, it is a good idea to spend a little time investigating the effect of such coupling on the D-C component of the video signal.

Section 7. EFFECT OF CAPACITIVE COUPLING

One principal effect of capacitive coupling betwen stages in video amplifiers is blocking of the D-C component of the composite video signal. The capacitive coupling readily passes the A-C component of the signal, however, so it can be amplified.

The action in a common amplifier circuit is shown in Fig. 7. There we see the action as it applies to an A-C signal. It is an action with which we are already fully familiar.

The A-C signal is passed; the only change in the signal is to place the output signal 180° out of phase with the input. This condition applies specifically to A-C voltages which are sine wave in nature.

Note carefully the levels of the voltages at the

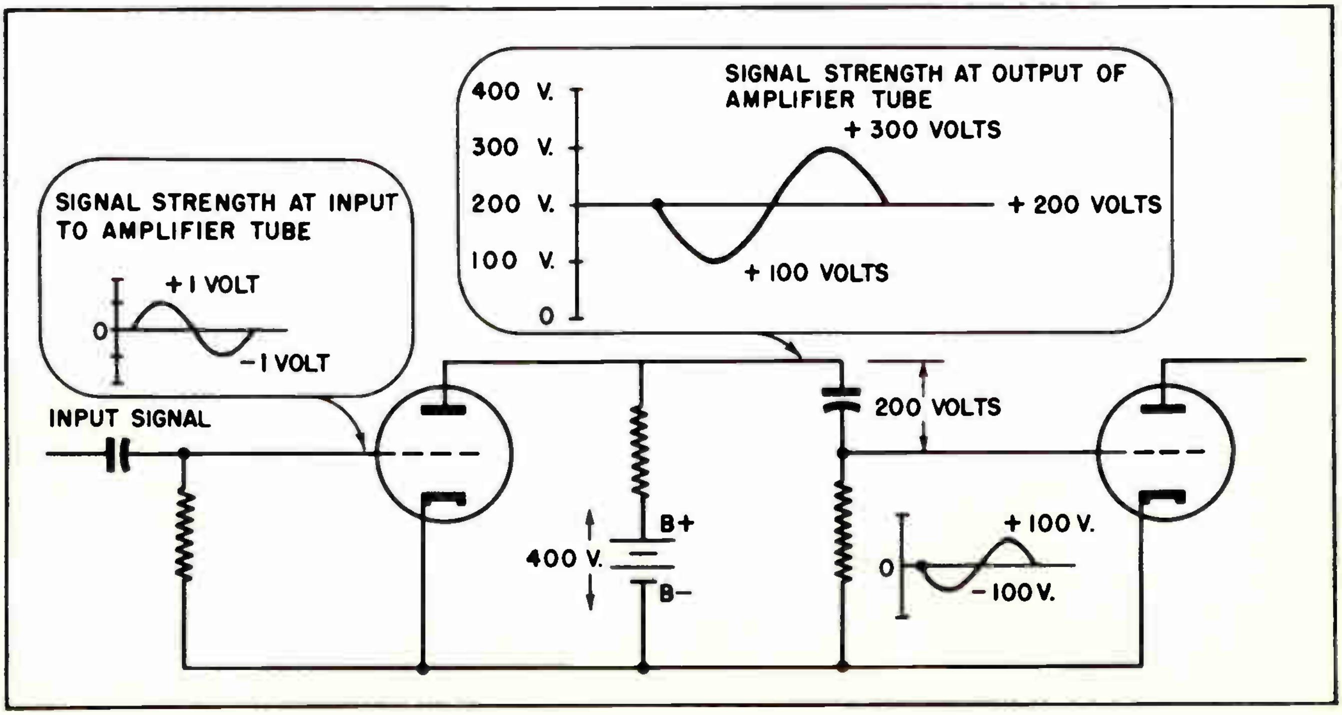

Fig. 7. Voltage relationship in an ordinary amplifier.

various points in the circuit. Since the sine wave is symmetrical in nature, it is a simple matter to fix an *average* level for it.

The average level is midway between the peak in a positive direction and that in a negative direction.

Section 8. THE AVERAGE AMPLITUDE LEVEL IN VIDEO SIGNAL

We are confronted with a somewhat different situation when we begin considering a video signal. The video signal, although A-C in nature. is decidedly different from the symmetrical sine wave.

We can begin our consideration by making the flat statement that the average value of any signal is the arithmetical mean — or average — of all the instantaneous values of the signal averaged over an entire cycle.

When we consider a sine wave, the problem is simple. Since half the voltage is in a positive direction, and the other half is in the negative direction, and each half is equal, it follows as a natural consequence that the average lies just halfway between the peak of the negative voltage and the peak of the positive voltage. This is shown in Fig. 8.

But let's consider the case of a video signal, and try to determine the average level of such a signal. If we have a picture which contains equal parts of light and dark we would have a video signal similar to that in Fig. 9, and in that case the average level of the signal would lie approximately halfway between the maximum positive and the maximum negative swings of the A-C video signal. For this particular case there would be little difference between a normal sine wave and the video signal.

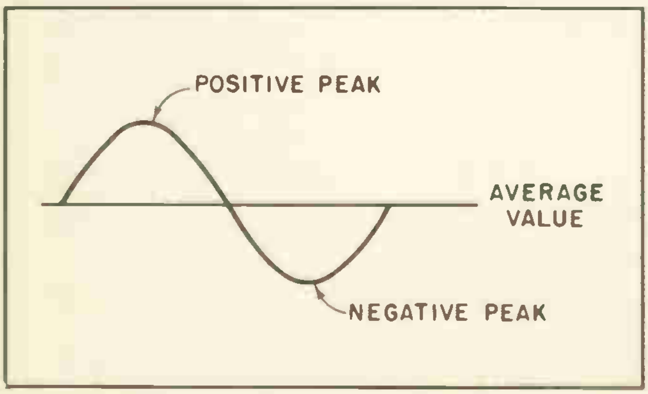

Fig. 8. Average Amplitude level of sine wave is zero.

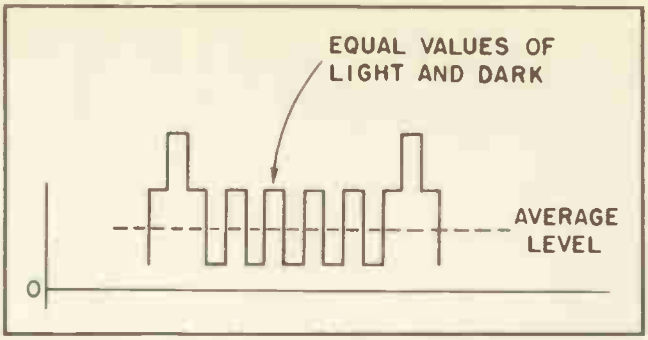

Fig. 9 Average Level of Video Signal when scene is evenly bright and dark.

But the normal video signal does not always maintain the regular rise and fall in the level of its voltages as that shown in Fig. 9. More often there is a preponderance of dark areas in the picture, as in Fig. 10, or a preponderance of light areas as in Fig. 11.

When the picture contains large dark areas it can be seen that the blanking pedestal does not rise very much above the average level of the voltage. On the other hand, when there are large light areas in the picture, the pedestal is considerably above the average level of the voltage.

The importance of what we are discussing is this: The pedestal voltage cannot maintain a constant voltage value above the *average* level of the video voltage unless some other means is provided to correct this condition. And, it should be remembered that the condition is brought about because of the unsymmetrical (irregular) nature of the video signal.

Instead of all the pedestals lining up in an even manner as shown in Fig. 5 they are unevenly lined up as in Fig. 10. The pedestal will be much higher when light areas are being scanned than when dark areas are being scanned.

It seems rather obvious that this is not a desirable condition. Some means must be used to re-establish the D-C component so as to have a stable reference voltage level, and so all the pedestals line up at the same level. This has been mentioned before, but is repeated for emphasis.

If the uneven voltage levels of the pedestals

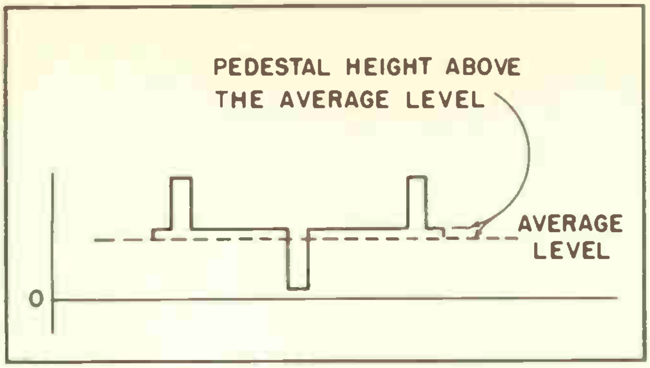

Fig. 10. Average level of dark signal.

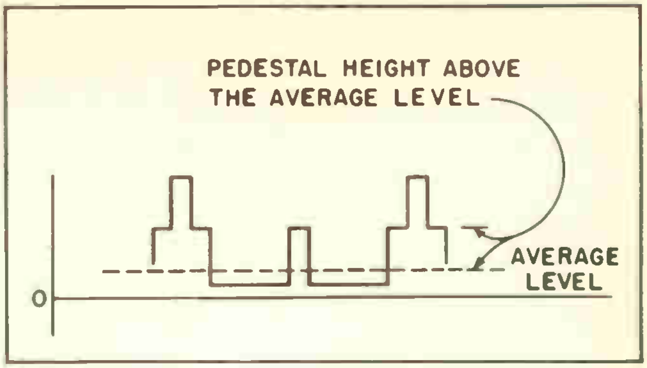

Fig. 11. Average level of bright signal.

shown in Fig. 12 are applied to the grid of a picture tube, the result would be very much like that shown in Fig. 13. It can thus be seen that since the pedestals have different voltage levels it will be impossible to provide the correct bias with a single setting of the brightness control. The pedestal levels should just correspond with the cut-off voltage of the tube.

The distance between the pedestal voltage level and the average-value axis of the signal is the pedestal height. Since the video signal is not a symmetrical signal, this pedestal height is a varying quantity.

The pedestal height can vary with respect to the average-value axis, or the average-value axis can vary with respect to the pedestal height. If left alone, the inclination of the circuit is such that the pedestal height will vary with respect to the average-value axis, but when this occurs the pedestals will not line up, and the reproduction of the picture lacks fidelity.

On the other hand, the level of the pedestal heights can be stabilized so all have the same height with respect to the bias on the tube, and this will allow the average-value axis to vary with respect to the pedestal height. But, in order to accomplish this purpose it is necessary to re-insert a D-C component into the signal to re-establish the reference voltage level for the pedestals of the signals.

When this is done the manual brightness control can be set for the proper brightness, and the pedestal level will provide the proper blanking and the correct brightness for all frames.

Section 9. D-C INSERTION

It is not particularly hard to understand the basic principles of D-C insertion in a television receiver. To demonstrate the basic principles suppose we go back to our elementary fundamentals of electricity and see what happens when an A-C voltage is combined in a circuit with a D-C voltage.

First, we apply an A-C voltage across a resistor, a voltage which has a swing of 5 volts each side of the zero axis, as in Fig. 14. This is simply a common A-C circuit.

Now suppose we remove the A-C generator for a moment and substitute a 5-volt D-C battery as

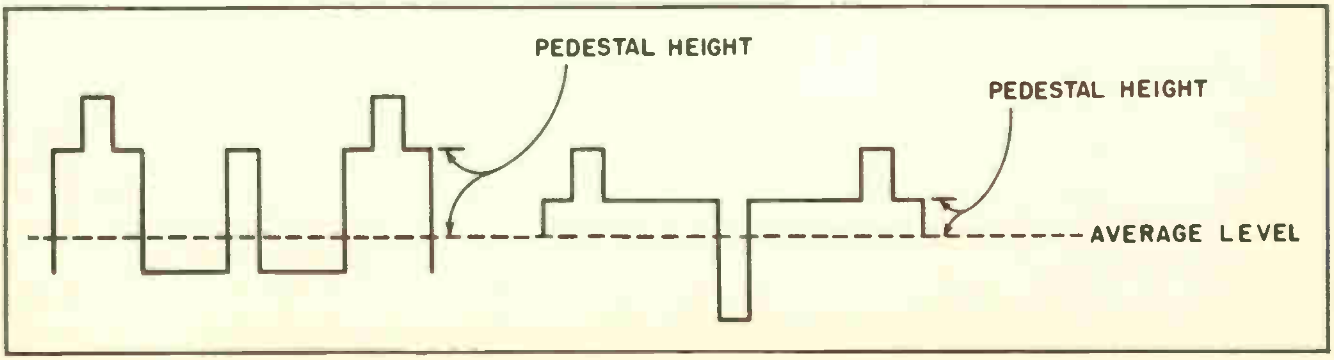

Fig. 12. Difference in pedestal levels for dark signals and bright signals.

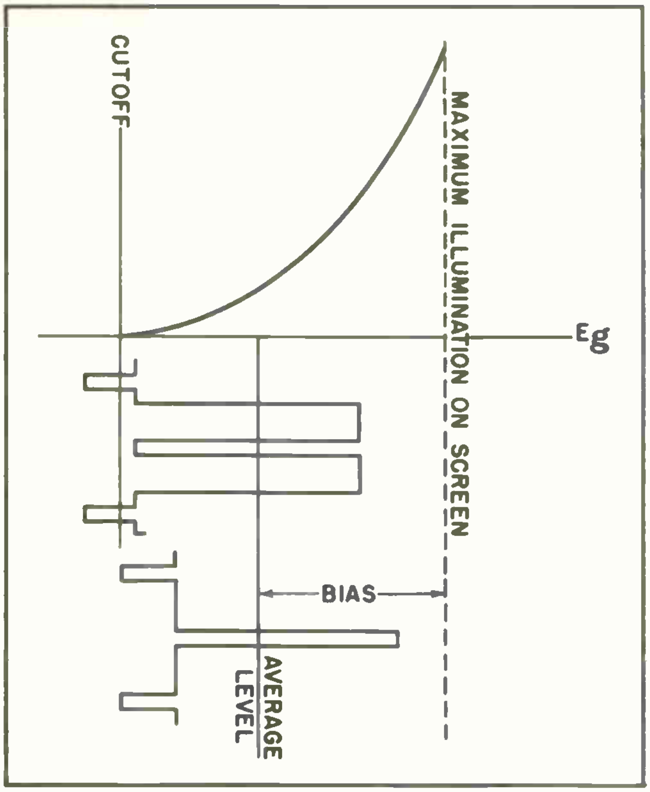

Fig. 13. How dark signal voltage and light signal voltage affect control grid with no D-C restoration.

shown in Fig. 15. Instead of the voltage rising and falling around the zero axis as in Fig. 14 it now remains at a constant level 5 volts above the zero axis.

The next step is to combine the two voltage sources and apply them simultaneously across the same circuit.

Suppose we let the A-C voltage first rise in a positive direction for a quarter cycle. The voltage across the resistor then will rise as shown in the graph at the right of the diagram in Fig. 16. At the instant the A-C voltage rises to its maximum value in the positive direction, there will be 10 volts across the resistor.

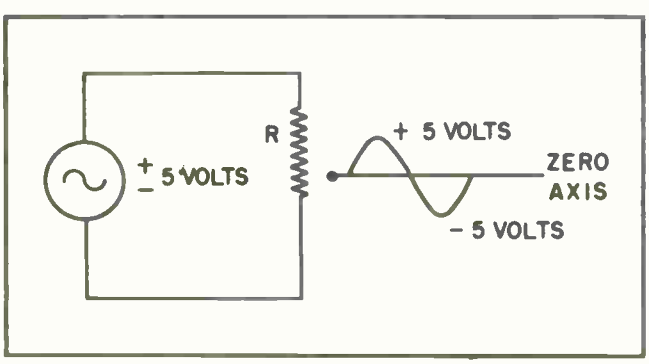

Fig. 14. Sine Wave Voltage across resistor.

Then let the A-C voltage continue in its normal cycle. As is the nature of such voltages, once it reaches its maximum in the positive direction the voltage will cease increasing and begin falling.

At the end of a half-cycle the A-C voltage will be at its zero axis. At this instant the voltage across the resistor is again only 5 volts. This is shown by the graph in Fig. 17.

In Fig. 18 the A-C voltage has continued in its cycle to the maximum value in the negative direction. At this instant the 5 negative volts of the A-C generator will exactly equal, and oppose, the 5 positive volts of the battery. The results are that the voltage across the resistor at that instant will be zero.

In Fig. 19 we can see the results of a complete cycle of the A-C voltage. The A-C voltage acts to increase or to decrease the steady D-C voltage, first making the combined voltage more positive than that of the D-C alone, then, as the A-C voltage swings in a negative direction, the A-C voltage tends to oppose the D-C voltage.

The resultant voltage is one which swings around a positive 5-volt axis, swinging to 10 positive volts in one direction and to zero volts in the other direction.

Returning to our composite video signal the first thought might be that we could use a battery to re-insert the needed D-C component into our video signal. But a moment's reflection makes us aware that the solution to the problem is not quite so simple.

The D-C voltage we re-insert must be of a

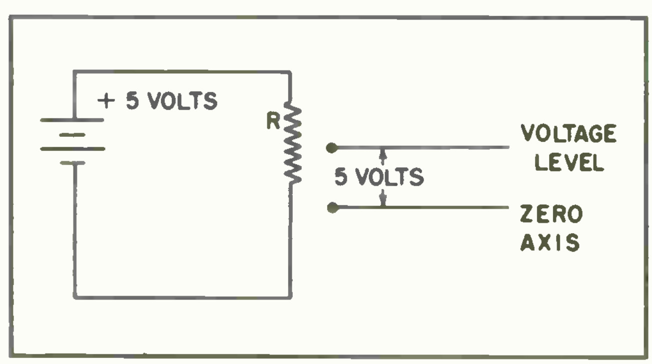

Fig. 15. D-C. voltage across resistor.

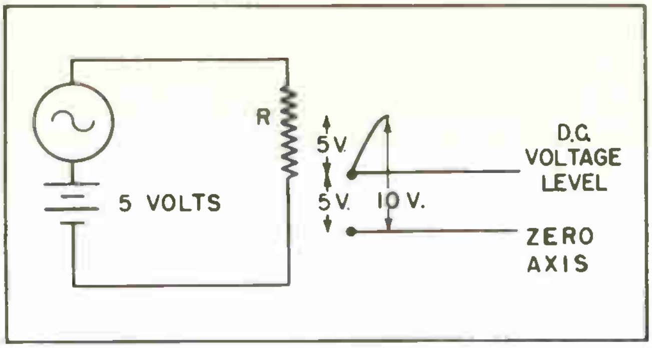

Fig. 16. Resultant voltage across resistor when both A-C and D-C voltages are applied.

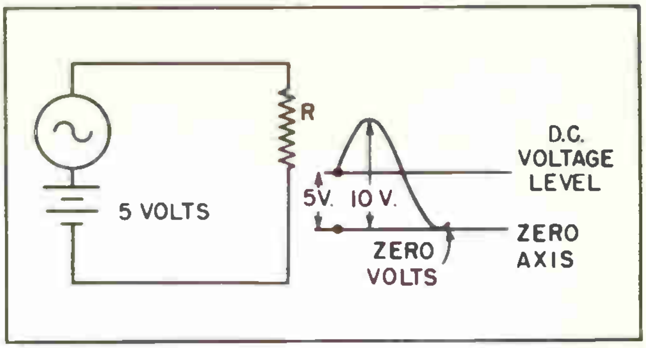

Fig. 18. When A-C voltage is maximum in negative direction it cancels D-C voltage.

varying amount in order to compensate for the varying heights of the pedestals, and thus line them up at a constant level.

In the early days of television, a circuit, called a D-C restorer circuit, was used to re-insert the necessary D-C component into the signal. The circuit was also commonly referred to as the *clamping* circuit.

Since the amount of D-C voltage needed varies with the brightness of the signal (which is the same as saying the varying height of the pedestal) the logical solution is to rectify a portion of the signal voltage itself, then use that rectified voltage as a bias on the grid of the final video amplifier tube. Then the D-C restorer circuit will keep all the pedestals lined up at a constant voltage level, a level which is just sufficient to bring them to the cut-off voltage level on the grid of the picture tube.

Section 10. USING GRID-LEAK BIAS AS THE D-C RESTORER

One of the most simple, and at the same time the most effective, methods of restoring the D-C component to the composite video signal is by means of the simple grid-leak bias. This method is quite similar to the old grid-leak detector which we studied in one of the earlier lessons.

Use of the grid-leak bias as the D-C restorer can be understood by first studying the diagram in Fig. 20. One important feature about such a circuit is there is no cathode bias, neither is there any fixed bias. By fixed bias we mean a bias fixed at some predetermined level by a battery, or by some negative voltage source.

What this means is that the grid is at the same potential as the cathode during any period when there is no signal on the grid. See Fig. 21. There will be zero bias. There will be no negative bias on the grid as is the normal custom in most vacuum tube circuits.

Now let's see what happens when an A-C signal is placed on the grid of the tube. Such a signal can be seen applied to the grid's normal zero voltage in the graph of Fig. 22.

You will note that the application of the A-C signal to the grid causes the grid to become alter-

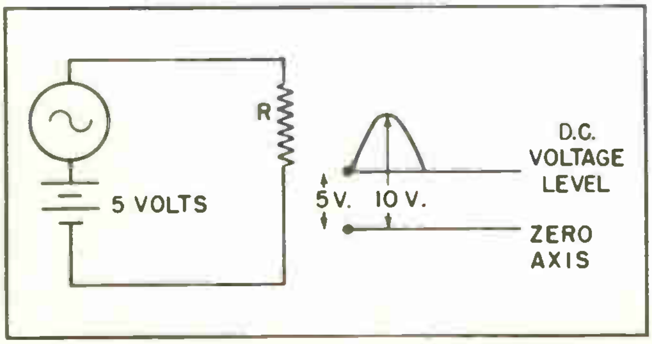

Fig. 17. With A-C voltage at zero the only voltage across resistor is D-C from battery.

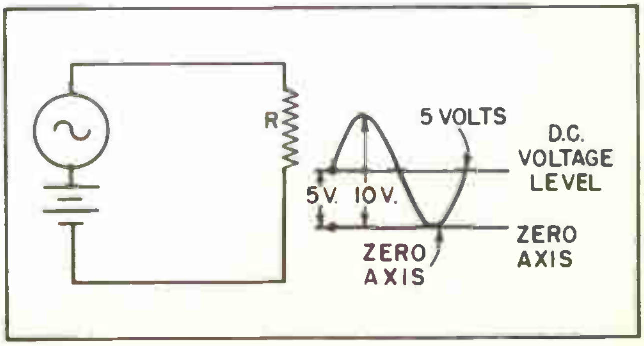

Fig. 19. Graph of complete A-C cycle superimposed on D-C voltage..

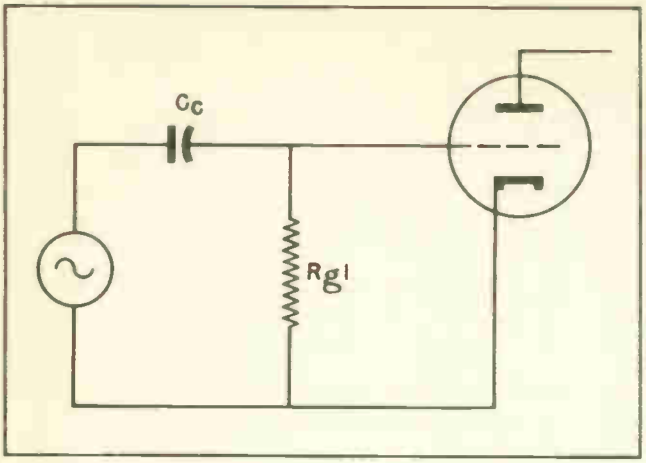

Fig. 20. Amplifier without cathode bias or fixed bias.

nately *positive* and then negative instead of being merely more or less *negative* as is the case when the A-C signal is superimposed upon a negative grid bias.

Whereas the negative bias on the grid of a vacuum tube prevents the grid going positive at any time under the influence of an A-C signal, the absence of such bias, as in the case of the circuit in Figs. 18 allows the grid to actually become positive under the influence of the positive half-cycles of the A-C signal. This means the grid becomes positive on each half-cycle of signal voltage.

In Fig. 23 we see what happens in such an unbiased circuit during the positive half-cycle of an A-C signal.

The grid becomes somewhat positive, the exact amount depending upon the strength of the signal. The grid, which is in the electron stream of the tube, attracts electrons. The electrons then become trapped. There is no escape for them except through the grid-leak resistor. The passage of the electrons through the resistor creates a voltage drop across resistor of such polarity as to make the grid more negative. The net effect of all this is that a negative bias is placed upon the grid of the tube — a grid-leak bias.

Another point should be noted. The strength of the negative bias is not constant. It will vary from instant to instant as the strength of the signal varies. If the signal is strong, strong enough to make the grid considerably positive, more electrons will be attracted to the grid. Then, as these additional electrons leak across the grid-leak resistor, a higher voltage is developed, and thus the bias made momentarily greater.

Fig. 24 shows how the bias across the coupling capacitor Cc automatically adjusts itself to fit the strength of the A-C signal. In the case of a video signal the bias automatically adjusts itself to fit the average-level of the signal amplitude.

The amount of the bias at all times is just that amount which barely allows the tips of the positive A-C signal to drive the grid slightly positive. It could not be otherwise.

The grid current should not be confused with plate current. Plate current can flow at all times, regardless of whether the grid is positive or negative. The effect of the voltage on the grid is to control the *amount* of the plate current flow, not necessarily to cut it off completely.

You will recall from your earlier studies of the vacuum tube that a steady negative voltage can be placed upon the grid of a tube without completely cutting off the plate current. In fact, it is customary to have such steady negative voltage present on the grid.

The grid-leak method of biasing can be used to operate a tube as Class A. as Class B or as Class C.

Class A, you will recall, is the method of biasing which places the operating point of the tube about

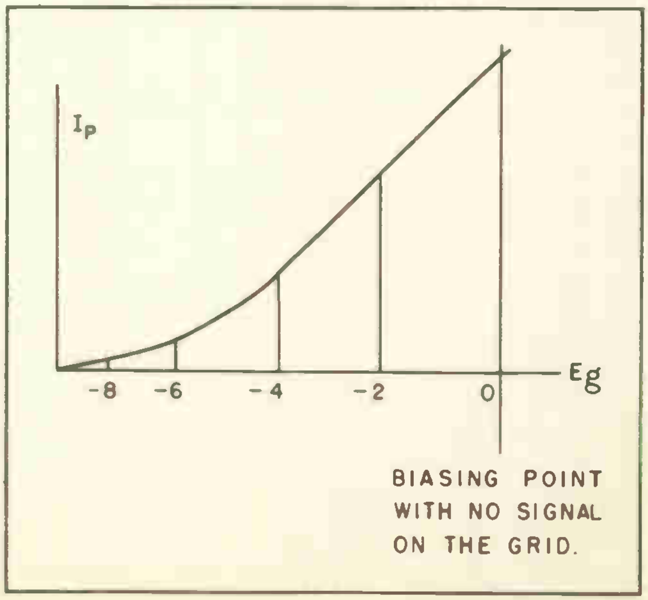

Fig. 21. Zero bias with no signal on grid.

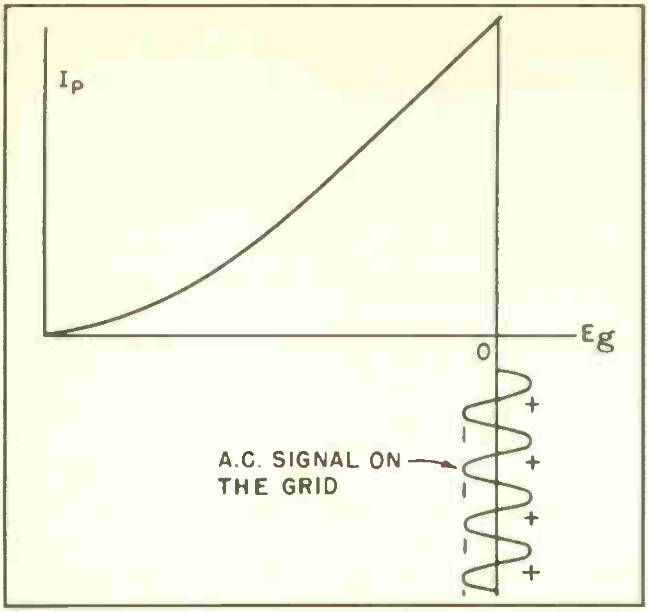

Fig. 22. Signal drives grid positive on the positive half-cycles when grid is unbiased.

midway on the linear part of the characteristic curve. Plate current flows at all times when a tube is biased for Class A operation.

In *Class B* operation the tube is so biased that little or no current will flow when there is no signal on the grid of the tube; in other words, the tube is biased at cut-off for Class B operation.

In *Class C* operation the tube is so biased that it takes a very strong signal for any plate current to flow at all. The grid is usually biased with such a strong negative bias in Class C operation that the negative voltage is far beyond cut-off. And as was mentioned earlier, and as is shown in Fig. 25, grid-leak bias can be used with any of the three classes of operation.

The amount of bias derived from the grid-leak has remained constant for each of the graphs shown in Fig. 25, but the plate voltage has been changed. In the graph for Class A operation we have full voltage applied to the plate of the tube. For Class B operation the plate voltage has been reduced somewhat. For Class C operation the plate voltage has been reduced still further.

The important point, however, is that the amount of grid bias voltage, with respect to the shape of the characteristic curve for that particular class of operation, is the determining feature in each instance.

Now let's see just how all this applies to the problem of restoring the D-C component to the video signal in a television receiver. We can see the signal being fed to the grid at the left side of Fig. 26. Note that the synchronizing tips of the composite video signal are the positive portion of the signal.

In Fig. 27 we can see how a video signal having various degrees of darkness or brightness will generate, through grid-leak bias, the necessary D-C voltage to keep the pedestals of the signals all lined up at the proper level.

The grid-leak method of D-C restoration is a negative restorer. This is because it inserts a D-C voltage that is negative with respect to the ground of the chassis. The video signal input must have a negative picture phase at this point if this method of restoration is to be used. This must be so in order for the synchronizing pulses to be the portions of the signal which drive the grid positive. If it were otherwise, the white portion of the signal would be clamped at zero grid voltage, and this is not desirable. It should be the synchronizing pulses which drive the grid positive.

The signal phase requirements for the use of grid-leak bias as the method of restoration is just opposite of the requirements for the grid of the picture tube. Positive signals on the picture tube grid tend to increase the brightness of the picture.

However, when the grid-bias method of D-C reinsertion is used it must be used on the last amplifier stage preceding the picture tube. The 180° phase inversion which results in the amplifier

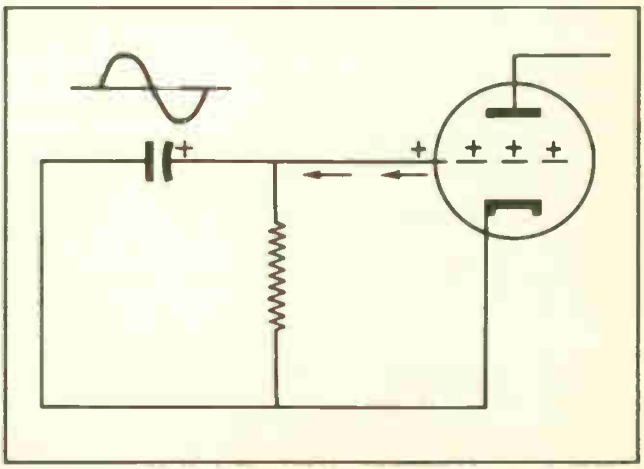

Fig. 23. Positive voltages on grid each half-cycle causes grid to attract electrons.

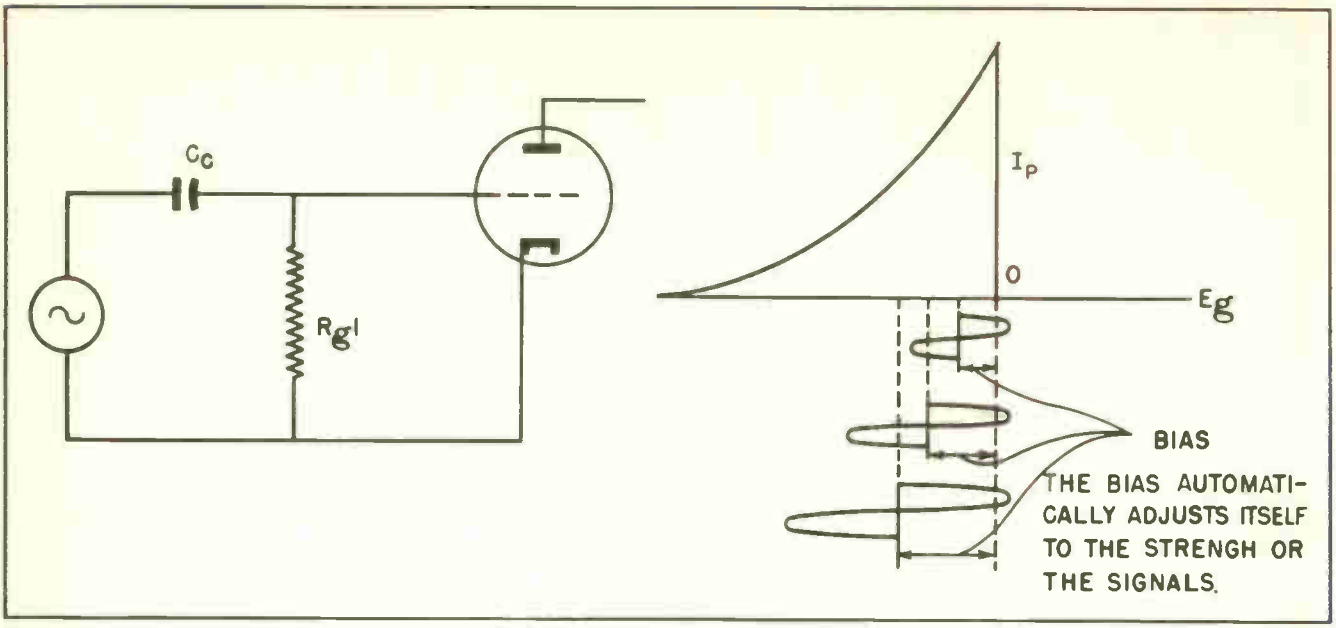

Fig. 24. Grid-bias voltage varies as A-C signal voltage varies in amplitude.

stage inverts the phase of the signal, and thus makes it suitable for application to the grid of the picture tube.

It should be noted, however, that direct coupling must be employed between the final video amplifier and the grid of the picture tube. Should an attempt be made to use resistance/capacitance coupling, the D-C component would be lost again.

Section 11. DIODE RESTORATION

A simple diode, such as one of the sections of the 6H6 or 6AL5, or one of the diode sections of the 6SQ7 or the 12SQ7, can be used as the D-C restorer. Such diode would function in almost exactly the same way as the grid-leak restorer, but applies the restored voltage somewhat differently.

Fig. 28 shows the essential elements of a diode D-C restorer which inserts a negative D-C voltage in the same manner as the grid-leak bias restorer described in the preceding section.

The resistor *R* is in series with the input video signal. The action of the diode rectifier is such as to provide the insertion of the proper amount of D-C in the video signal. The video signal, together with its re-inserted D-C component, will

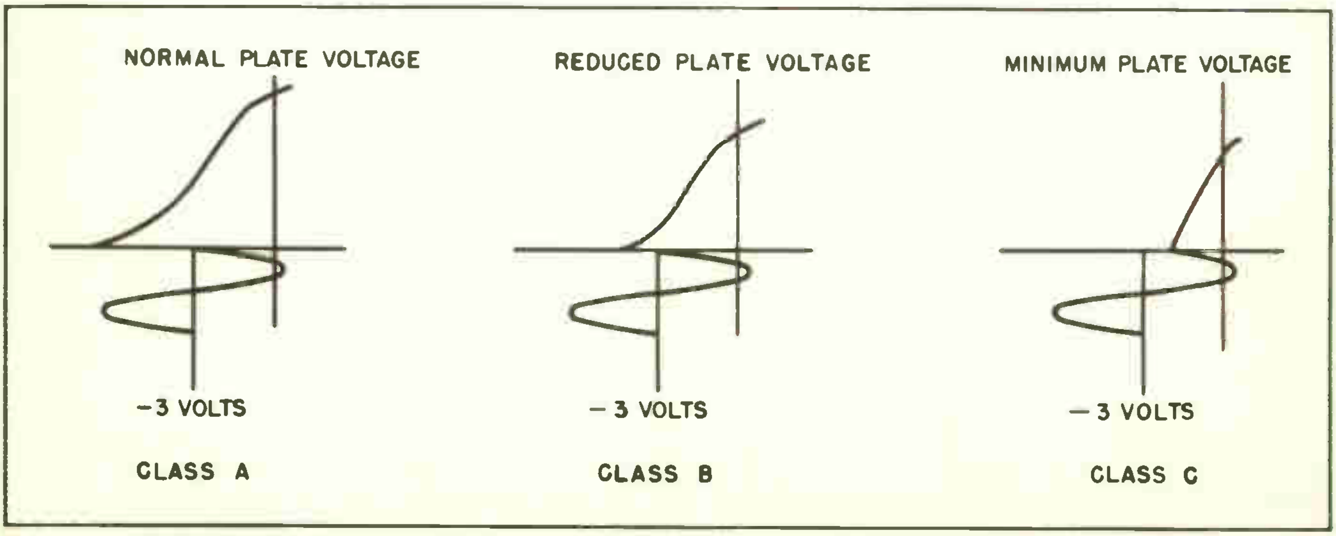

Fig. 25. Biasing for different classes of operation.

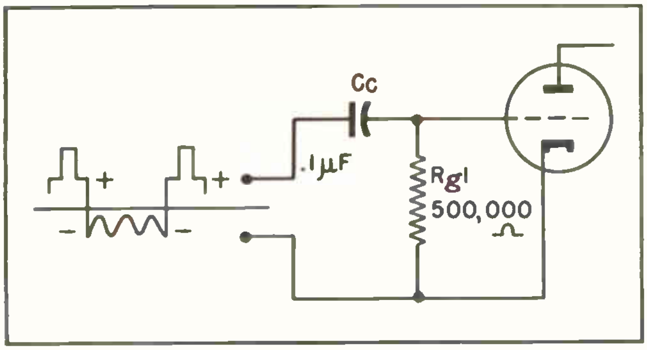

Fig. 26. Applying video signal to grid-leak biased tube.

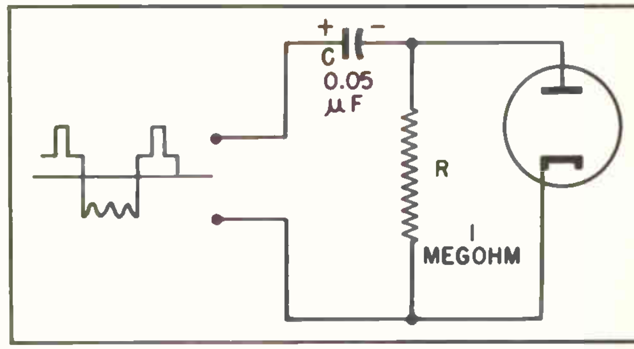

Fig. 28. Diode restorer connected for negative voltage re-insertion.

then appear across the risistor *R*. It can then be fed directly to the grid of the picture tube.

Sometimes it is more desirable to insert a positive D-C voltage. A circuit which can reinsert the D-C voltage in the form of a positive voltage is shown in the diagram of Fig. 29. You will note that the signal which is fed into the circuit has an opposite phase from the one fed into the circuit of Fig. 28. You will also see that the diode tube has been inverted. But the signal will be tapped off across the resistor, and can then be applied directly to the grid of the picture tube.

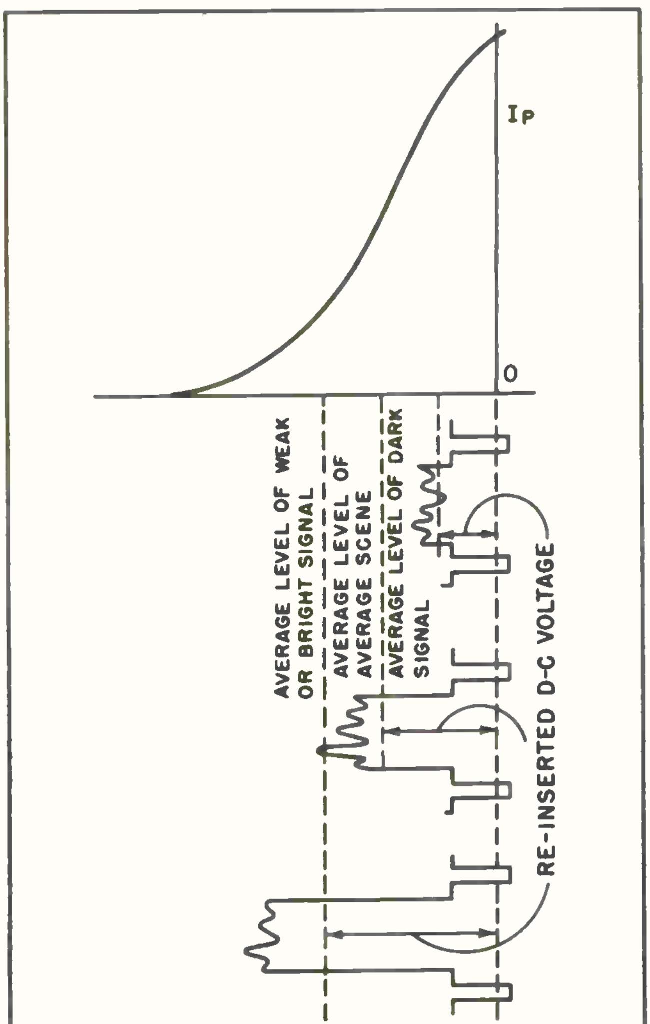

Fig. 27. Effect of varying video signals on grid-leak biased tube.

Section 12. RE-INSERTION VOLTAGE AND BRIGHTNESS CONTROL

A D-C restorer circuit, used in conjunction with a manual brightness control, provides the necessary facilities for controlling the brightness on the screen of a television picture tube.

Normally, the manual control is set so a bias voltage is applied to the grid of the picture tube, even though there is no video signal input into the grid of the tube. This is done by applying a positive voltage to the cathode. Then, when the contrast control is turned up for the desired amount of contrast, the D-C restorer automatically provides the positive D-C voltage necessary to reduce the negative picture tube bias voltage by exactly the right amount to make the pedestals line up at the cut-off value of the tube.

The result of the inserted D-C voltage upon the appearance of the picture can be better understood by studying Fig. 30. This is what could be called an automatic brightness circuit, but what it amounts to is the re-insertion of the D-C component.

The entire operation of the circuit is automatic. For a dark frame there is relatively little swing in the A-C video signal voltage. Thus the bias is not far from cut-off. The pedestal voltage can then easily drive the grid voltage to cut-off.

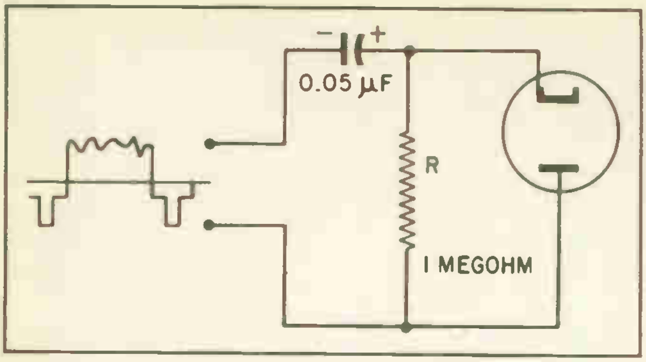

Fig. 29. Diode connected for positive voltage re-insertion.

For a video input signal which has a wider swing, that is, for one having a higher brightness level, the negative voltage must be reduced by a greater amount. The action of the D-C restorer is such as to provide the extra voltage needed for this purpose.

It can be readily understood that the polarity of such a D-C restorer must be such as to provide a positive voltage, since it is to be applied directly to the grid of the picture tube. This, then, calls for a positive restorer, such as the one in Fig. 29.

Section 13. RESTORER CIRCUIT USING GRID-LEAK BIAS

The full circuit of the final video amplifier stage, and its connection with the picture tube, is shown in Fig. 31. This is the type of circuit which would be used with a grid-leak bias D-C restorer circuit.

The peaking coils in the coupling circuit have relatively little D-C resistance. The coupling must be direct to avoid losing the D-C component after it has been re-inserted in the output stage of the amplifier.

A few calculations will show the relative voltages at the various elements of the circuit. We can take 25 milliamperes as being the probable plate current from the 6V6 when there is no signal on the grid of that tube. There will be a voltage drop of 100 volts as the current flows across the 4000 ohm load resistor. This means there will be 200 positive volts applied to the plate of the 6V6 tube. Since the grid of the picture tube is directly connected to the plate of the 6V6 tube it also means there will be 200 positive volts on the grid of the picture tube.

Assuming the picture tube is a type which requires about 50 negative volts on the grid, with respect to the cathode, to cut-off the electron beam, it means that the cathode of the picture tube must be 50 volts more positive than the grid. The manual brightness control can be set so that it can be brought up to 300 volts positive with respect to ground. By making it just 250 volts positive with respect to ground means that the cathode will be 50 volts more positive than the grid. This is the same as saying the grid is 50 volts negative with respect to the cathode.

When an A-C video signal is impressed on the grid of the 6V6 tube the grid-leak bias circuit of that tube provides a bias voltage proportional to the A-C swing of the video signal. This reduces the current through the 6V6, and that through the

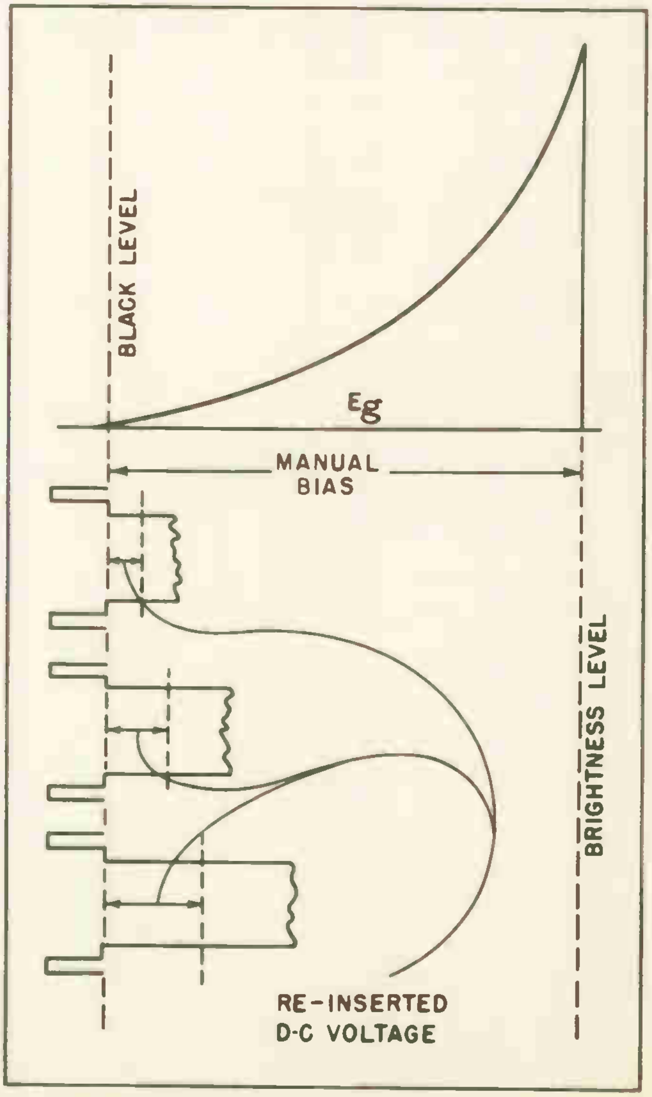

Fig. 30. Pedestal heights kept at same level by D-C re-insertion.

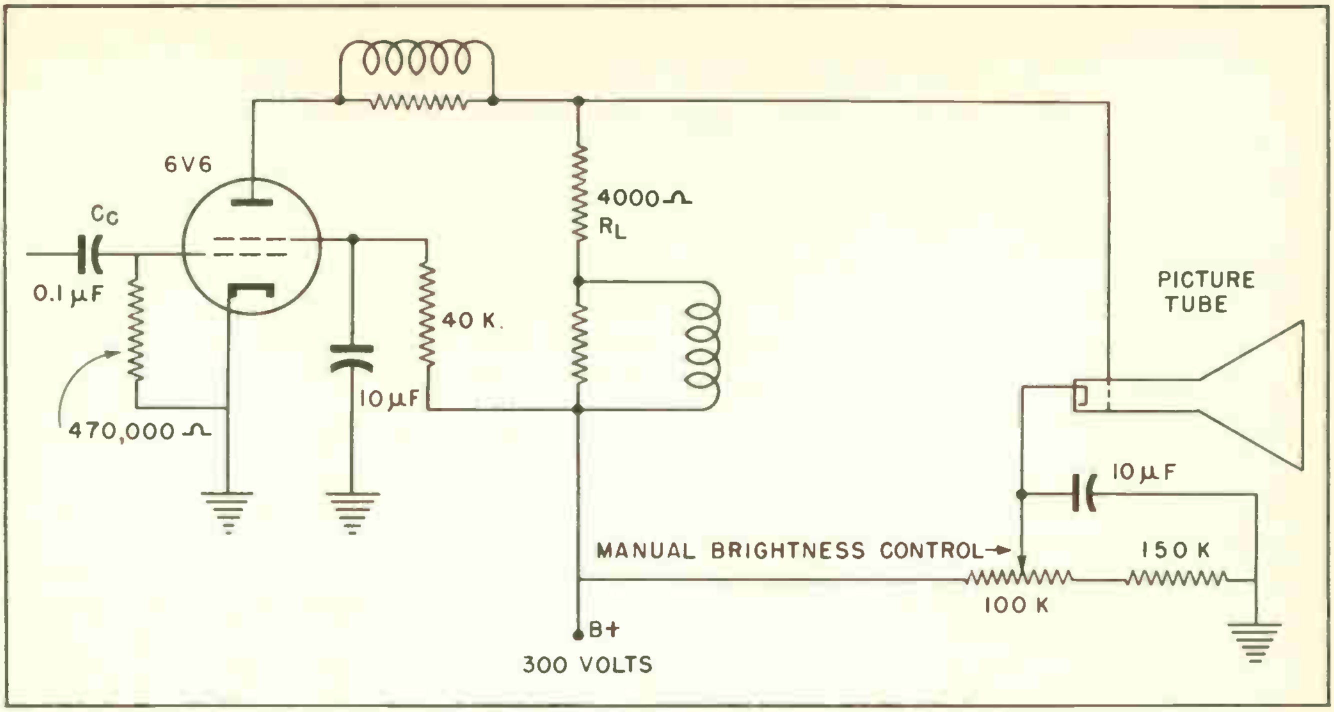

Fig. 31. Coupling between grid-biased video amplifier and picture tube.

4000 ohm load resistor. The voltage on the plate of the 6V6 will rise, so will that on the grid of the picture tube.

There is one disadvantage of using a directly coupled circuit with grid-leak bias. If, for any reason, the grid-leak bias fails, the voltage on the grid of the picture tube may become too positive. This could result in an electron beam current so heavy it would damage the screen of the tube. It is because of this that this type of restorer circuit has rarely been used in practical commercial receivers.

Section 14. DIODE RESTORER CIRCUIT

The full circuit of a diode restorer circuit coupled directly to the picture tube is shown in Fig. 32.

The video signal, which is developed across R_L, is applied to the D-C restorer circuit consisting of R_1, R_2, and C_1. It is also applied to one-half the 6H6 duodiode rectifier tube.

The reason for making the connection from the restorer circuit to the plate circuit of the 6AC7 is so the capacitances in the restorer circuit will not be in shunt with the output load impedance of the 6AC7 tube.

Resistor R_3, the 470,000 ohm resistor, serves to couple the D-C restorer circuit directly to the picture tube grid, and also isolates the diode's shunt capacitance from the video amplifier.

Additional isolation is provided by resistor R_2. R_2 is only 10,000 ohms. It should be large enough to isolate the shunt capacitances, yet not so large as to place too much impedance in the path of the signal being fed to the diode rectifier tube.

With the required positive picture phase for the signal being applied to the grid of the picture tube, the negative synchronizing pulses act to drive the cathode of the diode tube quite negative with respect to its plate. This will allow C_1 to charge to a voltage proportional to the negative swing.

The D-C voltage, which is thus inserted into the signal, is in series with the A-C across resistor R_1. The restored output across R_1 is directly coupled to the picture tube grid. The re-inserted D-C component can then reduce the fixed negative bias which has been previously set by the manually controlled brightness control. The result is that the pedestals will then all line up at the same level.

A disadvantage of the diode restorer circuit is that it requires an additional tube, but it does not

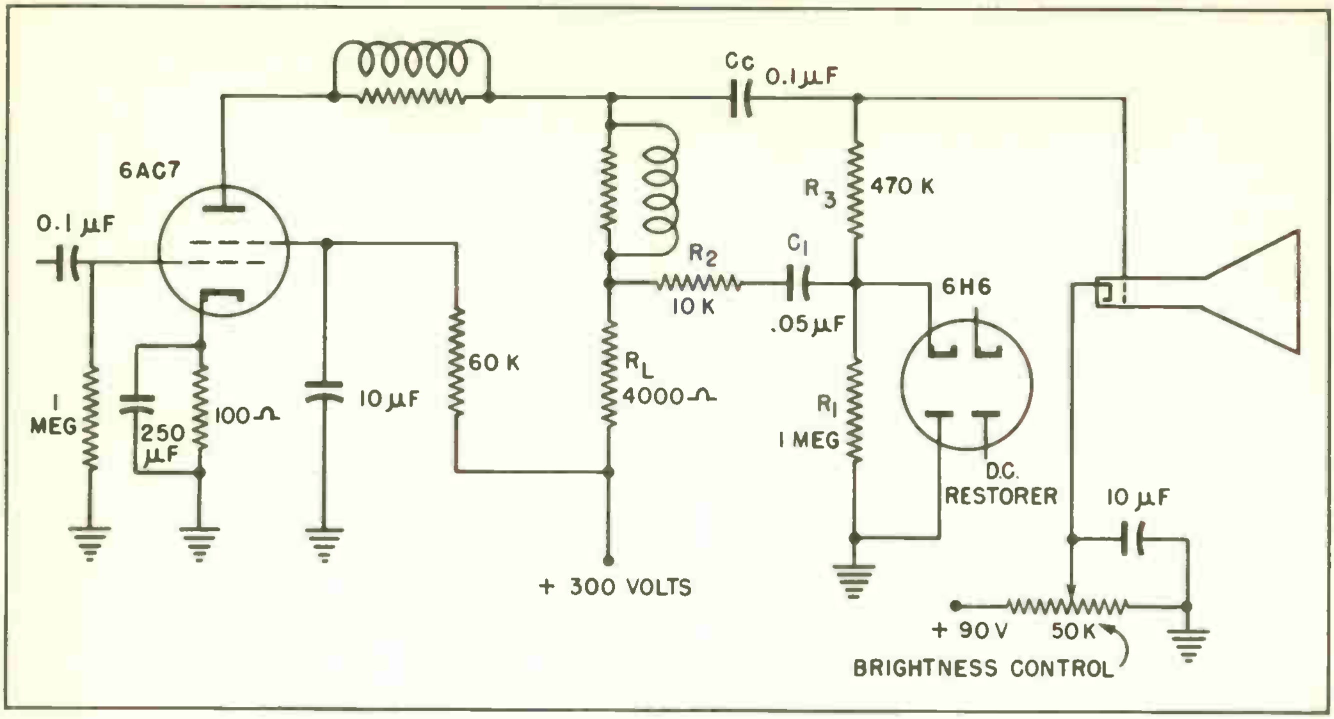

Fig. 32. Coupling to picture tube when diode restorer is used.

have the drawback of the grid-leak bias restorer. Since the grid of the picture tube is not directly connected to the B+ voltage of the power supply, there is no danger of damaging the picture tube in case of failure of the video signal. Further than this, the D-C restoration follows the changes in signal swing more closely and there is a wider choice of the time constant of the components in the circuit.

Section 15. D-C RESTORER COMBINED WITH SYNC SEPARATOR CIRCUIT

In an effort to conserve or reduce the number of tubes in a television chassis, and still avoid the dangers a grid-leak bias type of restorer, a circuit was designed somewhat differently from any of those we have described.

It combined the necessities of a D-C restorer circuit with those of the sync separator circuit.

We have not yet gone into the details of the sync separator circuit. Essentially it consists of an amplifier with low voltage on the anode which permits it to reach saturation quickly.

The essentials of such a combined circuit is shown in Fig. 33. The tube used for that purpose is shown to be one-half of a 12AU7. This is the tube most frequently used for that purpose, but other tubes can be used. The 12AU7 is a twin-triode of the miniature type, which possesses many of the characteristics of the 6SN7, and is similar to it in most respects.

In action, a very low positive voltage is placed on the anode of the tube, often not exceeding 15 positive volts. Sometimes the positive voltage is even lower than that.

Very often the normal voltage on the *cathode* is slightly positive. This is not because a positive voltage is deliberately placed on the cathode; instead, it results from the fact that at intervals pulses of electrons pass through the tube, and after they have left the cathode it becomes slightly positive.

It can be seen there is a direct electrical connection between the cathode of the restorer tube and the control grid of the picture tube. This is true despite the fact a 4700-ohm resistor and an 820K resistor are in the circuit between these two tubes.

Any voltages developed on the elements of either tube automatically affect the other.

The video signal is fed to the control grid of

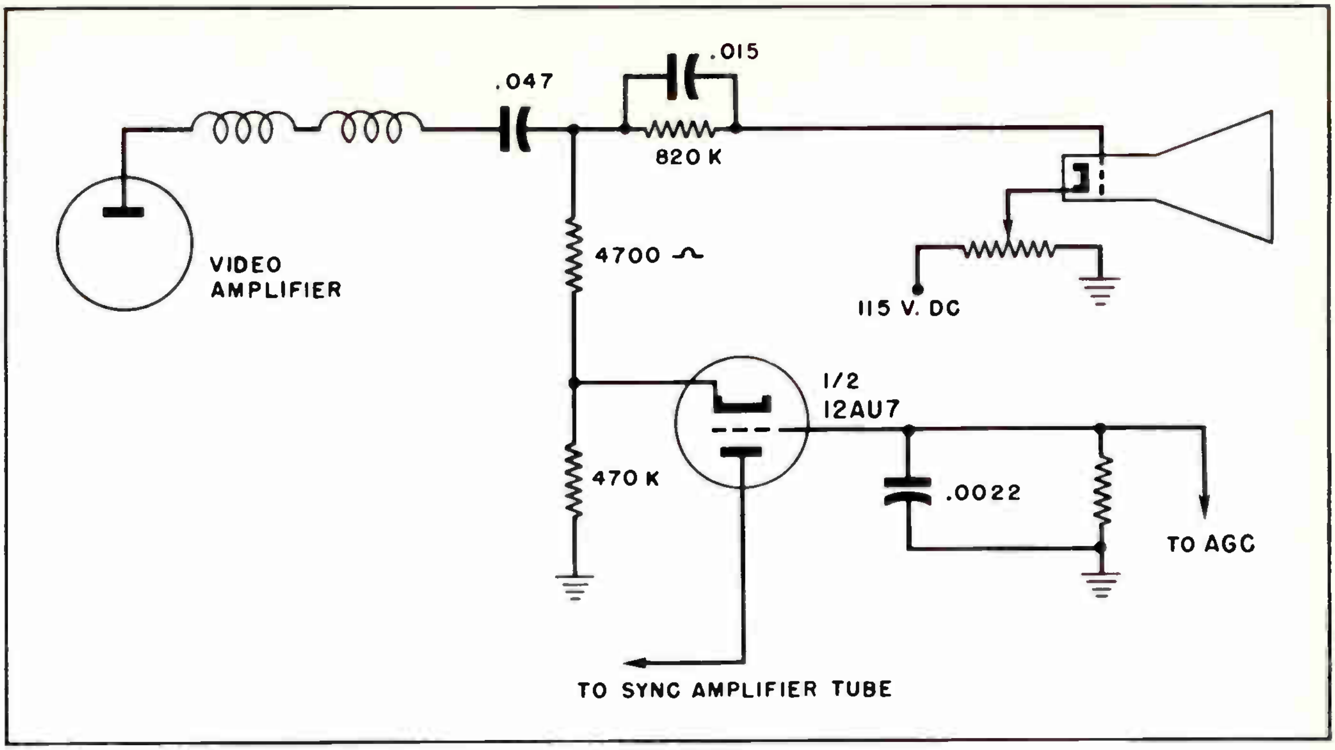

Fig. 33. D-C restorer combined with sync separator.

the picture tube from the anode of the video amplifier. Passage of D-C between these two tubes is prevented by the presence of the .047 mfd. coupling capacitor. The handling of the video signal in the circuits is such that the blanking pulses in the composite video signal place a strong negative voltage on the control grid of the picture tube to blank out the picture, and the stronger negative voltage of the sync pulses ride along on top of the blanking pulses.

The point is, the phasing of the video signal at this point is such that the sync pulses are the most negative portions of it.

The negative pulses which are applied to the picture tube are also applied to the cathode of the restorer-separator tube.

Those negative pulses placed on the cathode of that tube momentarily make the cathode very much more negative than the anode. This has the same effect as placing a momentary positive voltage on the anode of the tube. The net result is that the tube passes a pulse of current.

Passing of that pulse of current does two things. It sends a voltage pulse to the sync amplifier circuit. But after the pulse of current ceases to flow through the tube it makes the cathode more positive than it was a moment before.

This positive voltage on the cathode prevents passage of any more current through the tube until the arrival of another synchronizing voltage pulse. It also serves to make the grid of the picture tube slightly more positive than it would otherwise be.

The amount of positive voltage placed on the control grid of the picture tube depends on the amplitude of the sync pulses applied to the cathode of the restorer-separator tube. Thus, the action is precisely the same as that of the diode restorer tube in Fig. 29.

This circuit was widely used by RCA, and can be found in many of their receivers. It was also used by many other manufacturers who operate under RCA licenses.

The circuit, however, had one defect which sometimes caused considerable trouble. Sometimes the control grid of a picture tube tends to become slightly emissive. This occurs when some of the emissive materials used to coat the cathode happen to get on the control grid. This is not an unusual condition in picture tube guns, because of the peculiar nature of the construction of those elements in a picture tube.

A study of the circuit in Fig. 33 may disclose what happens when that occurs. Emission from the control grid of a picture tube, even though that emission is at very low level, causes the grid to become progressively more positive. This is accounted for by the manner in which the control grid is isolated from ground.

Presence of that positive voltage on the control grid of the picture tube brings about an increase of the brightness on the screen, and usually that brightness cannot be controlled by the brightness control. The control grid becomes positive with respect to the cathode, regardless of how the brightness control is adjusted.

Even more serious, the positive voltage developed on the control grid, due to the emission occurring there, places an increasingly positive voltage on the cathode of the 12AU7 restorer-separator tube.

The positive voltage on that cathode does not have to become very high before it is too high for the sync pulses to affect it. This is because the magnitude of the negative sync pulses is not great enough to overcome the positive voltage on the cathode of the restorer-separator tube. As a result, pulses of current can no longer pass through that tube. Even so, emission from the picture grid may make the grid — and the restorer cathode — as much as 50 volts more positive than normal.

When those pulses fail to get through the restorer-separator tube the pulses are no longer able to reach the sync amplifier tube. When this happens synchronization fails, and it becomes impossible to lock the sync circuits of the receiver with the sync circuits of the transmitter.

Usually the only remedy is to replace the picture tube with a new one. This has to be done despite the fact that the only defect in the tube is a slightly emissive grid.

Section 16 VIDEO SIGNAL VOLTAGES AFTER INVERSION

In the early days of television the composite video signal was always applied to the picture tube by injecting it on the grid. This was only natural, since electrical signals of all kinds have always been applied to the control grids of amplifier tubes.

From the various discussions in this lesson, it should be clear to you that when that is done it is necessary to apply some type of D-C re-insertion voltage so as to maintain the proper background level for the picture. And so it is.

By the very nature of things, it requires a heavy negative voltage on the control grid of a picture tube to blank out the picture. A lesser negative voltage permits varying amounts of electrons to pass through to the tube to strike the screen, and thus reproduce the picture.

All of which means that relatively low negative voltages — on the order of 5 to 35 negative volts — permit varying amounts of electrons to strike the screen, and thus create a picture. But an ad-

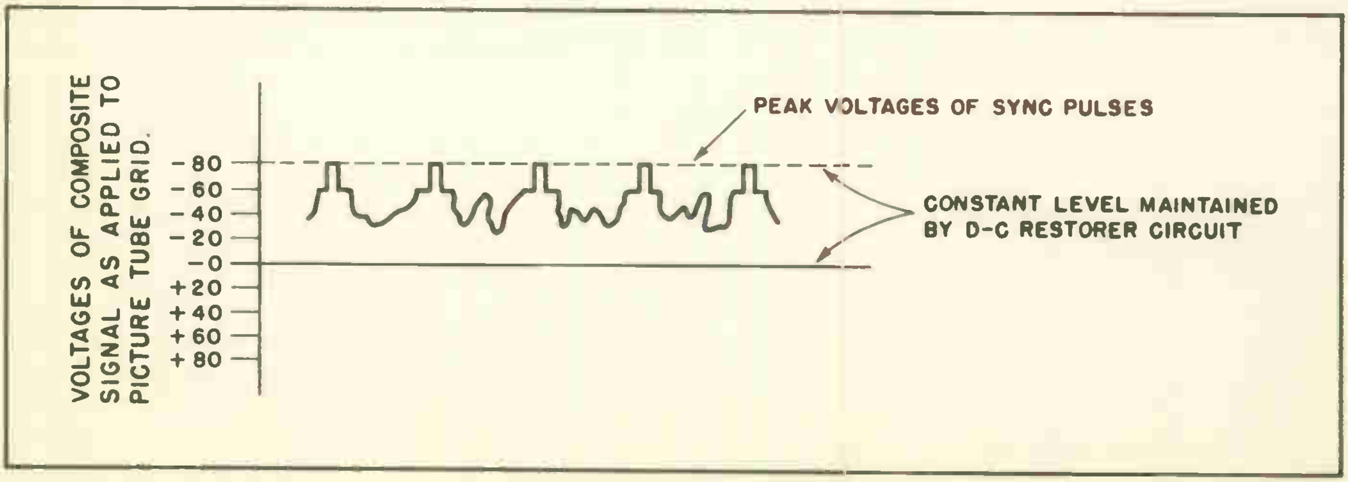

Fig. 34. Approximate voltages applied to control grid of typical picture tube.

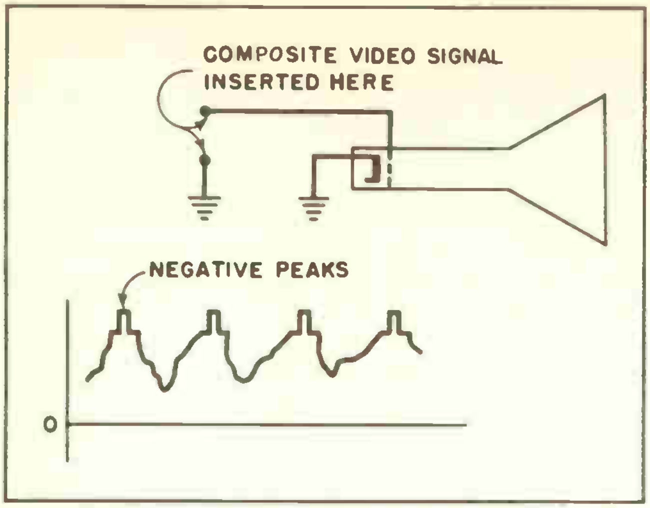

Fig. 35. When composite signal is applied to control grid its polarity must be such that peaks of sync pulses are most negative.

The composite signal which has been graphed in Fig. 34 is typical of such signals when they reach the control grid of a picture tube. There will be some variations in the exact voltages from one tube to another; some may be somewhat higher, others somewhat lower. But the voltages mentioned are reasonably typical.

For all practical purposes that signal is applied to the control grid in such manner that it is between the grid and ground. And, since the cathode is normally connected to ground, this means the signal is applied so that it is between grid and cathode. This is shown in Fig. 35.

The polarity of the signal must be such that the most negative part of the signal applied to the grid represents the peaks of the sync pulses.

ditional negative voltage — say on the order of 50 to 60 volts — is used to blank out the beam, and thus blank the screen.

This means the voltages used to reproduce the picture are lower amplitude voltages than those used to blank the screen, and of lower amplitude than those used to carry the synchronization information. Which is merely another way of saying that the blanking and sync pulses represent the highest amplitude portion of the composite video signal. Approximate voltages of a typical composite video signal at the time it is applied to the picture tube control grid are shown in Fig. 34.

These things are not new to you. We have mentioned them many times since first introducing you to the composite video signal.

This matter of polarity is important when handling the composite video signal. The video signal, like any other signal applied to a vacuum tube, is subjected to 180° phase reversal every time it passes through a vacuum amplifier.

The graphs in Fig. 36 make this matter of phase reversal somewhat more clear than words alone can do. It can be seen that the composite signal is applied to the grid of the amplifier tube with a polarity which would be proper for direct application to the control grid of a picture tube. But, after passing through the video amplifier the phase of the signal has been completely reversed, or inverted.

Instead of the sync pulse peaks of the amplified signal being the peak amplitude of the signal, they are actually the lowest level of amplification after the signal has passed through the video

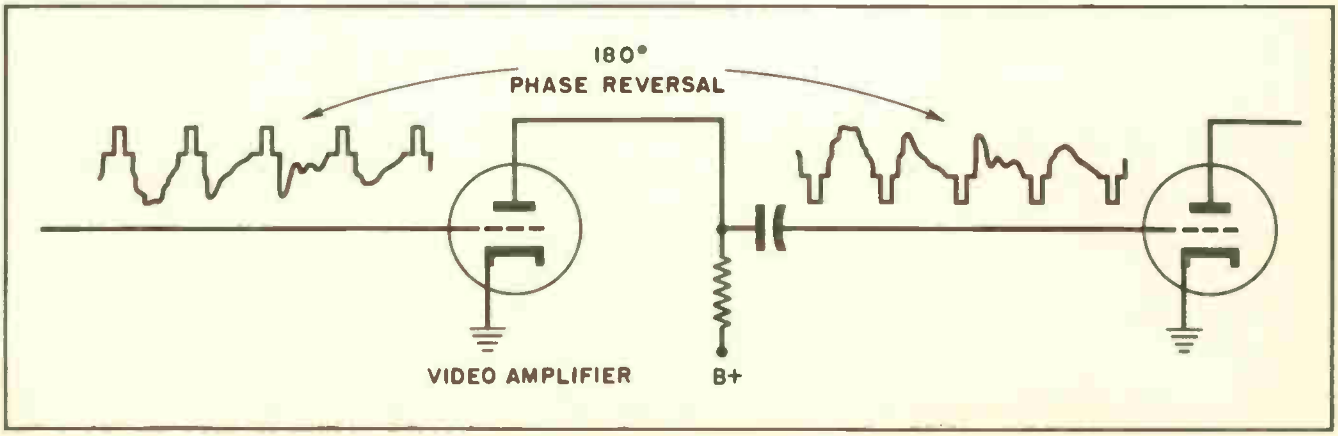

Fig. 36. Phase of video signal is reversed 180° each stage of amplification.

amplifier. Furthermore, the polarity of all the picture information in the camera signal has also been reversed, or inverted. Those voltages which normally represent white picture elements now represent black picture elements. And those which should represent black picture elements now represent white ones.

It is quite obvious that the polarity of the signal at the output of the video amplifier is such that it cannot possibly be applied to the control grid of a picture tube.

Section 17. APPLYING INVERTED VIDEO SIGNAL TO PICTURE TUBE

Reversal of the polarity opens up the possibility the signal might be applied to the picture tube in some other manner. There is the possibility of applying the signal to the cathode rather than to the control grid.

It is well recognized that applying a voltage to the cathode of a vacuum tube in such manner so the cathode is made increasingly positive with respect to the grid has exactly the same effect as applying an equivalent negative voltage to the control grid. This is demonstrated in crude form by the elementary diagrams in Fig. 37.

Of course, the opposite is also true. Applying a negative voltage to the cathode has exactly the same effect as applying a positive voltage to the control grid.

Applying a signal like the one in Fig. 34 to the grid of the left-hand tube in Fig. 37 would produce a result exactly the same as that produced by applying a signal like the one in Fig. 38 to the cathode of the tube at the right in Fig. 37.

A study of the graph in Fig. 38 discloses it is the same signal as that graphed in Fig. 34, except the polarity has been reversed. Instead of the peaks of the sync pulses being the peak amplitude voltages, as in Fig. 34, they represent the lowest levels of amplification in the graph of Fig. 38.

One very interesting thing about the signal graphed in Fig. 38 is that the sync peaks *line up with equal amplitude.* Although they represent the lowest level of amplification, they are all *equally* low.

This might be said in another way. Every other voltage of the composite video signal has a higher degree of amplification than the peaks of the sync pulses.

Section 18. D-C RE-INSERTION NOT NEEDED WITH CATHODE MODULATION

One very significant thing about this is that variations in the levels of the camera signal no longer affect the line-up of the sync pulse peaks. They all retain exactly the same amplitude regardless of the content of the camera video signal.

All other levels of voltages in the composite video signal can now be referred against the peaks of the sync pulses, instead of the peaks of the sync pulses being referred against the camera signal, as was true in Figs. 10, 11, and 12.

The point we are leading up to with this explanation is this: if the composite video signal

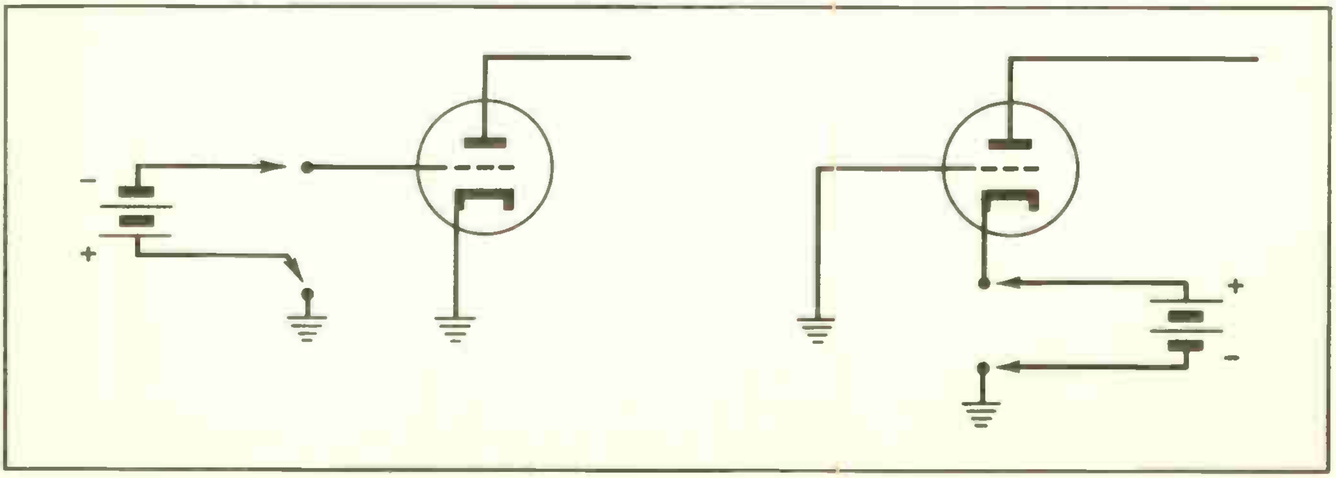

Fig. 37. Applying a positive voltage to cathode has same effect as applying negative voltage to grid.

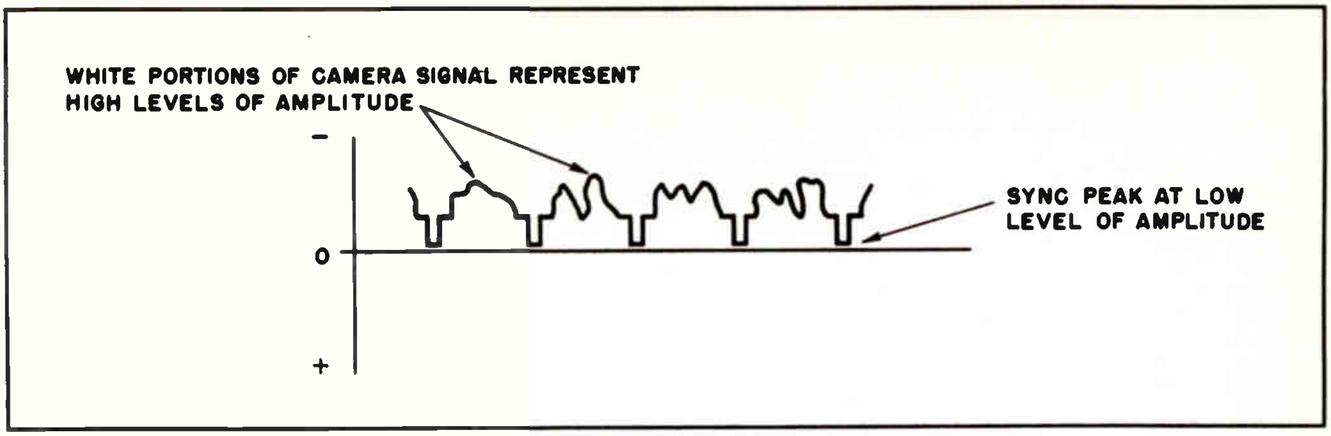

Fig. 38. Reversed video signal with peaks of sync pulses representing lowest level of modulation.

could be applied to the picture tube while it has the polarity shown in Fig. 38 it would not be necessary to re-insert the D-C component. The signal would take care of that automatically, since the peaks of the sync pulses represent a stabilized level for the entire signal.

Section 19. PRACTICAL CIRCUIT EMPLOYING CATHODE MODULATION OF PICTURE TUBE

Becoming aware of the advantages which would follow application of the composite video signal to the cathode of the picture tube, rather than to the control grid, engineers began efforts to design a circuit which would permit that type of operation. The circuit shown in Fig. 39 is one that is widely used by TV receiver manufacturers.

The circuit shown in Fig. 39 can be considered typical; but actual coupling circuits used in commercial TV receivers may vary in minor details.

This circuit shows the brightness control consisting of a 5-megohm potentiometer. Some manufacturers use other values of resistance for that purpose.

This circuit shows the brightness control tied to the 140-volt B+. Some manufacturers tie it to other values of B+ voltage, and find they have to use other values of resistance.

Most circuits include a fixed resistor between the potentiometer and ground. This acts as a fixed bias to prevent the positive voltage on the cathode dropping too low. If the voltage on the cathode drops too low it creates the danger of permitting too strong a beam to strike the screen; a beam so strong it might possibly ruin the screen.

In this circuit the demodulated signal from the video detector is fed to the 6AH6 video amplifier tube. The action of the tube amplifies the video signal, and makes it stronger.

But the action of the video amplifier also reverses the phase, or, to use another expression, inverts the signal.

The amplified video signal passes through the .1 mfd. coupling capacitor into the cathode circuit of the picture tube. The signal is applied directly to the cathode.

Since the control grid is tied directly to ground, the action of feeding the signal to the cathode has the effect of causing the voltage on the cathode to swing more or less positive with reference to the voltage on the control grid.

Causing the cathode voltage to swing up and down with reference to the control grid has the same effect on the electron beam as causing the voltage on the control grid to swing up and down with reference to the cathode. Swings in the cathode voltage which cause the cathode to become less positive have the same effect as voltage swings on the control grid which would cause it to become more negative.

The reverse is also true. Voltage swings on the cathode which cause it to go more positive have the same effect on the beam as a voltage swing on the control grid which makes it more negative.

Carrying this analysis a little further we can

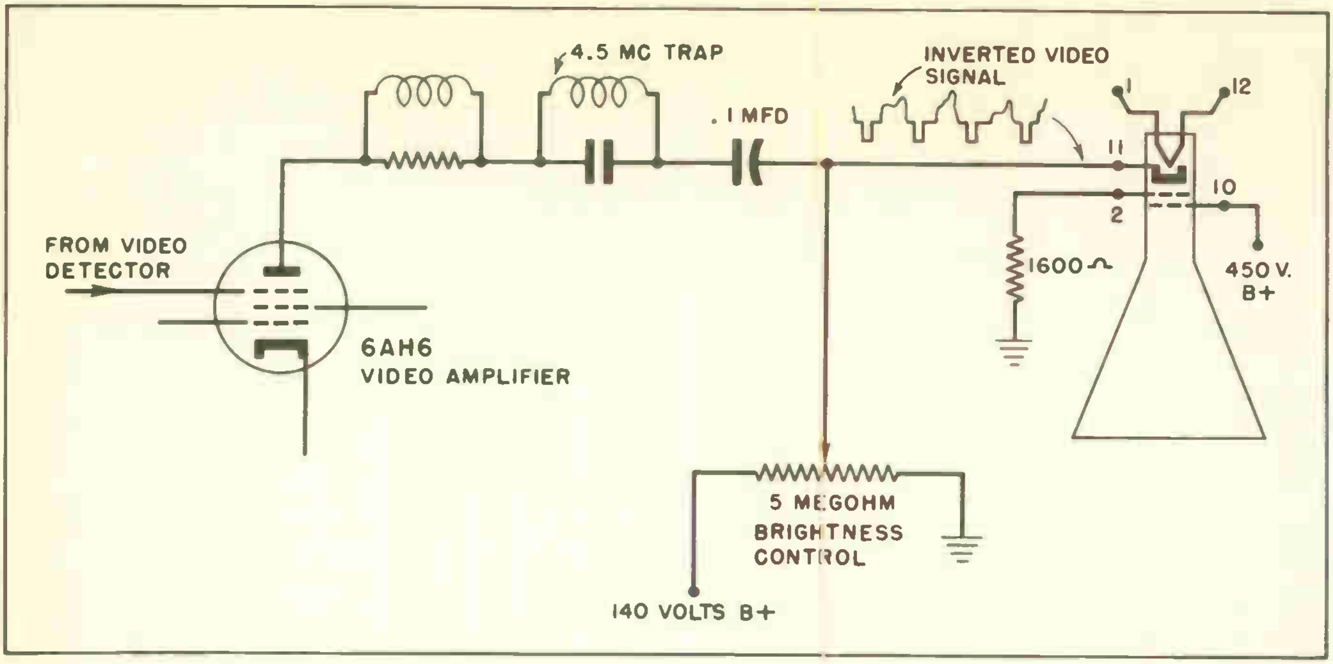

Fig. 39. Circuit used to apply composite video signal to cathode of picture tube.

apply it to the voltage graph of a video signal in Fig. 38. The peaks of the sync pulses are the *least negative* portions of the video signal. This means that when the peak of a sync pulse is present the video signal is applying the least amount of negative voltage to the cathode of the picture tube. At that instant the full positive voltage established by the brightness control is applied to the cathode.

The full positive voltage on the cathode makes the cathode so positive with respect to the control grid — or the control grid so negative with respect to the cathode — that the electron beam is blanked out. That blanks the pattern from the screen. In the normal course, the blanking pulse, which arrives immediately ahead of the sync pulse, does the actual blanking, but the sync pulse creates an even greater voltage difference between the cathode and control grid. In any event, the electron beam is blanked during the sync pulse.

At the other extreme are the actions of the voltages which represent the camera signal. The peak amplitudes of the camera signal in Fig. 38 represent those conditions in which the pattern on the screen is most bright. The electrical action is such that the higher amplitude of signal voltage places a higher negative voltage on the cathode of the picture tube. That higher negative voltage partially cancels the normal positive voltage on the cathode, making the cathode less positive.

Making the cathode less positive is precisely the same as making the control grid less negative. The result is that the electron beam will contain more electrons, and the pattern on the screen becomes brighter.

Varying degrees of voltage in the signal causes varying voltage conditions between the cathode and control grid. Making the cathode more positive reduces the strength of the electron beam, thus making the screen darker. Making the cathode less positive increases the strength of the beam, and creates brighter areas on the screen.

This method of feeding the video signal to the picture tube — which is sometimes called *cathode modulation* — is being used in increasingly larger numbers of receivers. At the rate it is being adopted by designers there is a strong possibility it will eventually be used on all receivers.

Advantages of this circuit are many. Since the control grid is tied directly to ground, or B−, any possible grid emission has no serious effect on the action of the picture tube. Usually they have no effect at all. Emitted electrons are immediately replaced from B−.

Picture tubes which have so much grid emission as to be unfit for use in circuits like that in Fig. 32, where the signal is fed to the grid, can be readily used in circuits like those shown in Fig.

39. In plain words, grid emission is not important when the picture tube is used in a circuit like that in Fig. 39.

Use of this circuit eliminates the need for special circuits to restore the D-C component in the video signal. This results in material simplification of the receiver circuits.

Use of this circuit also makes it possible to reduce the number of stages of video amplification. Since video amplifier circuits were often the source of major troubles in earlier TV models this is a distinct advantage. Some television receivers feed the video signal directly from the video detector to the cathode of the picture tube without additional video amplification. Few modern TV receivers employ more than one stage of video amplification. This is in definite contrast to the circuits of earlier models where it was commonplace to employ as many as three stages of video amplification.

NOTES FOR REFERENCE

The composite video signal has a varying amplitude. Thus, it is A-C in form, but it is not symmetrical.

The brightness control is used to adjust the average background brightness of the pattern on the screen. It should be adjusted so the level of the blanking pedestal is just at the cut-off point of the picture tube.

The electrical function of the brightness control is to set the operating negative bias on the control grid of the picture tube.

In most receivers the action of the brightness control serves to control the amount of positive voltage on the cathode of the picture tube.

If the brightness control is set too high the picture appears "washed out." It is too thin, and has little contrast.

Setting the brightness control at too high a level often causes the vertical retrace lines to become visible on the screen.

Vertical retrace lines slant diagonally upward from lower left hand corner of screen.

It is impossible for the D-C component of the composite video signal to pass through coupling capacitors.

Whenever the composite video signal is applied to the control grid of a picture tube it is necessary for the D-C component to be re-inserted in the signal.

The D-C component should be such as to maintain the pedestal level at approximately 75% of the maximum amplitude of the signal.

The pedestal level voltage should correspond to the cut-off point for the picture tube.

Grid-leak bias can be used to restore the D-C component, but this method is seldom used.

Grid-leak biasing for restoration of the D-C component is unpopular because the picture tube grid is connected to the B+ power supply voltage. Failure of the biasing voltage may cause serious damage to the picture tube.

Diode rectification was used quite generally in older model receivers for the restoration, or reinsertion, of the D-C component.

Diodes can be used to insert either a positive or negative voltage.

Disadvantage of diode D-C re-insertion is the additional cost of an extra tube, and its associated circuits.

A more common method for re-inserting the D-C component in the composite video signal is to utilize the sync separator tube for that purpose. D-C voltage is developed at the cathode of the sync separator tube.

If the picture tube is slightly defective, especially if the grid has any tendency to emit, it can produce malfunctioning action in the restorer-separator tube.

Present tendency among design engineers is to feed the composite video signal to the picture tube on its cathode.

The composite video signal must be fed to the cathode of a picture tube with a reversed polarity from that used when it is fed to the control grid.

Feeding the composite video signal to the cathode of the picture tube eliminates the need for a special circuit to re-insert the D-C component.

NOTES

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VIDEO AMPLIFIERS

Contents: Introduction — Purpose of Video Amplifier — Measuring Video Signal Voltages — Contrast Control — Frequency Distortion — Phase Distortion — Requirements of a Video Amplifier Circuit — Factors which Limit Gain of Video Amplifier — Stray Capacity — Effect of Stray Capacity at Different Frequencies — Items Included in Stray Capacity of Amplifier — Compensating for Stray Capacity — Gain of a Video Amplifier Stage — Grounded Grid Amplifiers — Importance of Video Amplifiers in Receivers — Notes for Reference.

Section 1. INTRODUCTION

A video amplifier circuit is one which is specially designed for amplifying composite video signals. Because of the wide range of frequencies present in the composite video signal, and the lack of symmetry in their wave-forms, a video amplifier deals with some difficult problems.

The video amplifier in a television receiver can be thought of as the connecting link between the video detector and the picture tube. It accepts the composite video signal, after it has been separated from the video I-F carrier in the video detector, amplifies it, then feeds it into the picture tube.

The block diagram and graph in Fig. 1 provides a pretty good idea of the relationships which exist among these circuits and the signals.

The signal enters the video detector in the form of a modulated I-F carrier signal. This situation is similar to that which exists at the detector stage in a radio receiver. The only major difference stems from the fact the video I-F signal has a frequency many times higher than the radio I-F signal.

The video detector acts to demodulate the I-F carrier. The output of the video detector is the composite video signal. The composite video signal, as you already know, is one which varies in

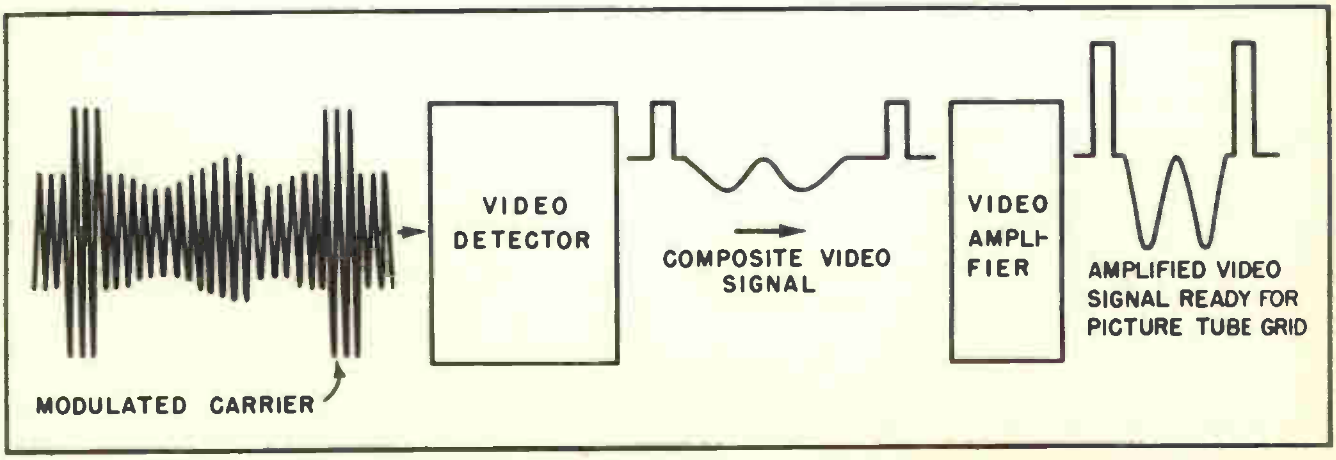


Fig. 1. Wave-form of composite video signal before and after it passes through video amplifier.

frequency between 60 cycles and 4,000,000 cycles, and carries within itself periodic blanking and synchronizing pulses.

It is the job of the video amplifier to accept the composite video signal from the video detector, amplify it to a greater voltage magnitude, and deliver it free of distortion to the controlling element of the picture tube. It is the necessity for the video amplifier to handle that signal *without introducing distortion* which makes its design such a difficult problem.

We have discussed various kinds of amplifiers. Particularly those for amplifying a limited range of audio frequencies, those for amplifying a limited band of R-F frequencies, and other types; but, this is the first time we have studied an amplifier which is called upon to handle a range of signal frequencies which include both audio and R-F frequencies, and do so without introducing distortion which would change the waveform of the signal.

The video amplifier is called upon to handle frequencies as low as 60 cycles per second, which are actually lower than most audio amplifiers are called upon to handle. This means the video amplifier must be capable of accepting and amplifying signals at frequencies lower than those normally handled by the audio sections of most radio receivers.

At the other extreme, the same video amplifier circuit must handle other signal frequencies which are several times higher than the highest R-F frequency handled by radio broadcast receivers.

The video amplifier must be so designed that the same amplifying circuit accepts and amplifies both the very low frequencies and the very high frequencies in the same circuit, and must do so without changing or distorting the signal in any manner. If the amplifier amplifies some frequencies more than others, or delays the passage of some signals more than others, it changes the information furnished to the picture tube, and thus changes the character of the picture reproduced there.

Knowing what you do about electronic amplifiers it should not be difficult to understand that these requirements pose a real problem for the video amplifier.

Section 2. PURPOSE OF VIDEO AMPLIFIER

Video amplifiers are used in the camera chain at broadcast studios to strengthen the camera signal, and thus bring it up to usable strength. It is a common practice to use several video amplifier stages, in cascade, in camera chains. This is because the original signal is very weak and the amplifying ability of each stage is relatively low.

Video amplifiers are also used in the modulator section of the television transmitter. They build up the strength of the video signal sufficiently so it can be used to modulate the R-F carrier.

In the early days of television it was a regular practice to use two to four stages of video amplification in receivers. In those days the voltage of the composite video signal, at the time it left the video detector, was quite low. Since peak-to-peak voltages ranging as high as 50 volts were needed on the grid of the picture tube it was necessary to use several stages of video amplification to raise the signal voltage level sufficiently to do its job.

The nature of the video amplifier is such that it has a relatively low gain. Most amplifier stages have a gain no higher than 15. Many have less gain. In the early days of television when less efficient tubes were in use, even lesser amounts of gain were the rule.

Section 3. MEASURING VIDEO SIGNAL VOLTAGES

Magnitude of signal voltages is measured in a slightly different manner in the case of video signals than the practice followed with sine wave signals.

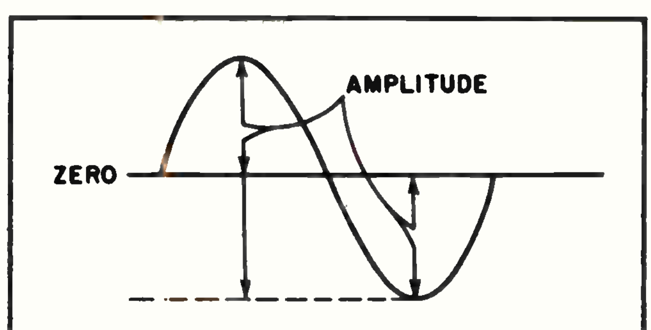


Fig. 2. Amplitude of Sine Wave

A sine wave signal, such as the one shown in Fig. 2, is symmetrical. Its voltage is measured as its *effective* voltage, or as its *peak* voltage. The value of the peak voltage is equal to 1.41 times the effective voltage. For some purposes the average voltage is used.

When working with composite video signals the greatest concern is usually directed toward the extreme voltages. These are referred to as the peak-to-peak voltages. In texts, and on schematics, they are often shown as the "P-P voltage."

Peak-to-peak voltages include the blanking and sync pulse voltages as well as those which carry the picture information. It is the practice to measure the voltage from the lowest level of amplitude, which carries the brightest picture information, to the tip of the sync pulse voltages. Fig. 3 gives a good idea of how peak-to-peak voltage is measured.

Peak-to-peak voltage of the composite video signal can be measured by observing the waveform of the signal on the screen of a calibrated oscilloscope. Some of the newer type oscilloscopes, which have been specially designed for television work, are calibrated so peak-to-peak voltages can be read directly from the screen. Even though an oscilloscope is not specifically calibrated it is possible for almost any technician to calibrate his own oscilloscope for that purpose. Our lesson on the use of the oscilloscope explained how it could be calibrated for measuring high-frequency A-C voltages.

Technical manuals, and schematics, provided by the manufacture of a television receiver, as well as those prepared by publishers who specialize in preparation of such information, usually show the normal peak-to-peak voltages of the video signal at various stages. In most cases a small graph of the video signal is placed on the schematic close to the input and output of each video amplifier stage, and the P-P voltages are indicated.

The manner in which the peak-to-peak signal voltage is indicated on a schematic diagram is shown in Fig. 4. Relative magnitudes of the signals at the input and output are shown on the diagram, although the full proportions are rarely in exact scale. The magnitude of the output signal voltage is clearly indicated as being greater than the input voltage, but no attempt is made to graph the two voltages in exact proportion. The correct value of voltage at the input and the output of an amplifier stage is marked on the schematic near the graph. Fig. 4 shows how that is done.

Incidentally, the phase of the signal at the output of the amplifier is exactly the reverse what it is at the input. This phase relationship is shown on the schematic.

The phase of the signal at the final output of the video amplifier section is always important. The signal must be correctly phased when it is applied to the control element of the picture tube. The exact phasing depends on whether the signal is fed to the control grid or the cathode of the picture tube.

Section 4. CONTRAST CONTROL

The varying voltage level of the camera video

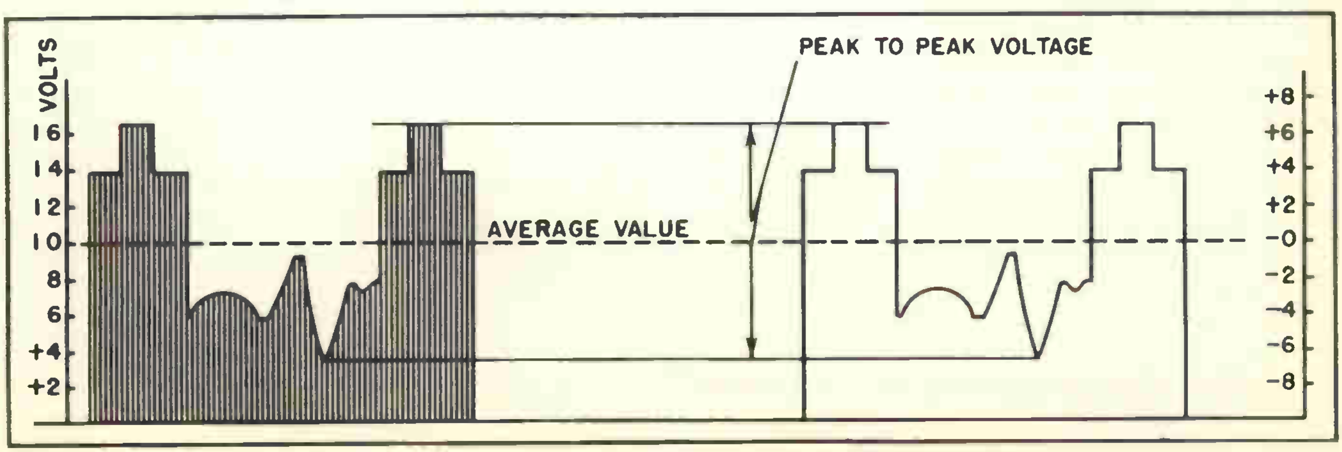


Fig. 3. Measuring peak-to-peak voltage of video signal.

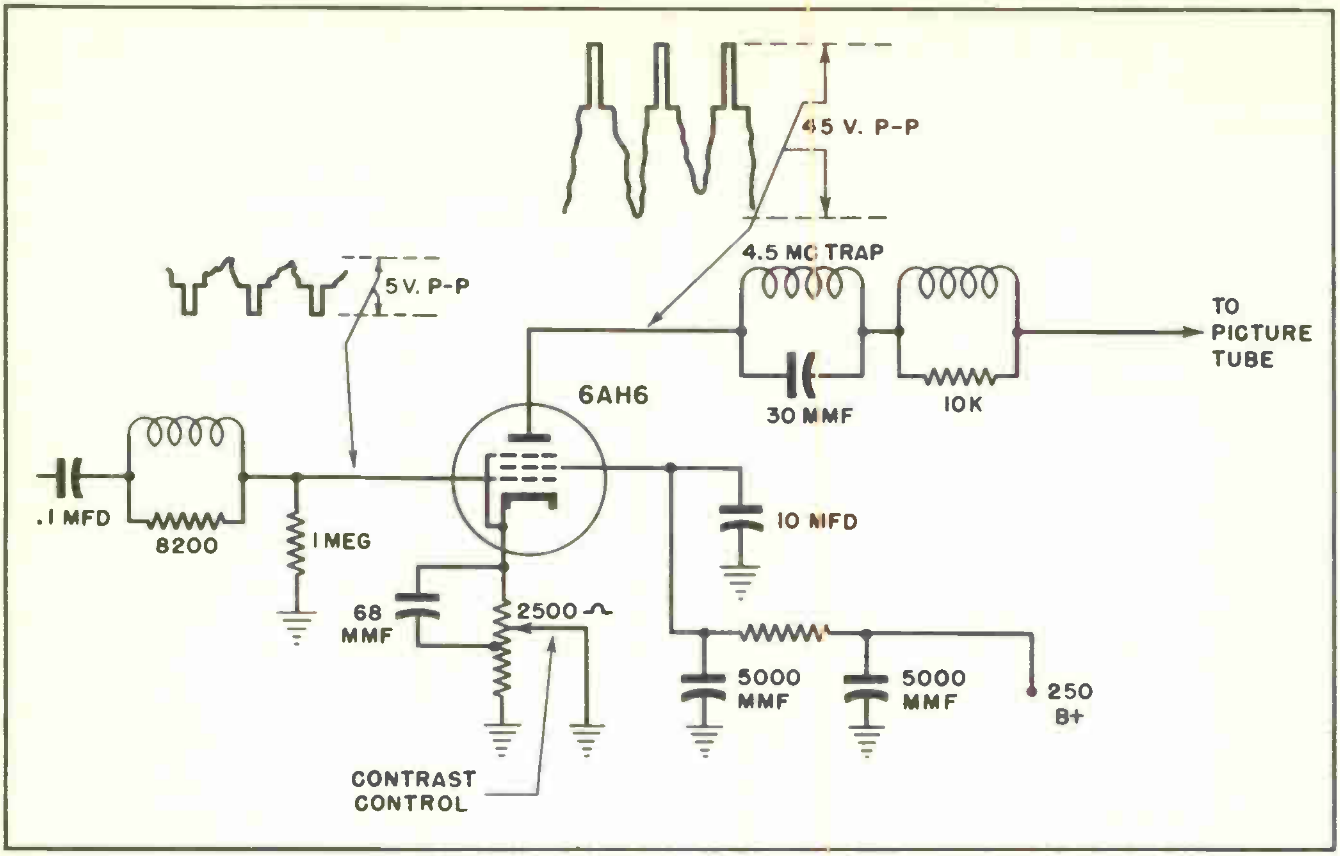


Fig. 4. Peak-to-peak voltages indicated on schematic.

signal acts to control the strength of the electron beam in the picture tube. The varying level determines the exact amount of brightness of shadow on any given area of the screen at any given time.

The degree of swing of the voltage level of the camera signal determines the difference between the blackness of the dark areas and the brightness of the light areas. If the voltage of the camera signal does not vary sufficiently between peak levels of brightness and peak levels of darkness there will not be a high degree of contrast between the bright areas and the dark areas of the picture.

Since the picture information is carried in the form of voltage variations of the camera signal it seems only proper that the various levels of the signal voltage should be clearly emphasized at the time the signal is applied to the control element of the picture tube. And such is, indeed, true. The voltage amplitude of the camera signal when reproducing light areas of the picture should be relatively low; but the voltage should be much higher when reproducing dark areas. This is necessary to clearly delineate the differences in light intensity between the light and dark areas.

On the other hand, if there is too great a swing in the camera signal voltages the dark areas of the picture will be over-emphasized. Areas which should be a darkly shaded gray will actually be black, and the reproduction of the picture will appear unnatural.

It is convenient to be able to adjust the video amplifiers and other signal circuits so they have just the correct amount of amplification for every set of conditions. Some signals are weaker than others. A-C line voltages vary somewhat from hour to hour during the day, and from day to day during the year. Aging of the amplifier tubes bring about changing characteristics in their amplifying ability.

All of which makes it desirable to have some method by means of which the gain of the amplifying circuits can be adjusted so the strength of the video signal which is applied to the picture tube will be just right for the conditions which exist at that moment. The need for such adjustment control over the amplifying ability of the video amplifiers is the reason the *contrast control* is included in all television receivers.

The contrast control may be used with one of the I-F amplifiers, but it is more commonly a part of the video amplifier circuits. In those television receivers which have a video amplifier section the contrast control usually controls the gain of the video amplifier tube. In those receivers which have no video amplifier the contrast control is a part of the final I-F amplifier.

In Fig. 4 the contrast control is located in the cathode circuit of the 6AH6 video amplifier tube. It consists of a 2500-ohm variable resistor, or potentiometer. Varying the amount of resistance in the cathode circuit acts to change the amplifying ability of the tube.

Almost any type of control which affects the amplifying ability of the I-F amplifier tubes or the video amplifier tubes or even the R-F amplifiers, can be used as the contrast control. For the sake of convenience the contrast control is usually inserted in the circuits of the video amplifier or those of the final I-F amplifier.

Section 5. FREQUENCY DISTORTION

The composite video signal includes a very wide range of signal frequencies. Each of those frequencies mean something — each carries its own bit of picture information.

If the reproduced picture is to resemble the original scene it is necessary that each of the individual frequencies, which carry items of information about the original scene, must pass through the video amplifier without being distorted. If they are distorted the information they carry will be distorted, and they will affect the picture tube differently. The result is that the reproduced picture will be different from the original.

It is no mystery to you at this time that different types of electrical circuits affect different A-C frequencies in different ways. A high frequency acts upon a capacitor in a different way from a low frequency. Much the same is true of inductances in an A-C circuit, they affect a high frequency differently than a low frequency.

The fact that the composite video signal contains within itself frequencies ranging from the lower A-F frequencies up into the megacycle range makes it difficult to design a circuit which will amplify all those frequencies by the same amount without discriminating against some or favoring others. Yet it is necessary for the video amplifier to handle all those frequencies without distorting any of them.

To better understand why it is so important to avoid distorting the video signal we can consider some practical examples to illustrate what we are discussing. If the amplifier is not able to handle the low frequencies properly some degree of distortion is certain to be introduced into those portions of the signal consisting of low frequencies. Perhaps the amplitude of the low frequencies is affected; perhaps their phasing, or timing, is affected.

The lowest frequencies in the composite video signal are those dealing with the vertical sync pulses. If the video amplifier is not able to handle low frequencies without distortion the vertical sync pulses are likely to be affected. It may be difficult for the vertical sync pulses to get through. They may be distorted. Their time phasing may shift in one direction or the other, so the pulses arrive earlier than they should, or arrive later.

One effect is to make it difficult to prevent the picture rolling vertically.

Large picture areas also represent low video frequencies. There may be a tendency toward blurring, or other distortion. If the large picture areas are near the right side of the picture they may interfere with the proper timing of the blanking or synchronizing pulses.

At the other extreme a video amplifier may have difficulty handling high video frequencies without introducing distortion. In that case fine details are omitted from the final picture. Changes in light intensity between dark areas and light areas are not sharp and distinct. They will be blurred.

All of which brings us to the necessity for providing an amplifier which can handle both the low video frequencies and the high ones, and do so without changing their original characteristics in any manner. We have no thought here of teaching you how to design a video amplifier circuit, but you should understand the purpose for which circuit components are used. Only by understanding them can you service them.

Section 6. PHASE DISTORTION

Here is a type of distortion which must be avoided in a video amplifier. Phase distortion is not especially serious in most types of amplifiers. This is because the small degree of time displacement which is involved cannot be detected by the human senses, and we are not aware of them.

But when phase distortion is introduced in a video amplifier the viewer becomes quickly and uncomfortably aware of the fact. The reason this is so is that the fast moving electron beam in the picture tube is affected by the phase displacement, and causes distortion in the picture which is reproduced on the screen.

Phase distortion refers to the matter of "timing," in which the output signal is delayed slightly more in some places than others, or advanced in some places a little more than in others.

Graphs of the two signals in Fig. 5 provide some idea of what we are talking about. In that illustration we see the graphs of two sine-wave signals. Both have the same amplitude and the same frequency. But they are not in *phase* with each other.

One of the signals is slightly ahead of the other. Or, we could turn that statement around and say that one of the signals is slightly behind

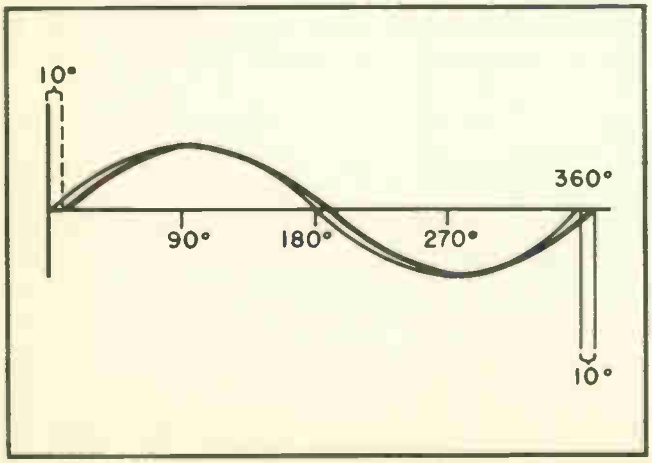


Fig. 5. Phase Displacement

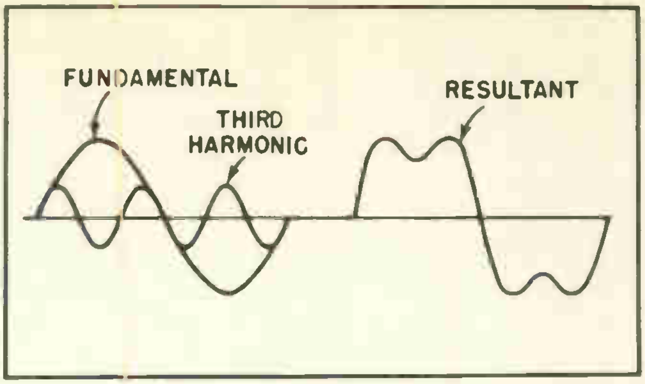


Fig. 6. Fundamental frequency and its third harmonic combine to form resultant signal.

the other. The point is that there is a time difference between them amounting to 10° (10 degrees) of each cycle.

If a pair of signals of that kind were used in an audio circuit we could not detect the difference between them because our ears are not sensitive to phase displacement unless it is really serious.

Serious phase distortion in an audio circuit becomes audible because it brings about a radical distortion in the resultant wave-form; but minor phase displacement is of no concern.

To better understand this condition suppose we consider what happens when we feed a fundamental frequency and its third harmonic into a circuit which introduces serious phase displacement. Fig. 6 shows a fundamental sine-wave signal and its third harmonic being fed into a circuit. The resultant of the two signals is shown in the graph at the right. In Fig. 6 there is no phase distortion, both signals are in phase with each other.

Some idea of what happens when one of the frequencies of the signal is delayed can be seen by studying Fig. 7. In that illustration the fundamental frequency is delayed by what amounts to 60° of its cycle while the third harmonic is delayed by 90° of its cycle.

When these two frequencies are delayed by some circuit constant they do not combine to form the same resultant as shown in Fig. 6. They recombine to form a resultant which has a voltage amplitude at each instant equal to the *sum* of the voltages of the two signals. Because the two signals have undergone phase displacement, and because the displacement has been different for the two frequencies, the resultant is distorted.

The graph at the bottom of the illustration in Fig. 7 shows the wave-form of the resultant signal after the two frequencies have been subjected to differing phase displacement. When the resultant at the bottom of Fig. 7 is compared with the resultant in Fig. 6 it becomes very clear the two resultant signals would affect a picture tube differently. The resultant signal in Fig. 7 would not have the same effect on the electron beam as the resultant in Fig. 6.

All of which means that a given signal could be introduced into two amplifiers, one of which contained circuit elements which introduced some degree of phase into the signal, while the other was free from phase delay. Despite the fact the same signal was introduced into both amplifiers, the signals coming out of the two amplifiers would affect a picture tube in different ways.

The phase displacement shown in Figs. 6 and 7 represents a high degree of displacement, enough, in most cases, to be troublesome even in an audio circuit. Even a small degree of phase distortion is troublesome in video circuits.

Suppose we return our attention to the 10° of phase displacement between the two signals shown in Fig. 5.

Before getting into the technicalities of what that phase distortion amounts to we should review the fact that picture elements are traced on the screen of the picture tube one at a time. Any delay in placing a signal voltage on the picture tube needed to reproduce a given picture element will cause it to be displaced from its correct position.

To further emphasize the matter of time in connection with placing these signal voltages on the picture tube, it must be kept in mind that the electron beam is constantly sweeping across the screen of the picture tube. It is sweeping across the screen at a very high rate of speed.

The beam crosses the face of a picture tube in 53.3 microseconds. In the case of a tube which has a screen 20 inches wide it means the beam is moving across it at the rate of an inch each 2.67 microseconds. That is really fast.

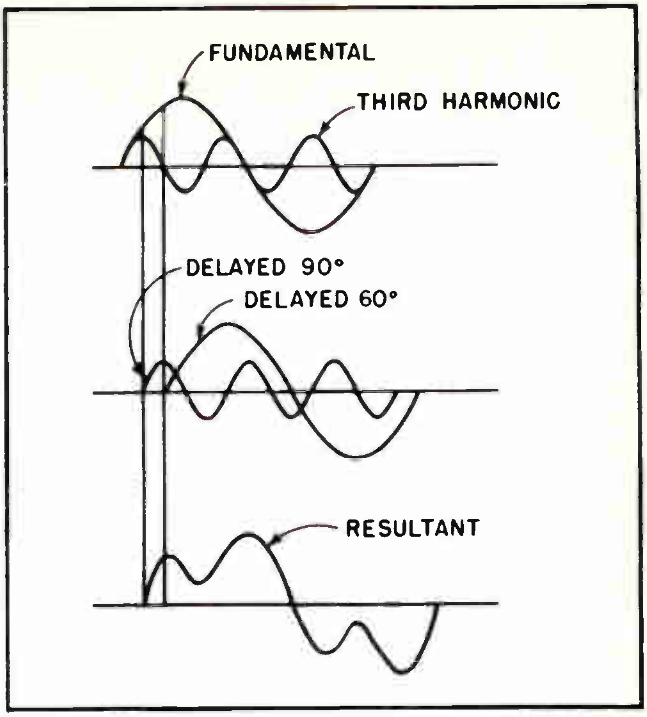


Fig. 7. Distortion introduced by phase displacement.

When we get down to the practical aspects of this situation it means that should a low frequency signal be displaced by a matter of 5.33 microseconds the picture element represented by that signal will be displaced by approximately 2 inches to the right.

This merely demonstrates the fact that a phase displacement is actually a matter of time displacement, and when applied to a rapidly moving electron beam it becomes a displacement of position.

The full significance of this situation can be better appreciated when we apply some actual figures for purpose of example. In the case of a video signal having a frequency of 100 cycles per second we know the signal goes through each cycle during 1/100th of a second.

We all know that each cycle has 360 degrees, so 10° would amount to 1/36th of a cycle.

To find the length of time for 10° of one cycle of a frequency of 100 cycles per second, we merely multiply 1/100th by 1/36th. When multiplied together that amounts to 1/3600th of a second. In short, it takes a 100-cycle signal 1/3600th of a second to go through 10° of one cycle.

It is easier to work with microseconds than with fractions of a second. We all know a second consists of 1,000,000 microseconds. An interval amounting to 1/3600th of a second would be the same as dividing 3600 into 1,000,000, or approximately 278 microseconds.

All of which means that a time delay amounting to only 10° in a signal which has a frequency of 100 cycles per second brings about a delay of 278 microseconds. When we remember that each horizontal sweep of the beam amounts to only 53.3 microseconds it is brought home to us quite forcefully that a phase displacement of only 10° at that frequency displaces the picture information by several lines on the screen.

As a matter of fact, the beam will trace more than five horizontal lines during this period, meaning that the picture information will be displaced by more than eight lines in a vertical direction because the beam traces only alternate lines. To make matters even worse, the picture information will also be displaced to some extent in a horizontal direction.

The necessity for avoiding phase displacement, and thus phase distortion, makes the design of a video amplifier a matter for serious thought.

Section 7. REQUIREMENTS OF A VIDEO AMPLIFIER CIRCUIT

An ideal video amplifier is one which provides a high degree of gain without introducing any frequency distortion nor any phase displacement. Unfortunately, no such amplifier has yet been designed. It is necessary to sacrifice gain in the interest of distortionless amplification, or some other compromise must be made. Because of the necessities involved, gain is usually sacrificed.

From one point of view the closest approach to an ideal amplifier would be one that is *directly coupled.* The essentials of such a circuit are shown in Fig. 8.

For all practical purposes, a direct-coupled amplifier is one which has no capacitor or transformer or other coupling device between the anode of one tube and the grid of the following one. Since there is no component in the coupling circuit which is affected by frequency such amplifier is able to provide amplification completely free from distortion.

The creation of such an amplifier carries with it other problems. Not the least of these is the fact the grid of the second tube is directly connected to the positive voltage on the anode of the first tube. In order to make the grid of the second tube negative with respect to its cathode it is necessary to place an even higher positive voltage on the cathode. The diagram in Fig. 8 shows one way this can be done.

This type of amplifier has found practical application in some kinds of electronic circuits.

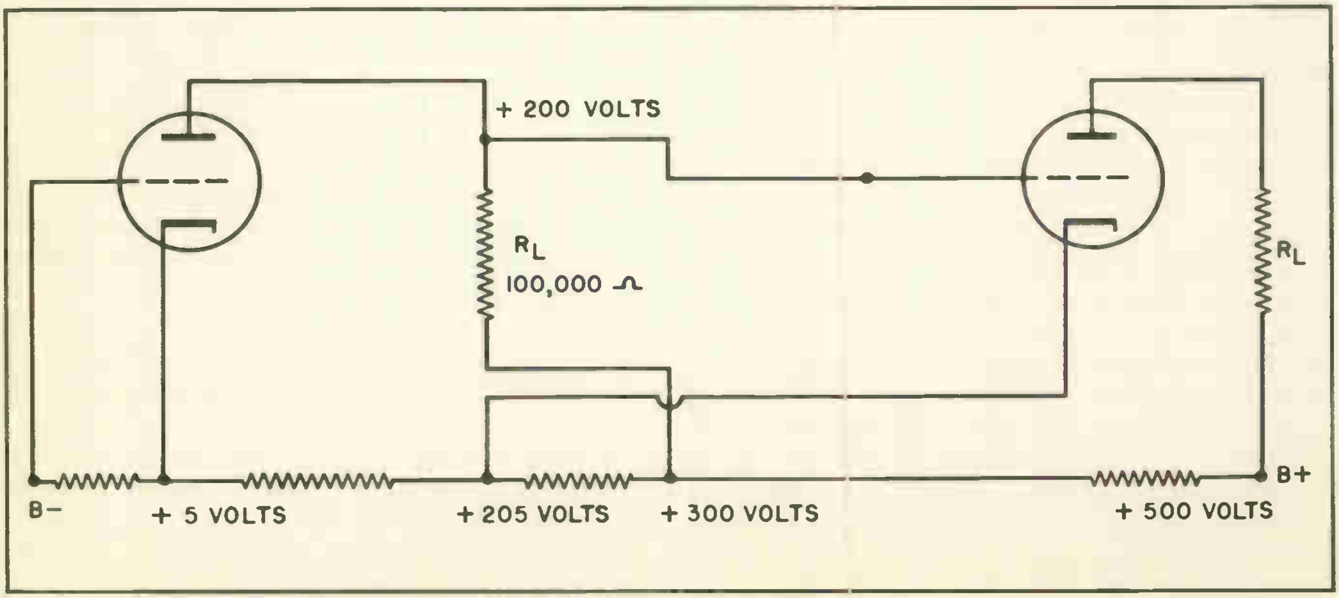


Fig. 8. Direct Coupled Amplifier

Especially in Industrial Electronic applications. But they have seldom proven successful in radio or television circuits.

The direct-coupled amplifier is highly affected by slight changes in working voltages, and also by changes in operating characteristics of the tubes as they age. Where skilled technicians are available to service the amplifiers, as in Industrial Electronic work, this is not a matter for concern. But in radio or television receivers, which are to be used by the general public, it is not desirable.

For the most part a modified resistance-coupled amplifier has come closest to being the ideal type of amplifier for video work. The essentials of a reasonably typical video amplifier are shown in Fig. 9.

It has been necessary to modify the circuits somewhat, and make them a little different from those normally used as audio amplifiers. The coupling capacitor is considerably larger than those used for audio work. The one shown in Fig. 9 has a capacity of 0.1 mfd. That is a reasonably common value of capacity, although a good many TV receivers use 0.22 mfd. capacitors for coupling. A few receivers have used capacities as high as 0.5 mfd. but those cases have been rare.

It is necessary to use a capacitor with a relatively large amount of capacity to avoid attenuating the lower video frequencies.

Another characteristic of a resistance-coupled amplifier used for video work is the low resistance in the plate load resistor. In the circuit shown in Fig. 9 the plate load resistor has a resistance of only 2000 ohms. The exact amount of resistance used for a plate load must be carefully determined, and is governed to a large extent by the type of tubes being used and other components in the circuit.

The plate load resistor in some video amplifiers has a resistance as high as 4700 ohms, but a more common value is 3900 ohms. The exact amount of resistance needed in a given video amplifier circuit has been carefully calculated by the designer of the receiver, and the one used is that which the designer has decided is the best for that particular circuit. A higher value of resistance may bring about attenuation of the

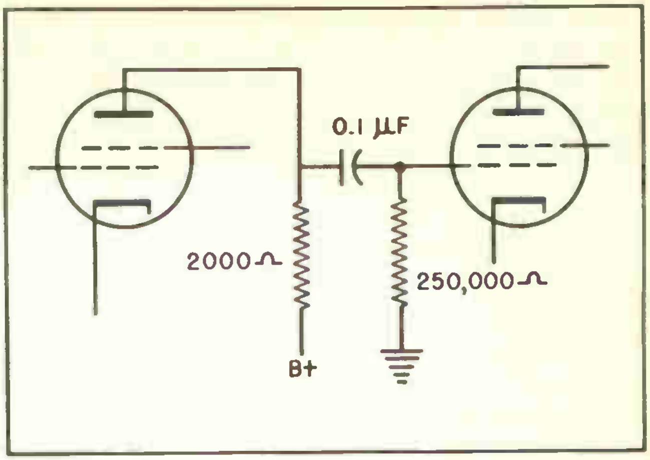


Fig. 9. Basic resistance-coupled amplifier for video work.

higher frequencies in the composite video signal; a lower value resistance may reduce the gain of the amplifier to such low level it is no longer able to drive the control element in the picture tube.

Section 8. FACTORS WHICH LIMIT GAIN OF VIDEO AMPLIFIER

We learned in earlier lessons that the gain of a resistance coupled amplifier is influenced to a large extent by the load resistance in the anode circuit of the amplifier tube. The higher the resistance the greater the gain.

We have already explained that a load resistance of approximately the same value as the plate resistance of the tube is known to provide about the best results when the amplifier is used for amplifying audio frequencies. The gain can be increased somewhat by increasing the load resistance slightly higher than the plate resistance, but there is then some danger of introducing an element of distortion into the output signal.

The plate resistances of vacuum tubes which are most commonly used as video amplifiers range as high as 100,000 ohms, and some have a plate resistance as high as 500,000 ohms. The 6AH6, which is used as a video amplifier in some TV receivers, has a plate resistance of 500,000 ohms.

When these values of plate resistance are compared with the load resistance in the circuit shown in Fig. 9, where the load resistance is shown to be 2000 ohms, it can be seen that the gain of such an amplifier must be much lower than we are accustomed to expecting in audio amplifier circuits. In the case of audio amplifiers, you will recall, we have come to expect gains on the order of 50 to 100, and even higher in the case of some voltage amplifiers.

All of which merely leads to the conclusion that the amplifier shown in Fig. 9 must have a gain much lower than would be expected in a comparable circuit used as an audio amplifier. It is inevitable that the low value load resistance used in the circuit shown in Fig. 9 results in the amplifier stage having a low gain.

The natural question, then, is why not obtain a greater gain from the amplifier by increasing the load resistance? In what particular does the circuit differ from an audio amplifier which prevents the load resistance being increased to a more efficient value?

If the amplifier were to be used to amplify only low frequencies, or relatively low frequencies, the load resistance could be increased, and thus the gain increased. But the composite video signal includes frequencies ranging up into the megacycles; up to 4 megacycles, to be exact. Those higher frequencies present a problem.

A clew to some of the problems which are encountered when trying to use a resistance-coupled amplifier to amplify high frequencies is shown in Fig. 10. That illustration is designed to show some of the electrical properties which are always present in the electrical circuits around a vacuum tube. Those electrical properties are present despite the fact they are not immediately apparent to casual observation.

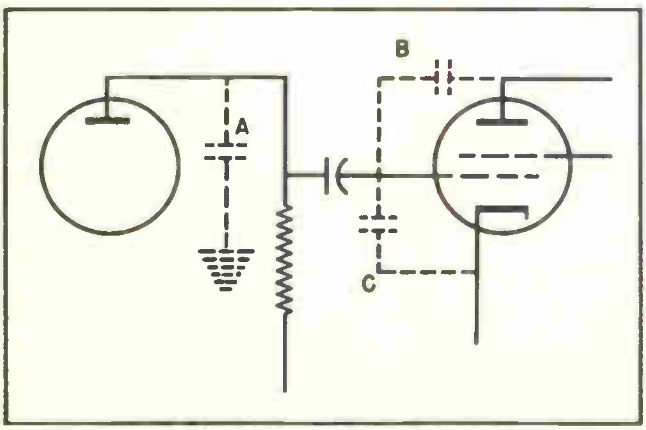


Fig. 10. Stray capacitances exist in every circuit around a vacuum tube.

Section 9. STRAY CAPACITY

The dotted lines in Fig. 10 are intended to show *stray capacitances* which exist in and around the circuits of a vacuum tube amplifier.

You may wonder just what "stray capacitances" actually are, of what they consist. In what way do they differ from other types of capacitances we have studied?

From an electrical point of view there is no difference between the effect of a *lumped capacitance* and that of a *stray capacitance*. But physically they are different.

A *lumped capacitance* is one in which all the capacitance exists at a single location. In the case of a physical capacitor, such as a paper capacitor or a mica capacitor, we have deliberately created an electrical component which is capable of lumping a considerable amount of capacitance into a single location or position. The capacity is all lumped together at one place.

But additional capacity is always present in and around an electrical circuit. This additional capacitance is always present whether we want it or not, and whether or not we may be aware of it. That is what we call *stray capacity*.

To better understand why this is so let us take a quick look at what constitutes a capacitor. A commercial capacitor, as you already well know, consists of two metal conductors separated by a dielectric. That definition holds true regardless of the metals used for the conductors and regardless of the kind of material used as the dielectric.

Different types of dielectrics will affect the total capacity, and will affect the voltage which can be withstood. But the basic fact remains that whenever we separate two metal conductors by some type of dielectric insulating material we are creating some definite amount of electrical capacity whether we intend to do so or not.

In the case of the electrical conductors in a radio or television receiver we know it is necessary to separate those conductors with some type of dielectric to prevent leakage of electrical current from one circuit to another. Electrical conductors are covered with insulation to prevent them short-circuiting against the metal of the chassis, and to prevent them short-circuiting against another conductor.

The dielectric insulation may be rubber or it may be fabric. In fact, it may be nothing more than the empty air which surrounds the metal conductors. But in every case the insulation is a dielectric.

Compared to the amount of capacity we can lump together within the limited confines of commercially built capacitors such as the common paper and mica capacitors, the stray capacity which exists among the conductors under a radio or TV chassis is very small. In most cases it amounts to no more than a few micro-microfarads, and often is less than a single micro-microfarad.

Such being true you may wonder why we pay any attention to it at all.

The truth is that when we are dealing with electrical power frequencies, and the common audio frequencies, and even with the lower radio frequencies, we can ignore the existence of such stray capacities. That is the reason we have failed to stress them in earlier lessons, because at that time they were a matter of little concern.

Section 10. EFFECT OF STRAY CAPACITY AT DIFFERENT FREQUENCIES

When electrical frequencies climb into the megacycle ranges, such as the higher video frequencies, we can no longer ignore these small amounts of capacity. They begin to assume significant degrees of importance, and they must be taken into account when working with video amplifier circuits.

Perhaps a few real figures will bring out the significance of this situation a little more clearly. Suppose we consider the effect of the stray capacity at the output of the first amplifier tube in Fig. 10. That is the stray capacity which is called *A*.

We have redrawn the circuit of Fig. 10 and added some actual values to the circuit elements. The redrawn circuit is shown in Fig. 11.

In Fig. 11 the load resistance into which the first amplifier is working is shown to be 4700 ohms. That is reasonably typical for a video amplifier. We have shown the stray capacity at the output of the tube to be 10 mmfd.

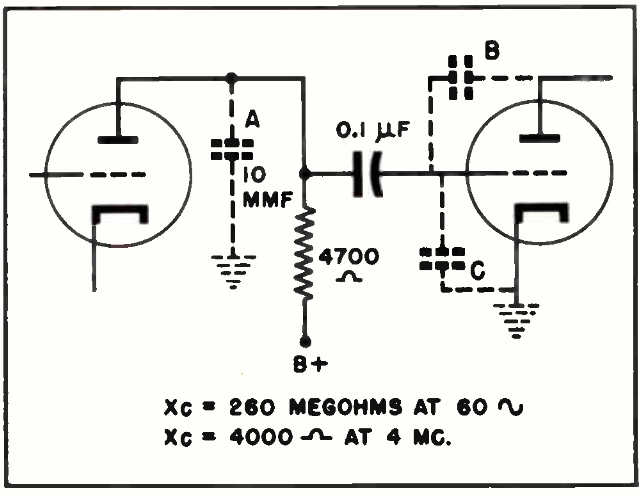


Fig. 11. Reactance of stray capacitance at low frequency and at high frequency.

The stray capacity actually consists of that which exists between the anode of the tube and the 0.1 mfd. coupling capacitor, plus other stray capacities between the two tubes which are marked *B* and *C*, plus certain peculiar conditions inherent in the tubes themselves. These other conditions will be discussed later, but for the sake of convenience we can accept them just now without further explanation.

The stray capacitances in the circuit are in parallel with the load resistance of the tube. This is a fact which we cannot avoid, and the conditions are present whether we want them or not.

The amount of reactance those stray capacitances present to any given signal depends entirely on the frequency of the signal. In the case of low frequencies, such as those found in audio work, the reactance is so high that it scarcely needs to be considered. When a 60-cycle signal is passed through the amplifier circuit the reactance of the stray capacitance to the 60-cycle frequency is well above 260 megohms.

The exact amount of reactance can be calculated by applying the well known formula for finding capacitive reactance. That formula, which we have used so many times in previous lessons, is

$$X_C = \frac{1}{2\pi f C}$$

It can be applied to the problem we are considering by substituting actual values in the formula. In this case the problem would look like this when it is properly set up:

$$X_C = \frac{1}{6.28 \times 60 \times .000,000,000,01}$$

Working out the arithmetic of the problem you will find the reactance amounts to a little more than 260 megohms. The exact figures are not important since the total reactance is so very high they can be rounded off by adding or dropping some of the exact amount without affecting the practical result.

This 260 megohms of reactance is so large, when compared with the 4700 ohms of the load resistance, that it passes so little of the A-C signal it can be completely ignored. Virtually every bit of the A-C signal current passes through the 4700-ohm load resistor rather than through the path provided by the stray capacity which exists in the circuit.

Even when the frequency of the signal climbs to 1000 cycles, or even 100,000 cycles, the reactance of the stray capacity continues to remain so high it can be ignored. It continues to be many times as high as the resistance of the load resistor, and very little of the signal current passes through the stray capacity.

But the composite video signal contains frequencies far higher than 1000 cycles, and even higher than 100,000 cycles.

Its top range of frequencies goes up to 4 megacycles. When frequencies as high as these are passed through the video amplifier the action of the stray capacity becomes significant.

When we take a second look at the circuit in Fig. 11 this significance becomes more clearly evident. We find the reactance of the stray capacity in the circuit has dropped to less than 4000 ohms when the signal frequency increases to 4 megacycles. This reactance is actually less than the resistance of the load resistor. This means the path provided by the stray capacity presents less opposition to passage of the signal than does the load resistance.

The amount of reactance presented to the signal current at the higher frequencies is arrived at in the same manner as we used with the 60-cycle signal. The same basic formula for finding capacitive reactance continues to apply.

The stray capacity is the same, but the frequency is now much higher. The formula would be set up like this for a 4-megacycle signal:

$$X_C = \frac{1}{6.28 \times 4,000,000 \times .000,000,000,01}$$

To simplify the mechanics of working the arithmetic connected with a problem of this kind it is usually desirable to combine the frequency and capacity before proceeding with the other arithmetical operations. This means we would multiply the frequency and capacity together in this manner:

$$4,000,000 \times .000,000,000,01 = .000,04$$

Then it is merely a matter of multiplying the 6.28 by the resultant figure of .000,04. This would be set up in this manner:

$$X_C = \frac{1}{6.28 \times .000,04}$$

When those figures below the line are multiplied together, then the product is *divided* into the 1 above the line we come up with a total reactance somewhat less than 4000 ohms.

When this happens we have the situation that the signal current has two paths through which it can pass. Instead of all the signal current, or at least the most of it, passing through the 4700-ohm resistor, more than half of it can now pass through the stray capacity. When that occurs the total impedance in the plate circuit of the amplifier tube is reduced approximately to half, and that reduces its gain.

This condition is emphasized even more if we were to consider what would happen if the load resistor had a resistance in the vicinity of 50,000 or 100,000 ohms, as is common in audio amplifiers. In that case the lower frequency signals would be amplified quite strongly because of the high load impedance in the anode circuit of the amplifier. But the high frequency signals would be amplified only a fraction as much because of the lower plate impedance resulting from the stray capacity in the plate circuit of the amplifier tube.

These facts point out quite clearly why it is necessary to keep the load resistance of a video amplifier so low. If this is not done there would be a high degree of amplification of the low video frequencies and very little amplification of the higher frequencies. This would result in serious distortion of the output signal.

Section 11. ITEMS INCLUDED IN STRAY CAPACITY OF AMPLIFIER

The general term "stray capacity" is applied to all those capacities which exist in and around amplifier circuits as a result of the mechanical and electrical construction of the circuits, but do not include those capacities which are deliberately inserted into the circuits. For example, the capacity which exists between a conductor and the metal chassis of a receiver is a part of the stray capacity in the circuit. But coupling capacitors, or by-pass capacitors, which are deliberately inserted into the circuit would not be included as a part of the stray capacity.

Stray capacity may be in shunt (parallel) with some portion of an amplifier circuit, or it may be in series with it. Most stray capacity is in shunt with some part of an amplifier circuit. Because of this fact the terms "stray capacity" and "shunt capacity" are often used interchangeably with each other.

From a strictly *practical* point of view most stray capacity *is* shunt capacity, which makes the two terms almost synonymous. Yet, despite the fact this is true, it is possible to have stray capacity which is not truly shunt capacity, although this situation rarely occurs in practical circuits.

A part of the stray capacity always found in an electronic amplifier circuit consists of the interelectrode capacities of the tube itself. For practical purposes the interelectrode capacities consist of the input capacity and the output capacity, although that is not wholly accurate from a purely technical point of view.

The output capacity of a vacuum tube consists of the electrical capacity which exists between the anode of the tube and the cathode. This usually includes the capacity which exists between the connections to the anode and the connections to the cathode.

The input capacity is slightly more complicated. It includes the interelectrode capacity which exists inside the tube between the anode and the control grid. It also includes a peculiar property of electronic amplifiers which is called the *Miller effect.*

A full explanation of the Miller effect would be rather lengthy, and to be fully appreciated it would necessarily include a number of mathematical computations. Fortunately for our purposes, a full understanding of the technical details associated with the Miller effect is not necessary, and could easily prove to be confusing. If, for any reason, you think you would like to go into this subject somewhat deeper, and feel you have the mathematical background to pursue such study, we merely refer you to any Electronic Engineering Handbook. (The mathematical formula for calculating the Miller effect is given in the Notes for Reference of this lesson.)

The basic action of the Miller effect in an amplifier circuit can be stated rather simply. The Miller effect refers to the *dynamic increase* in input capacity which occurs in a vacuum tube amplifier when a signal is applied. It includes the anode-to-grid capacity multiplied by the gain of the stage, modified by a fixed numerical factor. Its net effect is to increase the normal anode-to-grid inter-electrode capacity of the tube.

Since tube manufacturers have succeeded in holding the anode-to-grid interelectrode capacity of high-frequency amplifier tubes to fractional parts of a micromicrofarad, it can be seen that the multiplying factor of the Miller effect can become quite large before it has any great effect on the input capacity, except when the frequencies are very high. Problems posed by the Miller effect are for the design engineer rather than the service technician. They deal with the selection of the correct tube and that does not usually affect the technician.

In a video amplifier the stray capacities which affect the gain of the amplifier at high frequencies include the output capacity of the tube. This is the shunt capacity circuit indicated as *A* in Fig. 11; but it also includes those which are marked *B* and *C*. The latter two are input capacities of the following tube into which the video amplifier is coupled.

We have already described how the stray capacity circuit *A* is in parallel with the 4700-ohm load resistor, but it is not always quite so easy to see how the input capacity of the following tube must be considered.

For a better understanding of the electrical forces which are at work in such a coupling circuit suppose we take a look at Fig. 12.

The coupling capacitor between the two tubes has such a large capacity that it introduces very little reactance at the higher video frequencies. For all practical purposes we could look upon it as though it provided a complete metal path from the anode of the first tube to the control grid of the following one.

When we view the circuit in that manner we see the load resistor has several items of stray capacity in parallel with it. The output capacity of the amplifier tube, the stray capacities of the connecting conductors and the input capacity to the following tube are all in parallel with the load resistor. We can ignore the grid-return resistor of the following tube because that resistance is so high it has no marked effect.

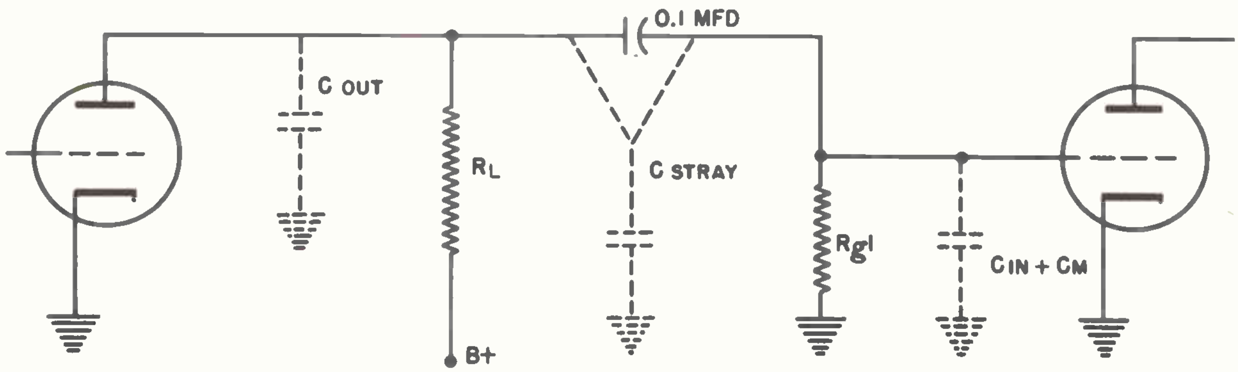
All of those stray capacities are in parallel with each other, thus the total stray capacity is equal to the sum of them all. All that stray capacity is in shunt (or parallel) with the load resistor.

Section 12. COMPENSATING FOR STRAY CAPACITY

The effects of stray capacity can be partially neutralized, and thus partially offset, by use of inductances. These inductances are effective only at the highest video frequencies, but it is only at those frequencies that stray capacities become troublesome, therefore, they provide some degree of compensation where it is needed most.

These inductances are known as *peaking coils.* Sometimes they are connected in shunt with the stray capacities to partially neutralize the loss of impedance brought about by the stray capacities. The most common method of connecting them in shunt with the stray capacity is to connect one in series with the load resistance. A schematic diagram showing how such a peaking coil can be inserted in the coupling circuit is shown in Fig. 13.

The exact amount of inductance needed in any given video amplifier coupling circuit depends on



COUT, OUTPUT CAPACITY

CSTRAY, STRAY CAPACITIES WHICH EXIST BETWEEN THE CONDUCTING CIRCUITS AND THE CHASSIS.

CIN, INPUT CAPACITY OF FOLLOWING TUBE

CM, DYNAMIC INPUT CAPACITY OF FOLLOWING TUBE WHICH IS EFFECTIVE WHEN SECOND TUBE FUNCTIONS AS AMPLIFIER.

Fig. 12. Stray capacity includes all capacity in shunt with load resistor.

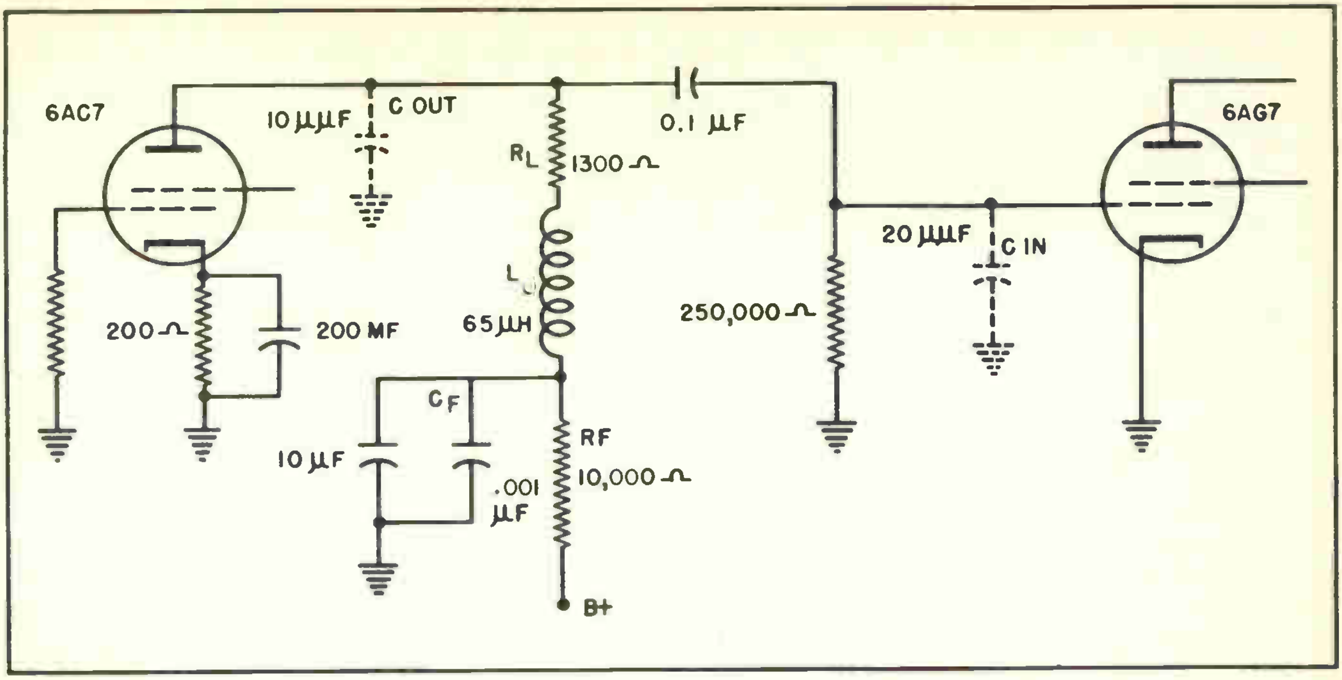


Fig. 13. Peaking coil connected in shunt with stray capacity.

the stray capacity which exists in the circuit. Actual inductances in terms of microhenries range from about 60 uh upward to about 500 uh. (The abbreviation stands for microhenries.)

When a peaking coil is found to be open during a service check of the circuits it is always a good idea to replace the defective coil with another having the same general characteristics of the original coil. Technical manuals covering a given model receiver provide information concerning the inductance of each peaking coil, thus making it a simple matter to reorder a replacement.

A skilled technician can set up testing operations through which he can ascertain for himself the exact amount of inductance needed in a given circuit. It consists of feeding a high-frequency R-F signal into the input of a video amplifier, then varying the inductance of a temporary coil until a resonant condition is reached. All that is then necessary is to measure the inductance of the coil.

But this method of testing takes too much time for the average service man. Furthermore, it is unnecessary, since that information can normally be obtained by merely checking the technical manual covering that particular model receiver.

Instead of placing the peaking coil in shunt with the stray capacity some manufacturers use what is called *series peaking*. When series peaking is used the peaking coil is connected, in series, with the coupling capacitor, as shown in Fig. 14.

Electrically, the effect of placing the peaking coil in that location is to put it in series with all the stray capacity, thus partially neutralizing the shunting effect of stray capacity.

There are some electrical advantages to each of the two basic methods of using the peaking coils to compensate for the loss of gain at high frequencies due to the shunting effect of the stray capacities.

However, it has become a rather widespread practice to combine both methods, and use what has come to be known as *combination peaking*. This consists of connecting one or more peaking coils for series peaking, and one or more others for shunt peaking. An illustration of how the circuits are wired for combination peaking is shown in Fig. 15.

Combination peaking is probably employed in more video amplifier circuits than either of the other methods alone. The cost of the peaking coils is not high, and it is not difficult to include them in a circuit. Since combination peaking provides advantages over either of the other methods

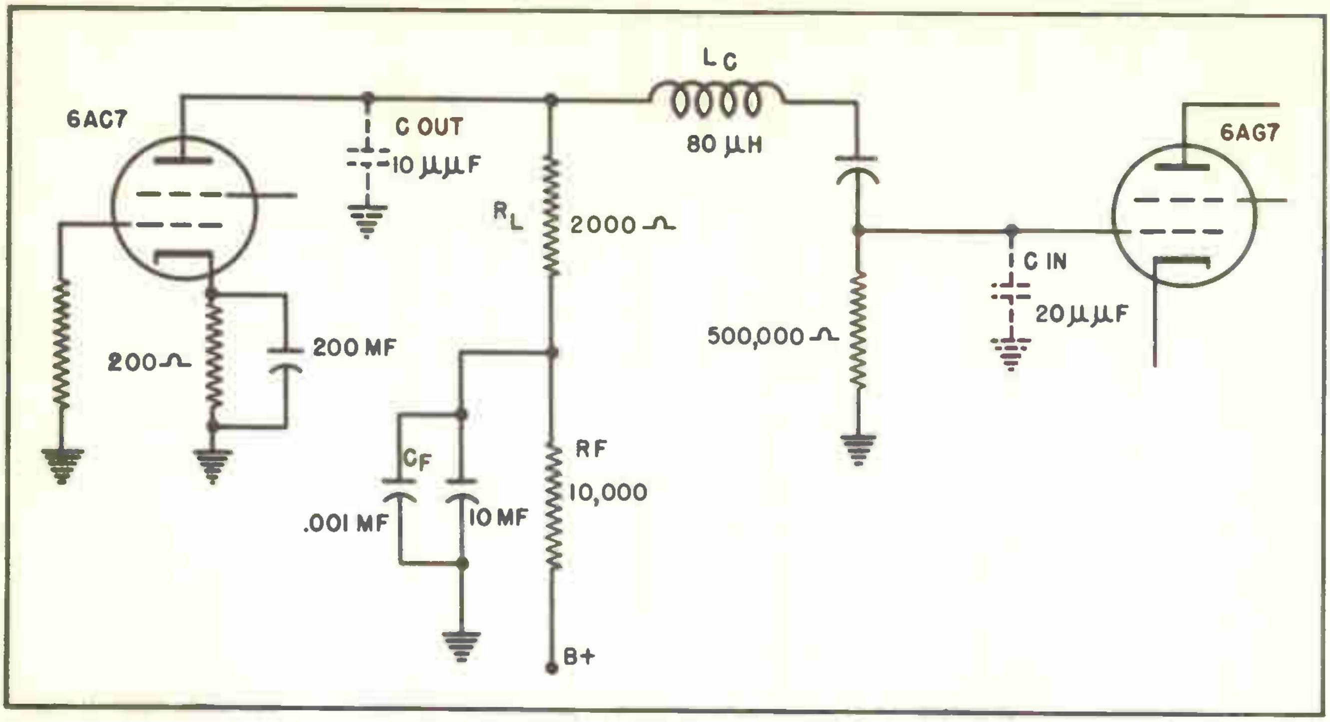


Fig. 14. Peaking coil connected in series with stray capacity.

alone, this is the method which is most widely used.

Component manufacturers have come up with new components which can be used in the coupling circuits of video amplifiers. For the most part they consist of a peaking coil combined with a resistor.

Fig. 16 shows the general changes in the electrical pattern of the coupling circuit which are made when these components are used. Instead of having the load resistor and the peaking coil in series with each other, as shown in Fig. 13 and again in Fig. 15, the load resistor and peaking coil are in parallel with each other. Resistor R-12 and peaking coil L-17 are shown paralleled so they form the shunt peaking compensation for the circuit.

Another example is furnished by resistor R-11 and peaking coil L-16. They form the series peaking portion of the circuit.

In practice, the component manufacturer merely winds a peaking coil around the body of a resistor. By selecting values of inductance and resistance commonly used in video amplifier circuits, the component manufacturer has made it easier for the receiver manufacturer.

By using one of these components the receiver manufacturer is able to install two components by making no more wiring connections than is normally required for one component. This simplifies assembly operations, speeds up production, and usually reduces costs.

Section 13. GAIN OF A VIDEO AMPLIFIER STAGE

A service technician rarely finds it necessary to calculate the gain of a video amplifier stage. But it is often convenient to know how it is done even though the knowledge is never used.

We have mentioned many times in earlier lessons the manner in which the gain of a resistance coupled amplifier is calculated when pentodes are used. To refresh your memory we will repeat it.

The gain of any resistance coupled amplifier can be calculated by multiplying the mutual conductance by the load impedance. This applies specifically to pentode amplifier tubes and is shown in the formula form in this manner:

$$\text{Gain} = G_m X_L.$$

Since every tube manual shows the mutual conductance — or transconductance — of every tube,

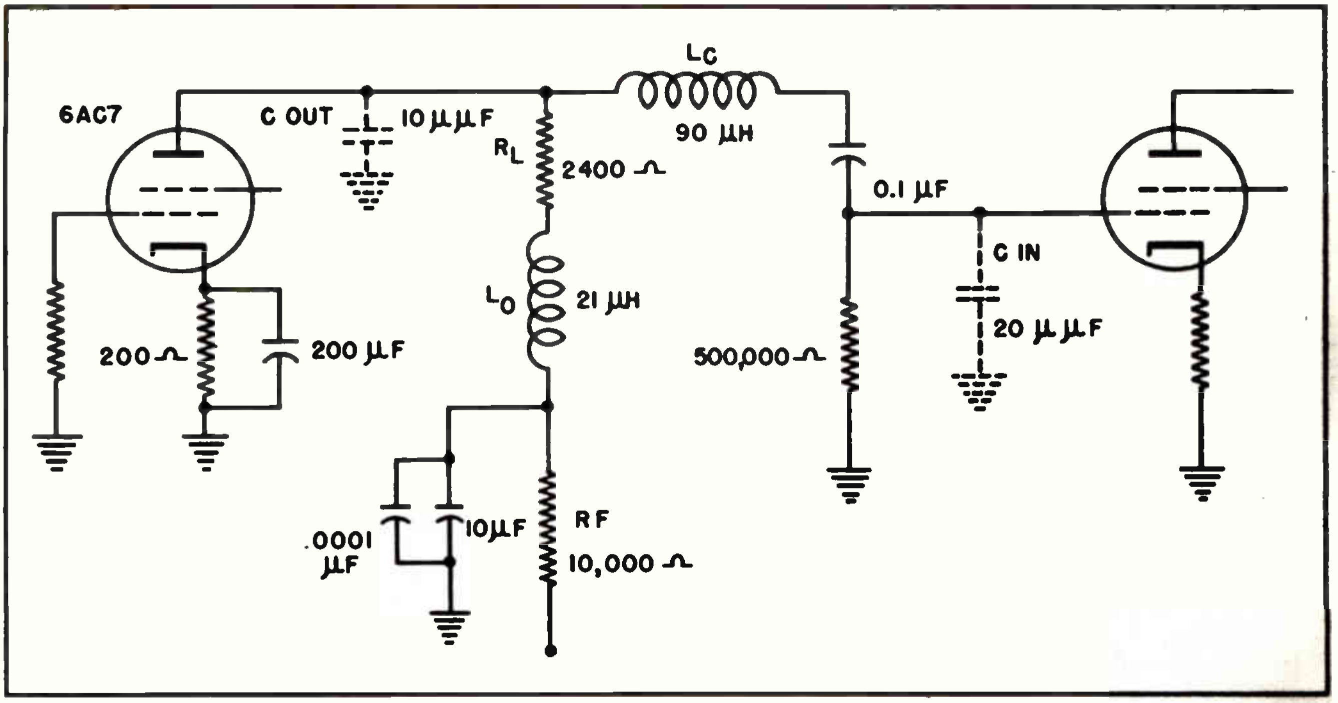


Fig. 15. Peaking coils arranged for combination peaking.

it is easy to find that item of information. In the case of a resistance coupled amplifier the load impedance is equal to the load resistance; at least, it is very nearly equal.

When resistance is used as the load impedance the formula for finding the gain is changed slightly. It then reads:

$$\text{Gain} = G_m R_L .$$

In this situation it is easy to calculate the gain of a stage by merely taking the factors which are known and combining them. Since the type number of the amplifier tube is almost always known it is merely necessary to look up the transconductance in a tube manual. It is equally easy to learn the resistance. It is merely necessary to check the rating marked on the outside of the load resistor, or measure its resistance with an ohmmeter.

For the purpose of demonstrating a practical example suppose we consider the situation presented in Fig. 14. There we have a 6AC7 tube feeding into a load resistance of 2000 ohms.

By looking into any handy tube manual we can

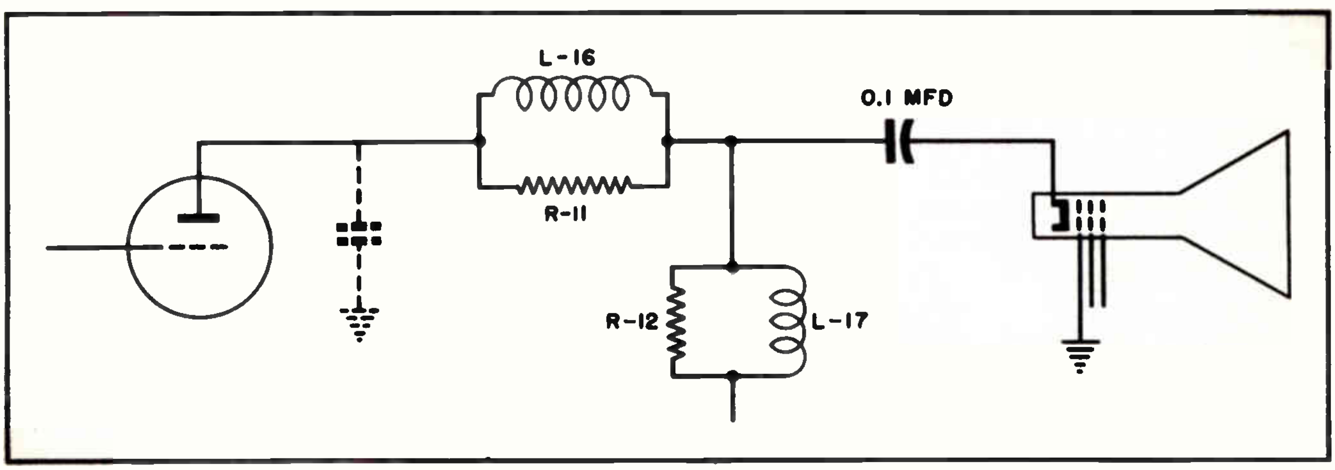


Fig. 16. Peaking coils are often connected in parallel with load resistors.

learn that the transconductance of the 6AC7 is 9000 micromhos. This is equivalent to 0.009 mhos.

We have already explained that the *mho* is the unit of conductance. It is the reciprocal of ohms. In fact, *mho* is merely the word ohm spelled backwards.

$$\text{mho} = \frac{1}{\text{ohm}}$$

Applying the numerical values to the formula for finding the gain of an amplifier we find that:

$$\text{Gain} = 0.009 \times 2000.$$

Multiplying these two values together we come up with the numerical value of 18, meaning that the gain of the amplifier shown in the circuit in Fig. 14 has a gain of 18.

Triodes are sometimes used in the video amplifier sections of television receivers. They are so used when other special effects are desired. But usually it is better practice to use pentodes, and most receiver manufacturers use them. Pentodes have higher values of transconductance, lower interelectrode capacities, and their tendency to introduce noise is seldom a matter of any consequence in video amplifier circuits.

Section 14. GROUNDED-GRID AMPLIFIERS

Triode tubes have certain inherent advantages for some purposes which make them more desirable in some applications than those with multi-elements. One of these is its high signal-to-noise ratio, and another is the fact that a triode can provide a reasonable amount of gain without introducing distortion. Its ability to handle electrical signals without introducing distortion has caught the eye of designers of video amplifier circuits.

The triode's poor interelectrode capacitance kept it from being used in many high frequency circuits, but designers have come up with a modified circuit which permits it to be used in many high-frequency circuits from which it was formerly barred. This newer amplifier circuit is called a *grounded-grid* amplifier.

The circuit in Fig. 17 gives a pretty good idea of the essentials of the grounded grid. As the name implies, the grid is connected directly to ground. Then the signal is injected into the cathode circuit in such a way that a varying voltage is impressed between the grid and the cathode.

The major limitations on the triode for use in high-frequency circuits have resulted from the high interelectrode capacitance which normally exists between the grid and the anode. Since the grid is a part of the input circuit, and the anode is a part of the output circuit, such interelectrode capacitance provided an ideal path for high-frequency signals to feed back from the output circuit into the input circuit. It is no secret that such unwanted feedback is definitely not desirable in most of the circuits in which it is desirable to use the triode.

In the circuit shown in Fig. 17 the grid is connected directly to ground. The grounded-grid provides a shield between the input circuit and the output circuit. This is because the grid is no longer a part of the input circuit, the input is on the cathode. The grid remains at ground potential under all conditions of operation.

When the voltages on the grid and cathode of a vacuum tube vary with respect to each other the varying voltages affect the movement of electrons through the tube. This fact has been mentioned and explained many times, and there is no need to go into it again now.

But the manner in which those voltages are caused to vary with respect to each other need not always be the same in all instances. Heretofore, it has always been the practice to isolate the

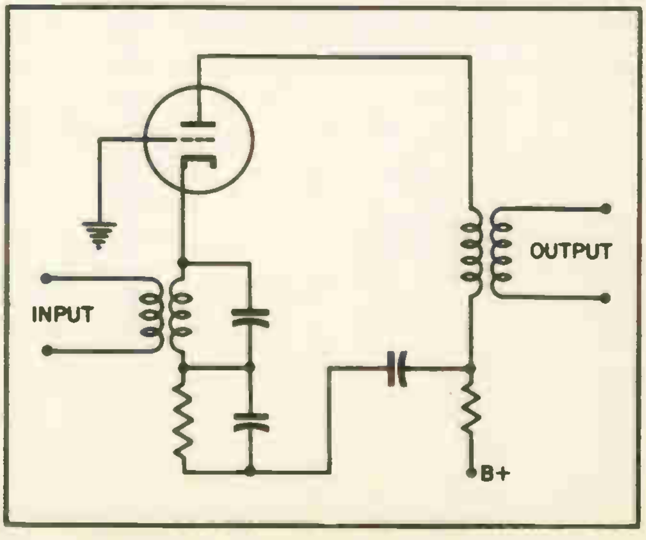


Fig. 17. Grounded-Grid Amplifier

grid from ground while the cathode has been connected to ground. Then the voltage on the grid has been caused to vary with respect to ground, and thus with respect to the cathode. Such varying voltage on the grid—with respect to the cathode — has been used to control the movement of electrons through the tube, and thus bring about amplification.

In the grounded-grid amplifier a varying voltage has been impressed between the grid and the cathode, but the manner of impressing it is different from those previously used. The grid is held at a constant potential. Then the signal has been injected between the cathode and ground, causing the voltage on the cathode to vary with respect to ground.

Causing the voltage on the cathode to vary with respect to ground is the same as making the voltage on the grid vary with respect to the cathode.

There is a certain amount of degeneration present in the use of a circuit like that shown in Fig. 17. Thus, it is not possible to obtain so much gain from any one stage as when the tube is used in the more conventional manner. Nevertheless, the grounded-grid amplifier has definitely found a place for itself in television work, and some designers have used it in the video amplifier sections.

Section 15. IMPORTANCE OF VIDEO AMPLIFIERS IN RECEIVERS

At one time television receiver designers depended very heavily on the gain they could obtain in the video amplifier section to raise the signal voltage to a level high enough so it could be used to drive the picture tube. Wide swings in the signal voltage were required to provide the desired contrast. This was particularly true in the early days of television when electrostatic deflection tubes, with their high anode voltages, were the ones most widely used.

As television receiver design has improved the number of video amplifier stages has gradually declined. Designers depend more heavily on the video I-F section to raise the signal voltage to a usable value. Furthermore, some of the newer types of picture tubes do not require such wide swing in the signal voltages as earlier tubes.

Some models of television receivers now in production use as many as two stages of video amplification, but the overwhelming majority use no more than one. Some manufacturers feed the video signal directly from the video detector to the picture tube without further amplification.

From the service technician's point of view the servicing of video amplifiers has been greatly simplified over what it was in the early models of TV receivers. There was no standardization of parts in the video amplifier section of the early model receivers. The result was that whenever a component became defective in the video section, or any other trouble developed, it was necessary for the technician to literally design a new circuit for himself.

That is no longer necessary. Video amplifier circuits have now become so standardized that whenever a component in the amplifier becomes defective it is merely necessary to order a standard replacement from one of the radio and television supply houses, and install it in the circuit; the technician often has the part in his own stock. If the values of the defective components cannot be immediately learned from the old component itself, the information can be obtained from a technical manual covering that particular model.

NOTES FOR REFERENCE

The video amplifier is located between the video detector and the picture tube.

Purpose of the video amplifier is to amplify the composite video signal so it has sufficient voltage swing to control the picture tube.

The video amplifier amplifies the composite video signal after it has been separated from the I-F carrier at the video detector.

The composite video signal includes a wide range of frequencies. They range from low audio frequencies to some which are several times higher than R-F carrier frequencies used in broadcast radio transmission.

The wide range of frequencies present in the composite video signal makes it difficult to design a high-gain video amplifier.

It is impossible to employ transformer coupling or impedance coupling in video amplifiers because of the wide range of frequencies used by the composite video signal.

Resistance coupling is employed in video amplifiers, but the load resistance must be kept low.

Load resistance of a video amplifier must be kept low, otherwise the reactance of shunting stray capacities at high frequencies becomes lower than the load resistance.

Shunting effect of stray capacities at high frequencies causes gain to drop. To prevent the possibility of high gain at low frequencies and low gain at high frequencies it is necessary to keep the gain low for all frequencies.

Although gain is *low* for all frequencies, all frequencies are amplified by the *same* amount.

There must be neither amplitude distortion nor phase distortion in the composite video signal. Amplitude distortion affects the synchronization pulses, phase distortion affects the position where the picture information strikes the screen.

Phase distortion in a composite video signal causes picture information to reach the screen at different location from where it should be.

Amplitude of the composite video signal is measured in terms of its peak-to-peak voltages.

The contrast control is used to maintain extremes of the dark areas and light areas in their correct proportions.

If contrast control is turned too low the video signal is not amplified sufficiently. Picture will appear lacking in contrast, and "washed out."

If contrast control is turned too high there is too much amplification of the video signal. When there is too much contrast the dark gray areas of the picture appear to be black rather than gray.

Too much contrast often interferes with synchronization of the picture. It may cause the picture to bend, or the entire picture to shift toward the right.

Stray capacity is an unavoidable circuit property which exists in all electrical circuits in which metal conductors are separated by dielectric insulating materials.

Gain of high-frequency amplifiers is affected by shunting effect of stray capacity on high-frequency signals.

The Miller effect is a peculiar condition which is present at the input of an amplifier tube when operating under dynamic conditions. The Miller effect increases the input capacity of a tube according to the gain of the circuit.

Increase in the dynamic input capacity of an amplifier due to the Miller effect can be calculated by using the following formula:

$$C(\text{total input}) = C_{in} + C_{gp}(1 + A)$$

Where C_{in} = normal input capacity into tube,

Where C_{gp} = grid-to-plate capacity, as found in tube manual.
A = gain of the stage.

The shunting effect of the stray capacity in the coupling circuits between two video amplifiers can be compensated for by inserting peaking coils in the circuits.

Peaking coils can be inserted in shunt with the stray capacity, or in series with it.

Best compensation results when combined peaking is employed. In that case both series and shunting peaking coils are used.

Peaking coils are often wound on the load resistor for the sake of making the circuit compact and easy to install.

NOTES

$$F = \frac{1}{6.28 \times \sqrt{L \cdot C}}$$

$$F = \frac{1}{6.28 \times}$$

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RADIO TELEVISION

VIDEO DETECTORS AND AGC CIRCUITS

Section 1. INTRODUCTION

The video detector in a television receiver performs much the same function as the second detector in an AM radio receiver. Its purpose is to demodulate the modulated I-F signal so the composite video signal is separated from the I-F carrier.

The video detector is almost invariably a diode detector. It may be a diode vacuum tube, or it may be a crystal diode, such as the 1N64.

Because the crystal requires no filament heating power, and because it requires no tube socket and is thus more easily wired, it is being used in many modern TV receivers. Furthermore, the crystal requires far less space than the smallest vacuum tube, and rarely requires replacement. It is very dependable.

Wave-forms of the signals which enter, and those which leave the video detector are shown in Fig. 1.

The entering signal is the modulated I-F carrier signal. The signal which appears at the output of the detector is the composite video signal. Signals

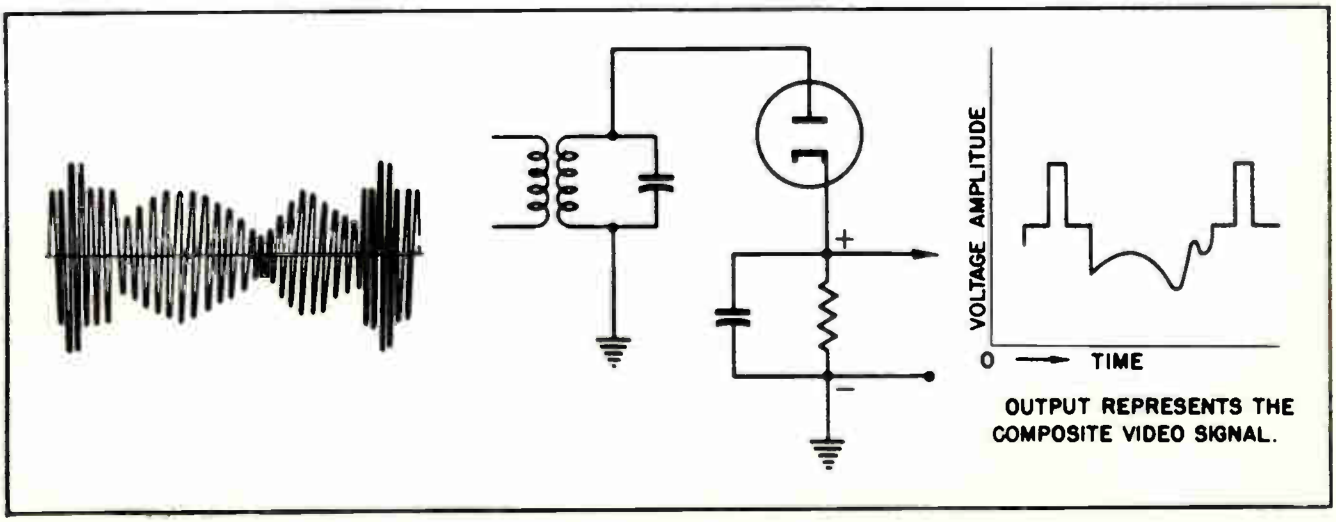

Fig. 1. Modulated I-F signal entering video detector, and composite video signal leaving it.

which contain other types of information also appear at the output of the video detector, and will be discussed in this lesson.

The I-F signal in early model receivers usually had an I-F frequency on the order of 21 to 26 megacycles. This meant the final I-F transformer, the one shown in Fig. 1, was tuned to that frequency.

Later model receivers tend to use a much higher I-F frequency; I-F frequencies on the order of 40 to 45 megacycles are much more common. In such receivers the final I-F transformer is tuned to that frequency.

The basic action of the diode detector is to rectify the high-frequency I-F signal, then tap off the modulating component. The R-F component is by-passed around the load resistor of the detector by the capacitor shown in the cathode circuit of the diode tube in Fig. 1.

Section 2. SIGNAL PHASE AT DETECTOR OUTPUT

Up to the time the I-F signal reaches the detector stage we are not greatly concerned about the phase of the signal. We are no more concerned with its phase than we are with any other R-F or I-F signal.

In the case of the *audio output* from a detector in an *AM radio* we are never concerned about the phase of the signal. The audio signal is symmetrical (uniform), and it is possible to use it in the loudspeaker circuit regardless of what its phasing may happen to be.

The composite video signal is something entirely different. That signal must be properly phased at the time it is applied to the control element of the picture tube. Otherwise the picture will be exactly reversed from what it should be.

There is a very definite *phase correlation* between the output signal of the video detector and the number of video amplifiers which are used. There is an equally close correlation between the number of video amplifier stages and the manner in which the signal is injected on the control element of the picture tube.

Each stage of video amplification subjects the composite video signal to a 180° phase reversal. Furthermore, when the signal is injected onto the cathode of the picture tube its phasing must be exactly 180° from what it is when injected on the control grid.

All of which means that careful attention must be given to the phasing of the signal when it leaves the video detector. The exact phasing in any given receiver depends on the other circuit arrangements. The exact phase at the output cannot be arbitrarily decided without knowing the number of video amplifier stages, and the exact manner the signal is applied to the picture tube.

This matter of phasing the signal at the output of the video detector, and the design of the video amplifiers, and the connections to the picture tube, are problems for the design engineer. Normally, television technicians have little need to understand all the technical details connected with them.

But it is well for you to understand the reasons why you will find some detector stages phased in one manner, and others phased in another. Were you not fully aware of the correlation among these three stages in a TV receiver you could easily jump to wrong conclusions at times, and believe that somebody made a mistake in designing the receiver circuits.

For example, suppose your early TV repair experience should happen to bring you into contact repeatedly with one particular model in which the output of the video detector had a positive signal phase. If, after you had acquired a considerable experience with that particular model, you were suddenly called upon to service some other brand or model which phased its video detector output with a negative signal, you could easily fall into the error of believing the detector circuit was wired wrong.

All of which merely means that phasing of the detector output depends on the design of the other two stages with which it is so closely related.

Section 3. PHASING THE DETECTOR OUTPUT

The phase of the composite video signal at the output of the video detector depends on the manner in which the detector is connected into the I-F section and the video amplifier section. A study of Figs. 1 and 2 shows this somewhat better than words alone.

In Fig. 1 the modulated I-F signal is fed to the anode of the detector. The diode tube conducts during each positive swing of the I-F signal, but does not conduct during the negative swings.

The diode tube causes current in the cathode circuit to flow in only one direction — toward the cathode from the other parts of the circuit.

A load resistor is inserted in the cathode circuit. As current flows through that resistor a voltage drop is created across it. When the amplitude of the I-F signal is low the voltage drop across the resistor is low. But when amplitude of the I-F signal is high the voltage drop across the resistor is high.

Individual high-frequency conduction pulses are smoothed out by action of the by-pass capacitor, and thus do not affect the voltage drop across the resistor. But the varying *average* of amplitudes of the I-F signal, the composite signal, are clearly reflected in varying voltage drops across the resistor.

Those varying voltage drops across the load resistor are tapped off and fed to the video amplifier. Those varying voltage drops represent the composite video signal.

By reversing the connections to the active elements of the diode tube the phase of the composite video signal can be reversed. This is shown in Fig. 2.

The signal from the I-F section is fed into the cathode of the diode in Fig. 2. Each time the high-frequency I-F signal swings into a *negative* cycle it makes the cathode more negative than the anode, and thus sets up a condition necessary for conduction through the tube.

Current in the anode circuit flows away from the anode in the form of high-frequency pulses, all the current moving in the same direction. The high frequency pulses are smoothed out by action of the by-pass capacitor around the load resistor in the anode circuit, but current through the load resistor varies from instant to instant to conform with the varying amplitude of the modulation signal.

The phase of the output signal is reversed from that in Fig. 1, where the load resistor was in the cathode circuit.

Section 4. PROCESS OF DEMODULATION OR DETECTION

There is no essential difference between the action of a diode *video* detector and that of a diode detector used for other purposes. Like any other detector, it acts to eliminate one of the two halves of the modulated envelope of the I-F carrier. It also provides circuit elements designed to accentuate the varying amplitudes of the modulation envelope, since it is those varying amplitudes which constitute the basic information included in the composite video signal.

Each half-cycle of the I-F signal places a voltage on the diode detector tube which causes it to conduct. Whether it is the positive half-cycles

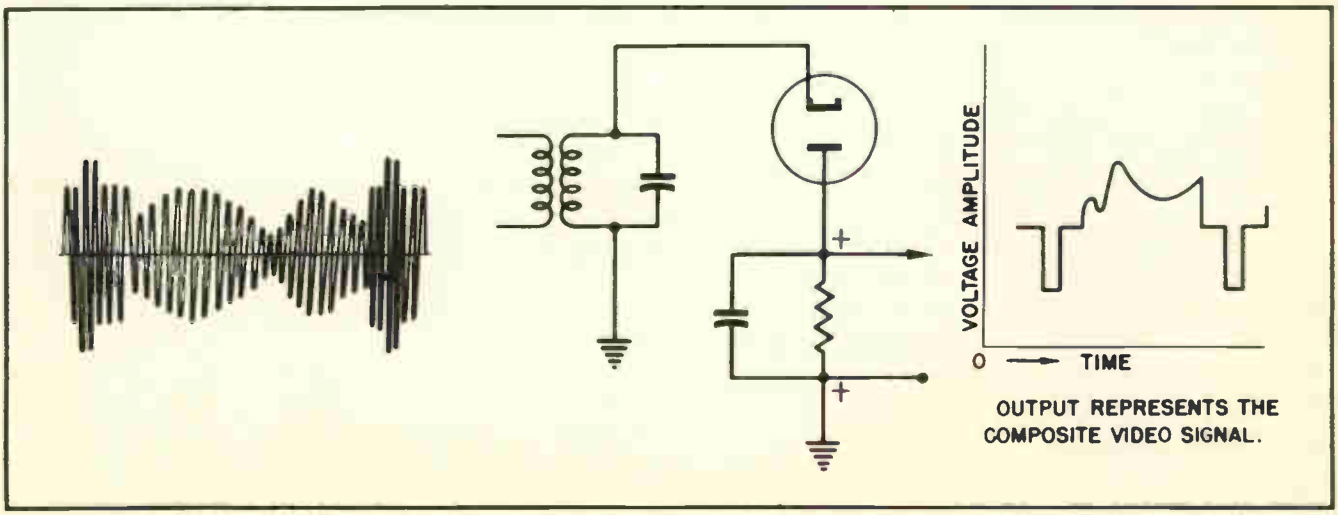

Fig. 2. Placing load resistor in anode circuit of detector reverses phase of output signal.

which cause the tube to conduct, or the negative half-cycles, makes no difference. Either half-cycle causes current to flow through the tube if the voltage is properly placed on it.

The point is that only one or the other of the two half-cycles affect the tube. Thus, only the positive half-cycles or only the negative half-cycles affect it. In either case, one half the modulation envelope is eliminated.

When that is done it is a simple matter to apply the consecutive half-cycles which affect the tube to some form of load, usually a resistor. In that case the voltage drop across the resistor at any given instant corresponds precisely to the amplitude of the I-F carrier at that instant.

All this results in the varying amplitude of the I-F carrier causing a varying voltage to appear across the load resistor. The varying voltage is the composite video signal.

During the demodulation process we are interested only in the varying *average* amplitude of the successive cycles of the I-F carrier signal. The amplitude of the *individual* cycles of the I-F carrier are not critically important — only the average amplitude of *successive* cycles of the I-F carrier.

The R-F component, represented by the swings of the individual cycles of the I-F carrier signal, are by-passed to ground through the by-pass capacitor shown in Figs. 1 and 2. That capacitor has low capacity so it affects only the high-frequency I-F carrier signal, and does not affect the lower frequencies of the *varying* amplitude of the composite video signal.

Please note this — the composite video signal includes some high frequency signals, ranging up to 4 megacycles. But even the highest of these are low when compared with the I-F *carrier signal frequency*.

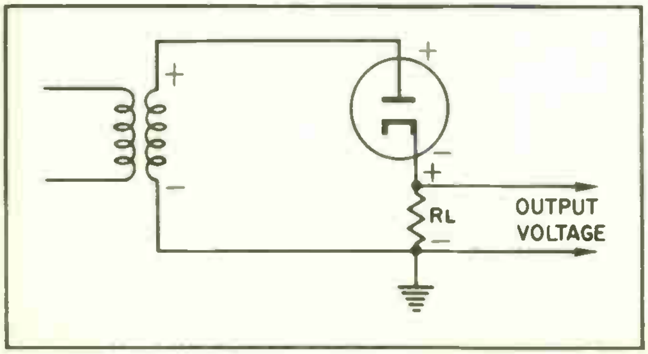

Fig. 3. Video detector with load in cathode circuit provides negative picture phase.

Thus, the by-pass capacitor must be selected so that it can readily pass the *individual* cycles of the high-frequency I-F carrier signal without passing *any part* of the composite video signal. This is especially true when the I-F frequency is in the 20 megacycle range, but is easier when the I-F frequency is above 40 megacycles.

Section 5. VOLTAGE POLARITIES AT DETECTOR CIRCUIT

In the United States negative polarity of transmission is used. This has been explained and discussed in other lessons, so there is no need to go into it much in this lesson.

Negative polarity of transmission means that maximum amplitude of the modulated I-F carrier signal represents the maximum negative voltage on the control grid of the picture tube. This also means that maximum amplitude of the I-F carrier represents the peaks of synchronizing pulses.

It is necessary that the composite video signal be so phased in a receiver that sync pulses represent the maximum negative voltage on the control grid, or the maximum positive voltage on the cathode. It all depends on which system is used in a given receiver to inject the signal voltage into the picture tube elements.

The manner of acquiring a specific polarity phase when a rectifier is used is sometimes a trifle confusing because there seems to be no voltage reference point. Perhaps a study of the polarities shown in Figs. 3 and 4 will aid in clearing up any possible confusion you may feel.

In both of these circuits we have shown one point connected to ground, or to B minus. Such arrangement provides a voltage reference point, since it becomes possible to refer all voltages against ground, or B minus.

The diode tube of the detector in Fig. 3 conducts only during those instants when the polarity of the secondary of the transformer is as shown. In such a circuit the signal voltage at the output of the detector always has such polarity that it is always positive with respect to ground, or to

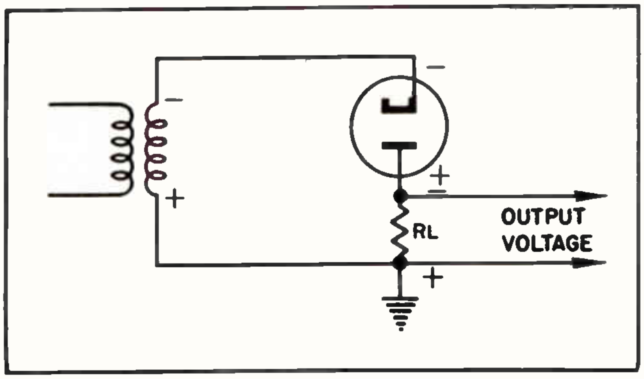

Fig. 4 Voltage polarities at video detector with load in anode circuit.

B minus. The *magnitude* of the signal voltage varies from instant to instant as the amplitude of the I-F carrier signal varies, but the composite signal voltage is always *positive* with respect to ground.

The reverse is true when the circuit is arranged as shown in Fig. 4. In that circuit the detector tube conducts only during those instants when the voltage polarity at the secondary of the transformer is as indicated.

The result is that the composite video signal voltage is always *negative* with respect to ground, or B minus. The magnitude of the signal voltage is not always the same. In fact, it varies from instant to instant as the amplitude of the I-F carrier signal varies; but it is always negative with respect to ground, or B minus.

In this connection it is worth pausing briefly to refresh your memory with the fact that ground is not always the same as B minus. In many receivers, in fact in most AC receivers which use a full-wave low-voltage power supply, the metal of the chassis "ground" is also B minus. But in some other receivers B— is deliberately separated from the ground of the chassis. This is especially true of receivers which use an AC-DC power supply.

If these items of information are a little hazy go back and review your lessons on power supplies. Review both the lesson on TV power supplies, and those on radio power supplies.

To return to the voltage polarity of the composite video signal at the output of the detector, let us take another look at Fig. 3. That diagram has been expanded somewhat in Fig. 5.

The composite video signal at the output of the video detector in Fig. 5 is so phased that the peaks of the signal are the most positive voltages in it. This means the synchronizing pulses are positive with respect to ground.

It would not be possible to apply a signal having this polarity to the control grid of the picture tube. If it were applied by mistake to the control grid of the picture tube all gradations of color in the picture would be reversed. Those picture elements which should be white or light would be black or dark. Furthermore, all those picture elements which should be black or dark would be white or light.

The picture on the screen of the picture tube would look like a photographic negative.

Because of these considerations it has become customary to speak of the composite video signal under such circumstances as having a *negative picture* phase.

While it would not be correct to place such a signal on the control grid of a picture tube there is no reason it could not be applied to the cathode of the picture tube. In fact, the polarity would be correct for such application.

The composite signal from a detector phased like the one in Fig. 5 would have to be fed directly to the cathode of the picture tube — provided, the composite signal had sufficient voltage amplitude to control the beam in the picture tube.

If the composite signal did not have sufficient amplitude it would have to be fed to a video

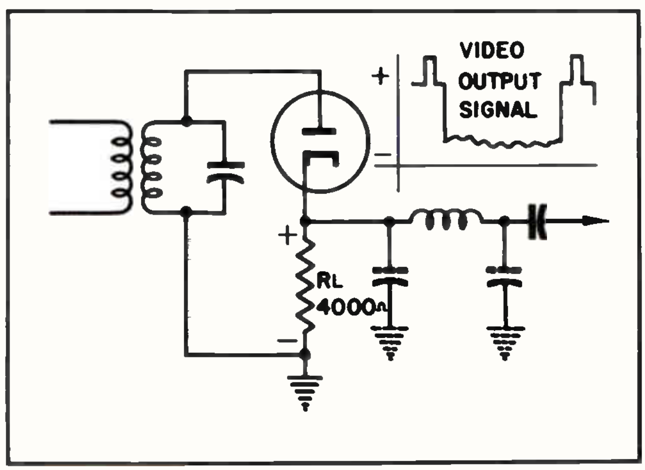

Fig. 5. Video detector phased for positive signal at output.

amplifier. The action of the video amplifier would strengthen the composite signal, and build up its amplitude. But the action of the amplifier would also reverse its polarity. In that case the signal would have to be applied to the control grid of the picture tube, rather than to the cathode.

Instead of the detector circuit being arranged as in Fig. 5 it is just as easy to arrange it as in Fig. 6. When it is so arranged the output composite signal is said to have a *positive picture* phase.

The composite video signal is said to have a positive picture phase in Fig. 6 despite the fact that all parts of the signal are *negative* with respect to ground, or B minus. The reason stems from the fact that the composite signal in Fig. 6 can be applied directly to the control grid of a picture tube, and the picture phasing will be correct to produce a *positive* picture.

This matter of positive and negative *picture phasing*, and positive and negative *signal phasing* tends to become confusing. The terms originated in the early days of television when the composite video signal was always applied to the control grid, and correct phasing was critically important to obtain a correct picture.

In those days it was necessary for the composite signal to have a negative voltage in order to drive the control grid sufficiently negative to control the action of the beam.

In more recent years the tendency is to apply the signal to the cathode. Therefore, the original designations of the positive and negative *picture*

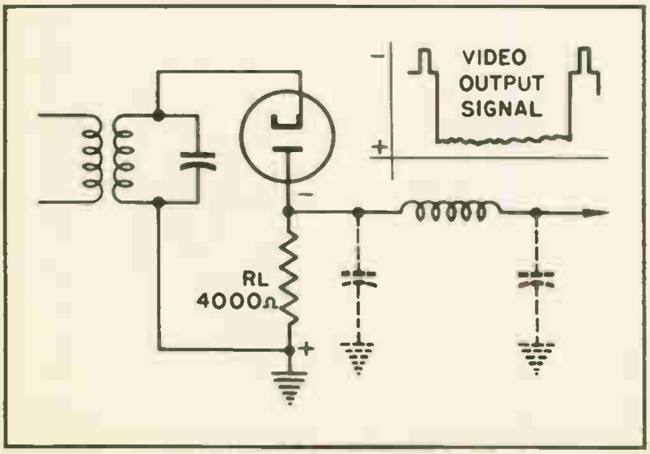

Fig. 6. Output signal when load is in anode circuit of video detector.

phases are no longer properly descriptive. Nevertheless, the terms continue to be used.

Fortunately, once you understand the electrical principles involved, the exact meanings of the terms are no longer so important. Once the background surrounding the origin of these terms is explained it is then possible to read and study other technical books without becoming confused. That is really the only purpose for including this explanation at this time.

Section 6. REVERSING SIGNAL POLARITY

From information in preceding lessons it should be clear to you that the signal may have either a *positive picture phase* or a *negative picture phase* when it is applied to the picture tube. Perhaps it would be more correct to say that the voltage of the composite signal may be either negative with respect to ground, or it may be positive with respect to ground. In either case it can be applied directly to the picture tube.

If the voltage of the composite signal is negative with respect to ground it can be applied to the control grid of the picture tube, and thus produce a positive picture phase.

On the other hand, if the voltage of the composite signal is positive with respect to ground it must be applied to the cathode. But when it is so applied it also acts to produce a positive picture phase.

When we approach this subject from another point of view we must remember that when the voltage of the composite signal is positive with respect to ground it must be applied to the cathode. But when it is so applied it acts to produce a positive picture phase.

All of which means that either a negative voltage composite signal, or a positive voltage composite signal, can produce a positive picture on the picture. But the signal must be properly applied to the picture tube with respect to its voltage polarity.

In addition to the fact that either a negative voltage signal or a positive voltage signal can be applied to the picture tube, provided it is properly applied, we have learned earlier in this lesson that we can control the polarity of the composite signal voltage at the output of the detector. The signal voltage can be either positive or negative, with respect to ground, or B minus.

This means that we have it within our ability to control the polarity of the composite signal at the time it leaves the detector, and we are also able to apply either a positive or negative voltage signal to the picture tube, provided we watch the phasing. Which means we have a very flexible arrangement, but at all times it is necessary to observe the polarities to make certain they are properly phased.

Despite all this flexibility, additional flexibility is attainable. This results from the fact that the phase of the signal goes through a 180° reversal at each stage of video amplification.

Multiple stages of video amplification are largely a thing of the past, and seldom found in modern receivers. Nevertheless, these facts must be kept in mind. They are much more important to the design engineer than to a service technician, yet it is well for a technician to know what is likely to happen if he is tempted to incorporate design changes in a receiver. Sometimes one is tempted to add another stage of video amplification, or change the manner in which the signal reaches the picture tube — or, even change the circuits around the video detector.

Any, or all, of such changes are possible, and are sometimes practical. Yet, it is well to understand just what one is getting into when such changes are considered.

Perhaps it is well to repeat a bit of advice mentioned several times during the early part of this course. Regardless of what we may think of the results, we can accept the fact the design engineers have created the best receiver circuits for a given model within the limitations imposed on them. It is rarely wise to re-design such circuits.

Section 7. THE DETECTOR LOAD

In selecting a load resistance for the video detector we are faced with much the same problem as that we encountered in selecting a load for the video amplifier. Frequency response in the video detector circuit is just as important as in the video amplifier circuit.

Stray and shunt capacitances exist around a

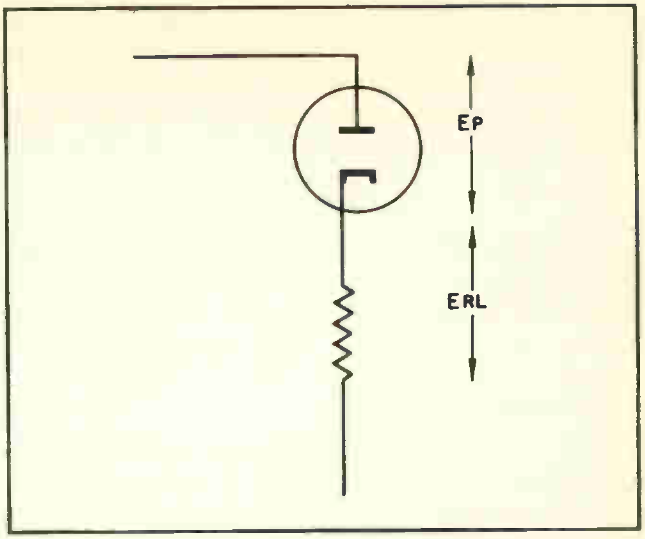

Fig. 7. Series resistances of tube and its load.

diode detector tube in much the same manner as around an amplifier tube. Perhaps the capacitances are not so large, nor of quite the same character. But they are real.

The plate resistance of the tube, and the load resistance into which the tube works, act as a voltage divider network. This is shown in Fig. 7.

In that diagram we see the plate resistance of the tube is in series with the resistance of the load. The two resistances, combined, form a voltage divider network. This condition is made even more clear in Fig. 8.

The shunt capacitances which exist around the tube, and in parallel with the load, tend to reduce

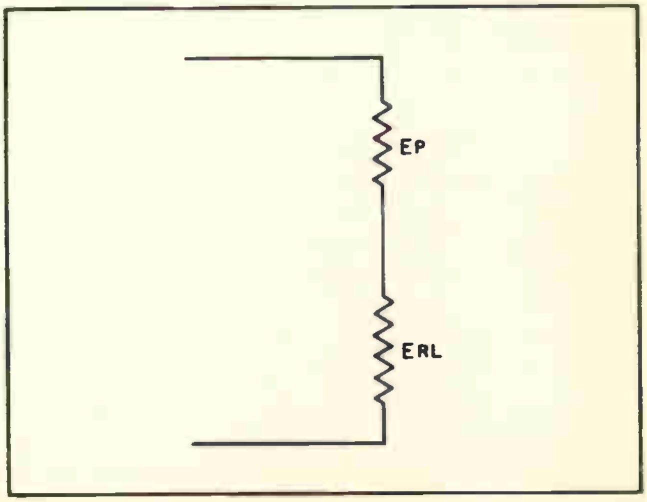

Fig. 8. Voltage divider network across tube and load.

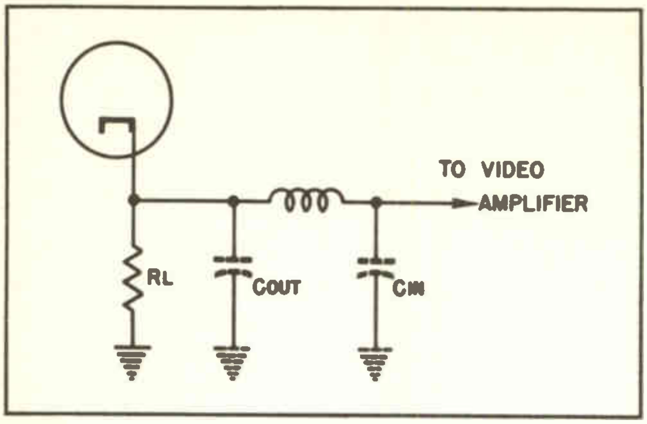

Fig. 9. Video detector filter circuit.

the effectiveness of the load resistance at the higher frequencies. This is the same situation which prevailed in the case of video amplifiers.

It has been found that when the load resistance is approximately the same as the internal plate resistance of the tube it is possible to obtain the best results. The tubes most widely used as video detectors are the 6H6 and the 6AL5. Because of its miniature size the 6AL5 has largely superseded the 6H6 for this purpose. Sometimes the diode plates of a combination tube, such as a 6T8 or a 6SR7, are used.

These tubes have a plate resistance on the order of 4000 to 5000 ohms. A load resistor of approximately that size provides good results.

When a crystal detector is used the load resistance is much higher. Often the resistance is on the order of megohms. A resistance of 4.7 megohms is not unusual. Several types of crystals can be used for this purpose, but the 1N64 seems quite popular with several manufacturers. The exact crystal used in any given receiver can always be determined by inspection, or by reference to the technical manuals covering that receiver.

Section 8. FILTER CIRCUIT FOR THE VIDEO DETECTOR

Earlier in this course, while studying radio detectors, it was learned that a filter circuit of some kind is desirable at the output of a diode detector. The filter serves to further separate the modulating signal from the carrier, and provides a low impedance pathway to ground for the R-F carrier.

A filter circuit is needed in the output of a video detector. Its design and appearance are somewhat different from that of the type found in radio work, but its functions are needed to serve much the same purpose.

There is not so great a difference between the highest frequencies in the composite video signal and those of the I-F carrier as is found in radio work. When the I-F carrier frequency is on the order of 26 megacycles it is only about 5 or 6 times as high as the highest composite video frequencies. This imposes some difficulties on the design of a filter circuit which will by-pass the I-F frequencies to ground, yet not have much effect on the composite video frequencies.

In general, a low-pass filter employing a choke as well as capacity has been found most effective. A diagram of such filter circuit would appear pretty much as shown in Fig. 9. A study of the circuit discloses it is merely a simple pi-filter.

An examination of the actual circuits in the chassis of a receiver may fail to disclose the capacitors of the filter. In many cases there are no actual physical capacitors, the designer merely takes advantage of the output capacity and the input capacity at the tubes involved in the circuit.

Sometimes a peaking coil is added in series with the load resistor. In that case the circuit will look something like that in Fig. 10.

Many designers use a pair of peaking coils in series in the filter circuit. This arrangement has several advantages. It provides sharper separation between the I-F carrier frequencies and the

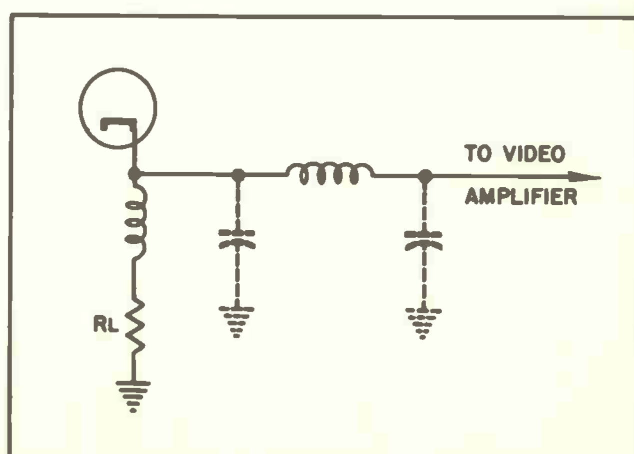

Fig. 10. Peaking coil added to output of filter circuit.

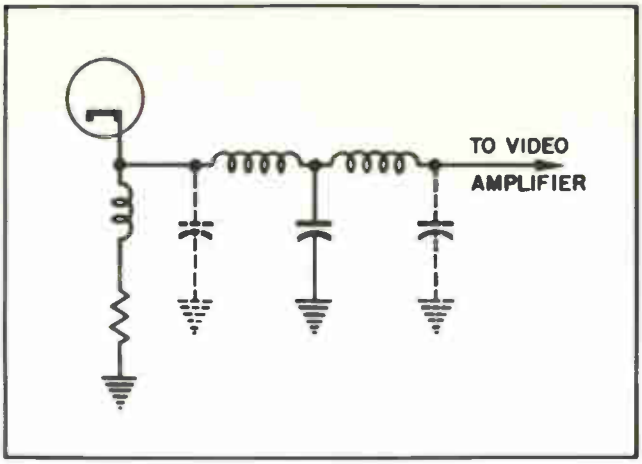

Fig. 11. Two-section Pi-filters

higher composite video signals. It also has advantages when tapping off portions of the video signal for the sync separator circuits.

A circuit employing two peaking coils in series in the filter circuit is shown in Fig. 11.

When two peaking coils are used in the filter circuit it is possible to connect an actual physical capacitor at the junction of the two coils. This provides sharper discrimination.

The inductance of the coils in the filter circuit vary from one brand or model to another. Some use inductances as low as 35 uh. (microhenries). Others use inductances as high as 100 uh.

Section 9. AUTOMATIC GAIN CONTROL

The *automatic gain control* circuit in a television receiver performs much the same duties as the automatic volume control in a radio receiver. The two circuits are not identical, however.

The nature of the composite video signal is such that it is not practical to use ordinary AVC circuits to control the gain in a television receiver, provided, of course, true control is desired. Nevertheless, many of the earlier model television receivers incorporated automatic gain control circuits which were not materially different from the AVC circuits used in radio receivers. As a matter of fact, many late model TV receivers have AGC circuits of that general type because they are simple and inexpensive.

An AGC circuit used in an early model receiver is shown in Fig. 12. That is a circuit used in the Scott Television Model 6T11.

A study of the circuit discloses the AGC circuit is virtually the same as the AVC circuit used on many radio receivers. The right half of the 6AL5 duo-diode tube is used as the video detector. The load is in the cathode circuit of the diode, being a 3900-ohm resistor. The video filter circuit is shown connected between the right-hand cathode of the 6AL5 and the following video amplifier tube.

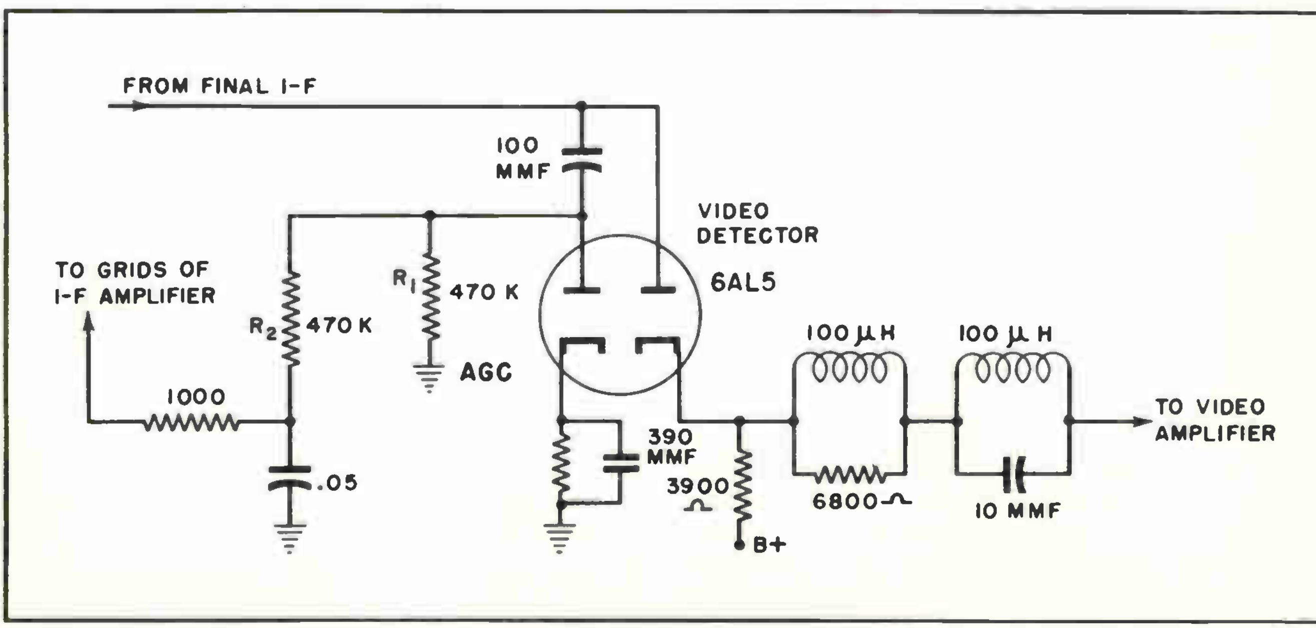

Fig. 12. Developing AGC voltage in early model TV.

The AGC circuit is fed R-F voltage through the 100 mmfd. capacitor connected in the anode in the left side of the tube. Each positive cycle of the R-F voltage causes the left-hand section of the 6AL5 to conduct.

The electrons attracted to the anode cannot pass through the 100 mmfd. capacitor, but they can move along the circuit to the left. Some leak off through the 470K resistor to ground, others pass through the second resistor, R_2, into the AGC circuit.

The voltage created by the surplus electrons in the AGC circuit is filtered by the effect of the 0.05 mfd. capacitor and the resistors. The negative voltage is then applied to the control grids of the I-F amplifier tubes.

The action of the 100 mmfd. anode capacitor, and the characteristics of the tube, are such that the R-F signal must be fairly strong before sufficient voltage is applied to the left-hand anode of the 6AL5 to make it conduct. In this respect the AGC circuits have little effect on the biasing of the I-F amplifier tubes when the incoming signal is weak.

However, when the R-F signal is stronger it places a much higher positive voltage on the anode of the AGC section of the 6AL5 each cycle, and this raises the excess of electrons in the AGC circuit, thus making the voltage in the AGC circuit increasingly negative.

The net effect of all this is that strong incoming signals raise the negative bias voltage of the I-F amplifier tubes, thus making them less sensitive. But weaker R-F signals do not maintain the AGC voltage so negative, thus I-F amplifiers have greater amplifying ability, and greater sensitivity.

A somewhat different approach to the problem of providing AGC to early model TV receivers is shown in Fig. 13. Designers of that circuit were striving to obtain a modified form of "delayed AGC" to make the receiver more sensitive when receiving weaker signals. The circuit shown in Fig. 13 is one used in a 1948 *Automatic* model TV-707, using a 7-inch picture tube.

The circuit was retained in some of their later models, and similar circuits were used in early model TV receivers built by other manufacturers. Modifications of that circuit can also be found in late model receivers.

In the circuit in Fig. 13 a 6AL5 duo-diode miniature tube has been used as the video detector and the AGC tube. The detector action is obtained in the upper half of the tube where the I-F carrier signal is fed into the cathode of the diode. The load is in the anode circuit of the upper half of the tube.

The lower half of the 6AL5 is used as the AGC circuit. The "delayed" action is obtained

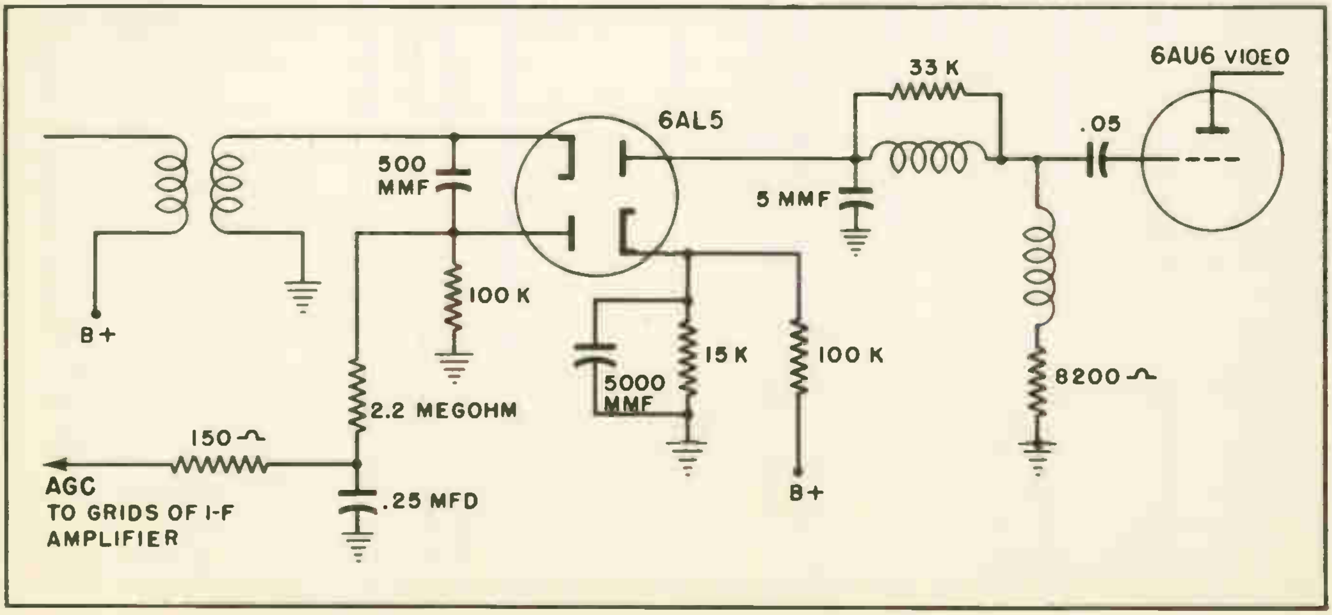

Fig. 13. Delayed AGC in early model TV receiver.

by placing a low positive voltage on the cathode of the AGC section of the 6AL5.

A study of the circuit discloses how the positive voltage is placed on the cathode of the AGC section of the tube. A voltage divider, consisting of a 100K resistor and a 15K resistor connected in series, acts to place a positive voltage on the cathode. The two resistors are connected in series between the B+ supply and ground. The major portion of the voltage drop is across the 100K resistor, so the voltage applied to the cathode amounts to that developed across the 15K resistor.

The action is such that no current flows through the AGC section of the 6AL5, and thus no electrons pass into the AGC circuit, until the R-F voltage applied to the anode becomes sufficiently strong to make the anode more positive than the positive voltage on the cathode. That provides the so-called "delayed" action.

Although the descriptive term "delayed" is applied to this type of circuit, just as it has long been applied to similar AVC circuits used in radio receivers, the term is actually a misnomer. The automatic feature of the circuit does not go into action until the signal strength reaches a given level. But the circuit goes into action *immediately* whenever the signal strength is above a given level. This means the circuit goes into action immediately if the *initial* signal level is high; there is no delay in it going into action under those conditions.

Once the level of the R-F signal is sufficiently high to make the lower half of the 6AL5 duodiode tube conduct, pulses of electron current pass through the AGC section of the tube. Each time the R-F voltage peak on the anode becomes more positive than the positive voltage on the cathode, the tube will conduct. This means electrons pass through the tube from the cathode to the anode.

On very strong signals the number of electrons which pass through the tube increases. These excess electrons pass into the AGC circuit, creating a negative voltage. This negative voltage is then applied to the control grids of the I-F amplifier tubes, and sometimes to the control grids of the R-F amplifiers.

Presence of excess negative bias voltage on the control grids of those amplifier tubes reduces their amplifying ability, thus reducing the gain of the amplifier circuits. As varying levels of R-F signal strength enter the receiver the AGC voltage varies up or down so as to counteract the variations of the R-F signal.

The net result is to hold the strength of the signal at the video detector to a fairly constant level. In its basic essentials this action is quite similar to that found in radio receivers.

Section 10. AMPLIFIED AGC

Simple AGC circuits similar to those originally employed in AVC circuits in radio receivers, were never entirely satisfactory, and are not completely satisfactory in those receivers where they are still used.

In contrast to audio-modulated R-F signals, those R-F signals which were modulated with composite *video* signals were much less symmetrical. Picture scenes which contain excessive amounts of dark picture areas affect the strength of the AGC bias voltage to a greater extent than those carrying picture information of more brilliant scenes.

The effect of this is to upset the normal contrast of the picture. Dark picture scenes generate excessive AGC negative bias voltage, thus reducing the sensitivity of the I-F amplifiers; and this, in turn, tends to make the scene more light.

The reverse is also true. Light picture scenes affect the AGC voltage in such manner that the scene is made darker than it should be. All of which interferes to some extent with the picture content on the screen of the picture tube. What it all amounts to is that the AGC circuit tends to counteract the varying levels of R-F signal strength, but in so doing acts to distort the contrast of the picture content, because it interferes with the varying average level of the composite video signal.

Naturally, this is undesirable. Nevertheless, the AGC circuits described in the preceding section were widely used in the early days of commercial television, just as modified versions of those circuits continue to be used in some commercial models.

The circuits had some good points. They were

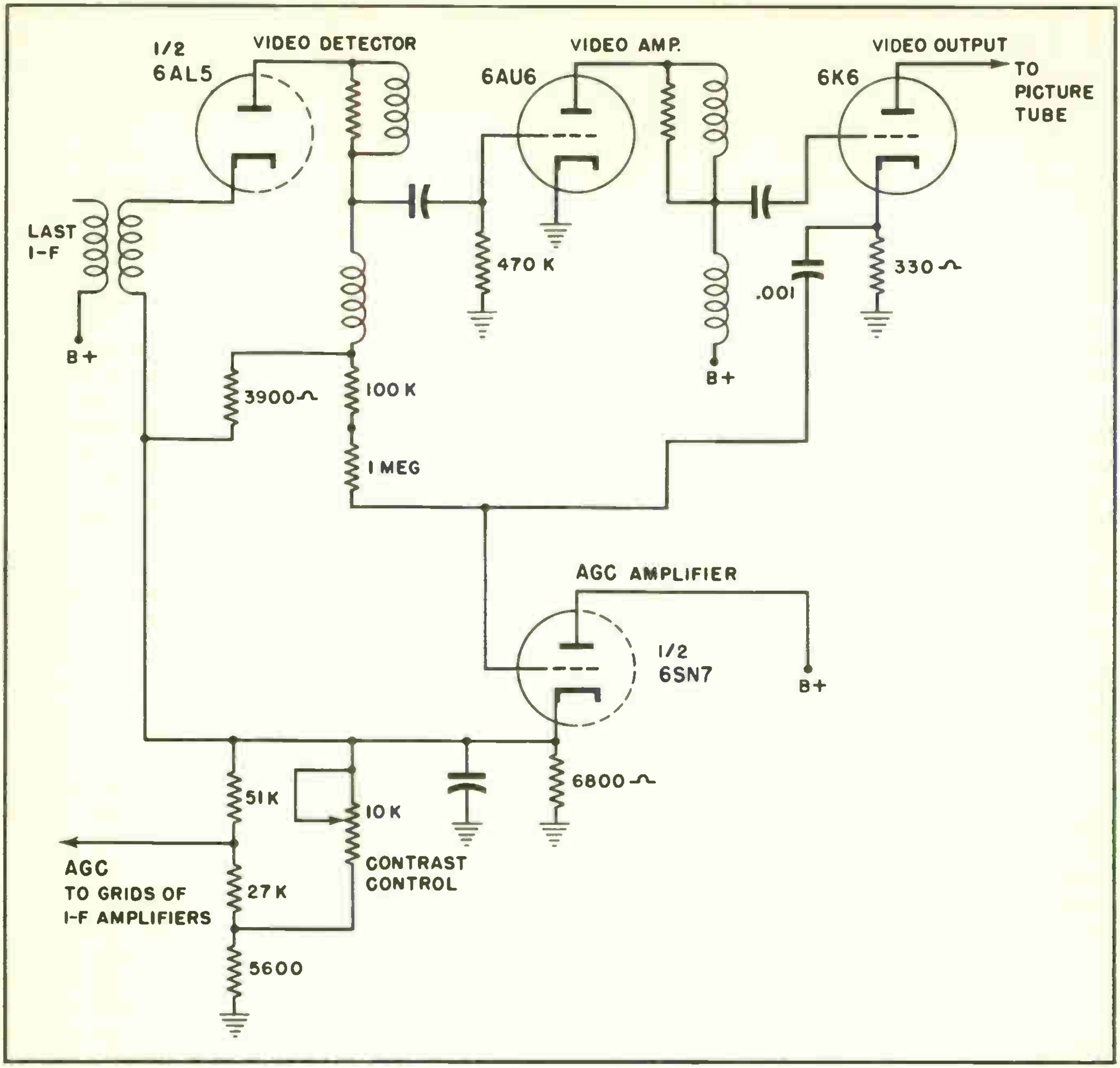

Fig. 14. AGC circuit using AGC amplifier.

relatively simple, and could be easily understood by service technicians who were already familiar with radio receiver circuits. They required no extra tubes, thus were inexpensive. The advantages were, and are, such that they are still in use in some of the less expensive TV receivers.

To overcome the defects of the simple AGC circuits designers came up with other, and newer, circuits. That shown in Fig. 14 came into widespread use, although some designers modified it with other variations not shown in that diagram. The circuit shown in Fig. 14 was used by the Starrett Television Corporation in their 1950 models.

A study of the circuit in Fig. 14 discloses that several types of controlling voltages are applied to the cathode and control grid of an "AGC amplifier" tube.

Any kind of R-F signal applied to the video detector by the I-F amplifier circuits causes electrons to move through the detector tube in the normal manner. That action makes the cathode of the video detector more positive and the anode more negative.

The positive voltage on the detector cathode is applied to the cathode of the AGC amplifier tube, thus making it more positive. At the same time, the excess electrons reaching the anode of the video detector tends to make it somewhat negative, and that negative voltage is applied to the control grid of the AGC amplifier.

Thus, the net action of applying an R-F signal voltage to the video detector is to place a positive voltage on the cathode of the AGC amplifier and a negative voltage on the control grid of the AGC amplifier. Thus, conditions are set up which tend to prevent the AGC amplifier tube from conducting.

To prevent the varying levels of the R-F signal voltage, which result from modulations of the composite video signal, from affecting the voltage on the control grid of the AGC amplifier a portion of the composite video signal is fed back to the AGC amplifier grid from the cathode of the video output tube. That composite video signal is fed back through the .001 mfd. capacitor.

When the negative voltage from the anode of the video detector tends to become strong as a result of a dark picture area, that voltage is counteracted by a positive voltage of equal magnitude fed back through the .001 mfd. capacitor at the cathode of the 6K6 video output tube.

The counter-acting action of these two voltages are such that the AGC action continues to be affected by overall *variations in R-F signal strength* but not to short-time variations due to *varying levels of the composite video signal.*

The action of this AGC circuit is somewhat different from any of those previously studied, either in radio or television. This circuit supplies a varying *positive* voltage for the AGC circuit rather than a varying *negative* voltage as is the normal practice.

The first three I-F amplifier tubes are provided with a fixed bias. This is arranged by deliberately maintaining the cathode of those tubes positive with respect to the control grids. The positive voltage for those cathodes is obtained in a variety of ways, but one of the most common is to use the positive voltage normally present at the cathode of a power amplifier tube, often the audio output amplifier.

The net effect, then, is that the cathodes of the I-F amplifiers are so positive with respect to the control grids that if the control grids were to be connected directly to ground, or B—, the tubes would have very low amplifying ability.

But the control grids of those I-F amplifier tubes are not connected to ground, or to B minus. Instead, they are connected, through the AGC circuit, to the cathode of the AGC amplifier tube. When there is no R-F signal applied to the video detector the AGC amplifier is free to conduct, and when it does conduct it places a positive voltage in the AGC circuit, and thus increases the amplifying ability of the I-F amplifier tubes.

To explain this action a little more clearly we will repeat the manner in which the various voltages are developed.

The cathodes of the I-F amplifier tubes are maintained at a positive potential. This would place a negative bias on the grids of those I-F amplifier tubes were it not for the fact the control grids are also kept slightly positive by the action of the AGC amplifier tube.

Then, when an R-F signal voltage is placed on the video detector, that action places voltages on the AGC amplifier tube of such polarity and magnitude as to reduce its conduction. As the conducting ability of the AGC amplifier is reduced it makes the AGC voltage less positive, and this makes the I-F amplifier tubes less sensitive.

The advantage of this circuit was that it permits the AGC voltage to vary only as the strength of the R-F signal varies, and not as its strength is varied by the composite video signal. Varying levels of the composite video signal, as it carries picture information for varying levels of light intensity, does not affect the AGC circuit, and thus does not affect the sensitivity of the I-F amplifiers.

Disadvantages of the circuit are that it is quite complicated, it is difficult for many servicemen to understand, it uses types of circuits which are strange to radio and TV servicemen, and it uses an extra tube. Despite these disadvantages, the circuit, with various modifications, has been used in many different models of television receivers.

Section 11. KEYED AGC

Despite the fact the amplified AGC circuit did the job it was intended to do, nobody in the television industry was satisfied with it. The circuit was quite difficult to service in the field, and when trouble developed in the circuit it was often difficult for a serviceman to decide if the trouble was in the AGC circuit or in some other part of the receiver. The symptoms were often baffling.

It became increasingly evident that some more simple type of AGC circuit was badly needed.

Along about 1950 or 1951 a new type of AGC circuit began making its appearance in television receivers. It was called *keyed AGC*.

Action of the keyed AGC circuit differs quite radically from the other AGC circuits which had been previously used. Most of the older circuits depended, in some manner, on the average magnitude of the R-F signal from the I-F circuits for their action.

Since the average magnitude of the R-F signal tends to vary with the variations in the average level of the composite video signal as well as with the changes in the signal strength such circuits were never fully satisfactory. One has only to study a graph of the voltages in two levels of composite signal voltage, such as those shown in Fig. 15, to realize that handling the AGC voltage in that manner can never be completely satisfactory.

In contrast to the manner in which the older AGC circuits obtained their reference voltage, the keyed AGC circuit obtains its reference voltage from the *average level* of the sync *pulse peaks*. Unlike the camera video signal component in the composite video signal, the peaks of the sync pulse should never vary in amplitude.

All of which means that if some arrangement can be created whereby a tendency for the sync pulse peaks to change amplitude automatically brings about a different degree of amplification in the I-F section, we then have an ideal AGC circuit. This has been accomplished in the keyed AGC circuit.

Instead of the keyed AGC circuit being fed a signal from the video detector, or from the final I-F stage, it receives its signal pulses from the video amplifier circuit. Only the tips or peaks of the sync pulses affect the control grid of the tube used with the keyed AGC circuit.

As you already know, the composite video signal may have a phase relationship such as that in Fig. 1, where the peaks of the sync pulses are positive, or it may have a phase relationship as in Fig. 2 where the peaks represent the lowest level of amplitude. The composite video signal must have a phase like that in Fig. 1 and Fig. 5 when it is applied to the keyed AGC tube.

If the video signal is fed to the cathode of the picture tube, the composite signal then has the proper phase relationship for application to the tube used in the keyed AGC circuit. Quite often the signal for the keyed AGC circuit is tapped off the video amplifier circuit just before the signal is injected into the picture tube.

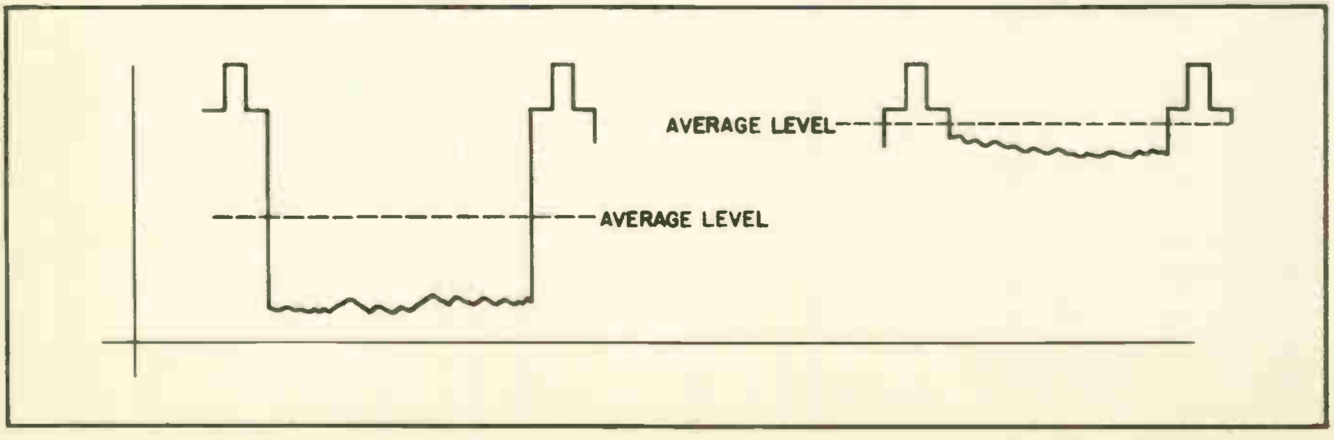

Fig. 15. Average level of composite video signal affects amplitude of R-F carrier.

Section 12. HOW KEYED AGC WORKS

In most ways keyed AGC is a relatively simple circuit, and is usually relatively easy to understand. The exact action which goes on in such a circuit can be understood somewhat better by referring to Fig. 16.

The exact circuit shown in Fig. 16 is one that is used in Stromberg-Carlson model 421CM. It is similar in most respects to keyed AGC circuits used in receivers built by many other manufacturers.

Let us first turn our attention to the voltages applied to the tube elements of the 6AU6, the keyed AGC tube. The grid is directly connected to the anode of the video amplifier section of the 6U8, which causes the control grid of the 6AU6 AGC tube to be approximately 80 volts positive. (The 6U8 is a double section tube, one section being a triode, the other a pentode.)

Such high positive voltage on the grid of an amplifier tube would normally make it highly conductive. However, in this case a positive voltage amounting to 100 volts is placed on the cathode.

Thus, despite the fact the control grid is highly positive with respect to ground, it is actually negative with respect to the cathode. It has 20-volt negative potential with respect to the cathode.

Even with a high positive voltage on the anode the tube would be at cut-off with such high negative voltage on the grid. But an examination of the anode circuit discloses the fact the anode voltage is actually negative. Thus, the voltages being what they are, the tube does not conduct.

Now let us turn our attention back to the grid circuit. Since the grid has such high negative voltage on it the camera video signal leaving the 6U8 video amplifier has no effect on the grid of the 6AU6 AGC tube. But 15,750 times each second

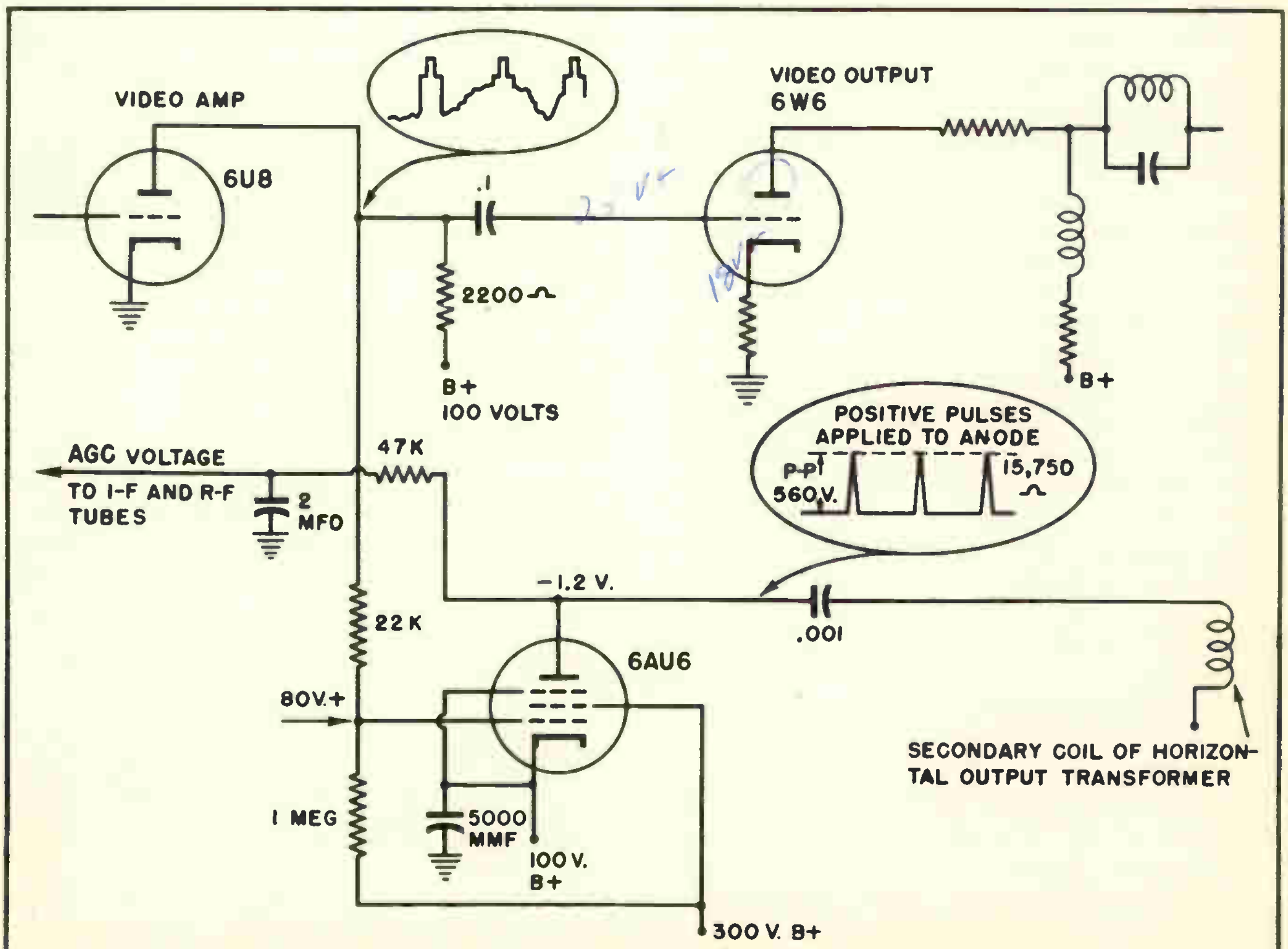

Fig. 16. Basic circuit for keyed AGC.

a strong pulse of positive voltage strikes the control grid of the 6AU6. Those positive voltage pulses represent the horizontal sync pulses of the composite video signal.

These sync pulses are sufficiently strong to make the control grid of the 6AU6 momentarily positive with respect to the cathode.

However, the mere fact the control grid is momentarily positive, and the tube momentarily set up for conduction, does not necessarily cause any electrons to pass through the tube. This is because the anode is normally slightly negative, and thus is in no position to attract electrons.

It is at this instant another factor comes into play.

The horizontal sync pulses trigger the horizontal oscillator to bring about the retrace action in the picture tube which returns the electron beam from the right side of the tube back to the left side. This means that immediately after the horizontal sync pulse hits the amplifier circuits the beam suddenly reverses its movement toward the right, and starts its retrace to the left side of the screen.

That sudden reversal of current in the horizontal output transformer creates a sudden peak voltage in the secondary of that transformer. We have not yet taken up the study of the horizontal output transformer, but its electrical action is not materially different from that of any other transformer.

A sudden reversal, or any sudden change, in the current flowing in the coils of any transformer creates sudden, short-lived peak voltages many times higher than those normally present.

In the case of the horizontal output transformer, when the current through the coils sud denly reverses, the voltage induced in those coils suddenly rises to very great peaks. In many instances the voltage peaks in and around the horizontal output transformer rises to many thousands of volts.

Only a relatively small portion of the voltage developed in and around the horizontal retrace action is used with the keyed AGC circuit. The exact manner in which that voltage is tapped off varies from one receiver to another. In the case we are studying here the voltage is tapped off by simply tapping the secondary winding.

That tap is connected to the anode of the keyed AGC circuit tube, the 6AU6, through a .001 mfd. capacitor.

Since the electron beam sweeps across the screen of a television receiver 15,750 times each second, this means a positive voltage peak is developed across the .001 mfd. capacitor 15,750 times each second. That is exactly the same number of positive voltage peaks which are applied to the control grid of the same tube from the video amplifier.

The action, then, is this: at the same instant the sync pulse from the video amplifier is applying a positive voltage pulse to the control grid of the 6AU6 the horizontal transformer is also applying a strong positive voltage pulse to the anode of the tube. The presence of the positive voltage peak on the grid, simultaneously with the positive voltage pulse on the anode, causes the tube to conduct.

The amount of conduction which takes place depends on the amplitude of the sync pulse placed on the control grid. If the signal coming from the video amplifier, and thus from the I-F section through the video detector, is strong, the passage of electrons through the tube is quite strong. On the other hand, if the sync pulse is weak the number of electrons which pass through the tube are fewer.

The point is this:—after the electrons pass through the tube, to the anode circuit, they are trapped. They cannot return through the tube nor can they pass through the .001 mfd. capacitor to the source of the momentary positive voltage. The only outlet for them is through the 47K resistor into the AGC circuit.

What this adds up to is this: when the sync pulses are strong the AGC voltage is made more negative. When the sync pulses are weaker, the AGC voltage is not so strong.

This explanation can be carried a step further. When the sync pulses are strong the negative bias voltage applied to the control grids of the I-F and R-F amplifier tubes is greater, thus reducing their amplifying ability and making them less sensitive. When the sync pulses are weaker the negative bias applied by the AGC circuit is weaker, and the tubes become more sensitive, and any signal passing through them is amplified to a greater degree.

The action is automatic. If the R-F signal picked up by the antenna circuit tends to increase in signal strength the AGC circuit acts to decrease the amplifying ability of the R-F and I-F amplifiers, and thus make the receiver less sensitive. On the other hand, should the incoming R-F signal become weaker the AGC negative bias voltage drops to lower levels, and the receiver becomes more sensitive.

A keyed AGC circuit, acting only on the peaks of the horizontal sync pulses, which normally represent the highest degree of amplification of any part of the composite video signal, is not affected by varying levels of the camera video signal. The camera signal can vary up and down over wide ranges, but the AGC is not affected in any manner.

Nor is the keyed AGC circuit affected by ambient (local) electrical noises. Electrical static, such as lightning, and other types of electrical noise may pass through the signal circuits on the R-F and I-F carrier, and may even get into the video amplifier circuits. But they do not affect the keyed AGC circuit, and do not affect the degree of bias applied to the amplifier tubes. The AGC tube is not capable of conducting except in the very short interval during which a strong positive pulse is applied to the anode through the .001 mfd. capacitor from the horizontal transformer. Should other electrical voltages reach the control grid, regardless of how strong they might

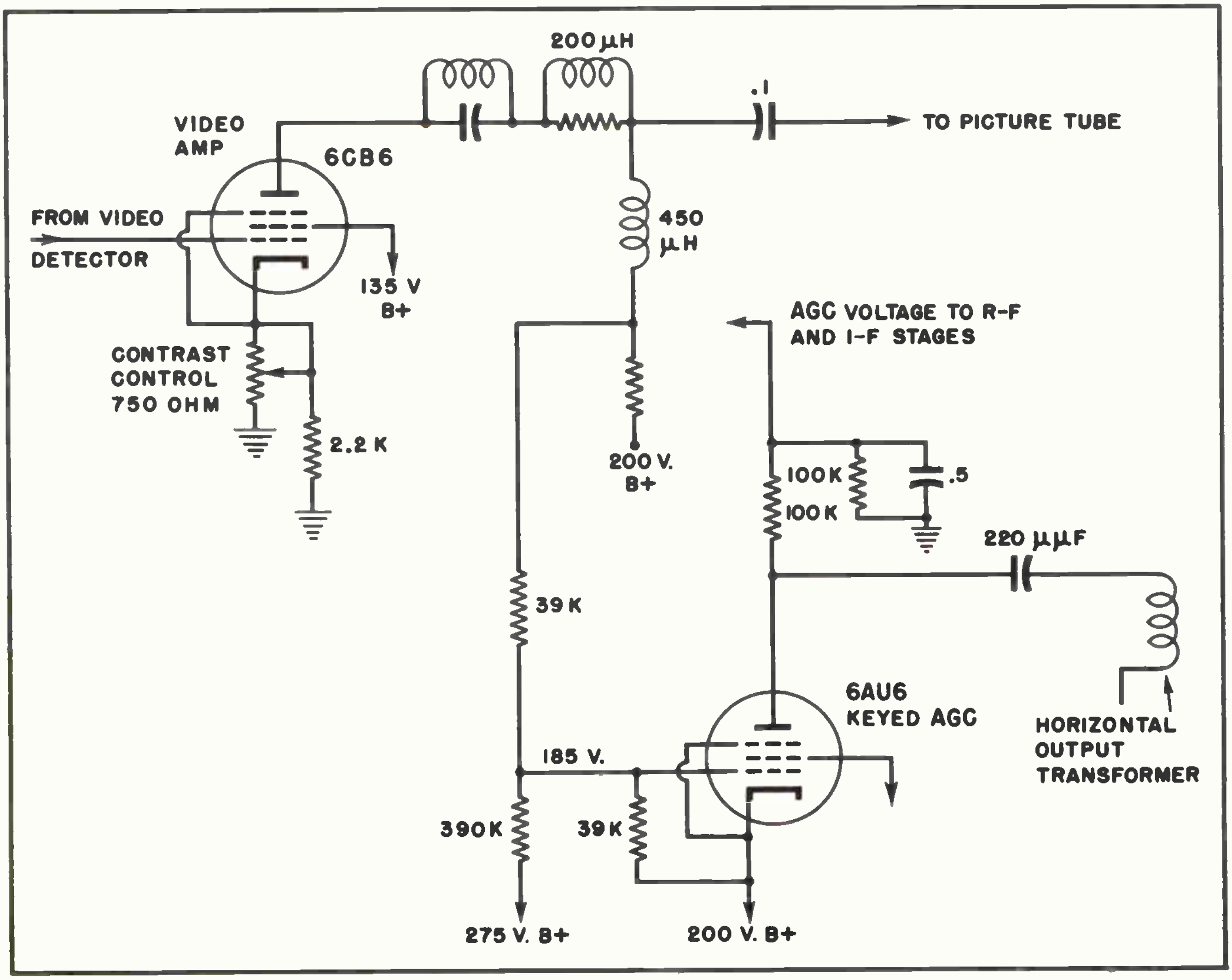

Fig. 17. Modified circuit for keyed AGC.

be, it is impossible for them to make the tube conduct.

Various manufacturers modify the keyed AGC circuit in certain ways to meet special conditions found in their receivers. But they do not normally vary in major respects from the circuit shown in Fig. 16.

Pacific-Mercury TV receivers use a somewhat different circuit, but there are no major differences in it. Fig. 17 shows the keyed AGC circuit used in Pacific-Mercury receivers. The voltages on the control grid and cathode of the keyed AGC tube are slightly higher than those used in the Stromberg-Carlson receiver. There are slight differences in the values of some of the resistors and capacitors used in the circuit, and there are other differences in some of the other components

Section 13. KEYED AGC USED IN EARLY ZENITH RECEIVERS

The Zenith Radio Corporation rarely uses a circuit in one of their radio or television receivers which is used by other manufacturers if there is any way they can change the circuit to make it different.

This is not to say the circuits they use are inferior in any way, because that would not be true. The company manufactures fine radio and television receivers, some of the finest on the market.

But the fact still remains that many of their circuits are different, and it is well to treat some of them separately.

Zenith modified the keyed AGC circuit to some extent when they first used it in their TV receivers. The circuit shown in Fig. 18 is one they used in some of the earlier models. This was used in some of their 1951 models.

Sync pulses for the keyed AGC tube are tapped off the first video amplifier at its cathode. The signal voltage which is tapped off the video amplifier represent that which is developed across the cathode resistor of the first video amplifier.

These signals are fed to the cathode of the

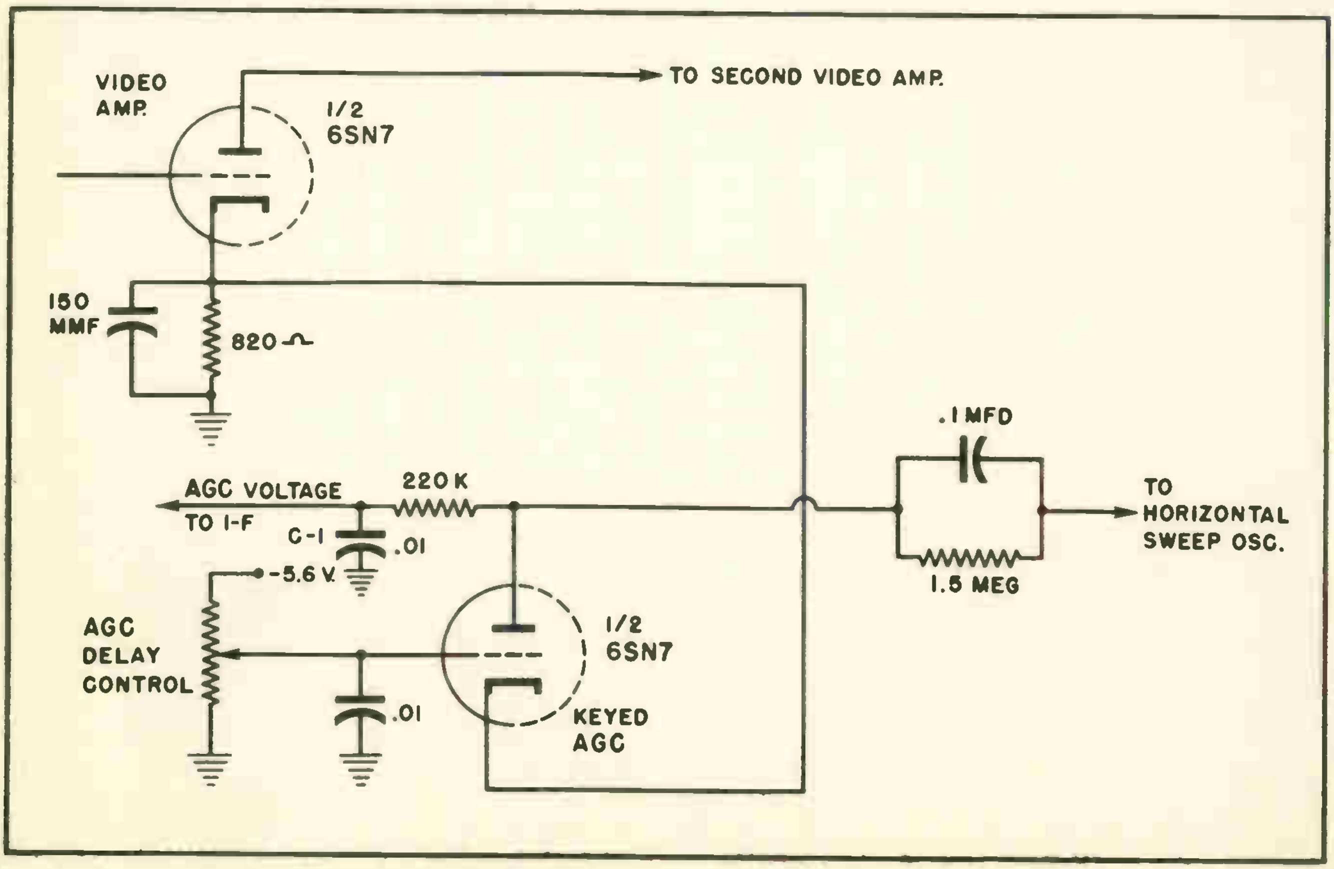

Fig. 18. Keyed AGC circuit used on early model Zeniths.

keyed AGC tube, which is one-half of a 6SN7 duo-triode.

The polarity of the signal is such that the pulses are negative when applied to the cathode of the keyed AGC tube.

Voltage pulses are fed to the anode of the keyed AGC tube. These pulses originate at the cathode of the horizontal oscillator.

This is in contrast to the origin of similar voltage pulses applied to the anode of the keyed AGC tube in many other receivers. The voltage pulses in circuits like those in Figs. 16 and 17 originate in the horizontal output transformer.

In the Zenith receiver the voltage pulses are a modified sine wave rather than being sharply peaked as in Figs. 16 and 17. Nevertheless, the positive half-cycle of the sine wave voltage fed back from the horizontal oscillator coincides with the arrival of a negative sync pulse on the cathode of the keyed AGC tube.

With the cathode sharply negative and the anode going positive the tube is in condition for momentary conduction. (In this connection you must remember that negative pulses on the cathode have the same effect as positive pulses on the anode or control grid.)

When the AGC tube conducts it serves to charge C-1, the AGC filter capacitor, with a negative voltage. When the signal is strong, and thus the pulse of current through the tube is strong, the capacitor charges up with considerable negative voltage. On the other hand, when the incoming R-F signal is weak the capacitor C-1 does not charge up with so much negative voltage.

The negative voltage which appears across capacitor C-1 acts as the AGC voltage, and is applied to the control grids of the first three I-F amplifier tubes. This circuit provided reasonably good AGC action.

One interesting item in connection with this particular circuit is the presence of the *AGC Delay Control*. A study of the circuit diagram discloses the fact that the delay control is merely a means for adjusting the bias on the control grid of the keyed AGC tube.

The effect of this control is to adjust the sensitivity of the AGC circuit for various conditions of signal strength. This potentiometer is usually mounted on the rear panel of the chassis where it is readily accessible to the service technician.

At the time the receiver is put into operation at the user's home the installing technician adjusts that control to accommodate the type of reception normally present in that area. This is actually a "fringe area control" similar to others discussed later in this lesson.

This means that in strong signal areas the control can be set for one sensitivity, but in fringe areas, where the signal is weak, it can be set for a different sensitivity. Since the strength of the AGC voltage has a strongly determining influence on the sensitivity of the receiver this control is able to adjust the normal, or minimum, level of the AGC voltage.

Section 14. CLAMPER CIRCUIT FOR KEYED AGC

It is often desirable to remove all AGC bias voltage from the R-F amplifier tube when the signal is very weak, yet retain some degree of AGC voltage on the I-F amplifier tubes. In order to bring this about special *clamper circuits* for use with keyed AGC have come into use. These "clamper circuits" should not be confused with D-C restorer circuits which are also called clamper circuits.

One might argue that the AGC bias voltage should be self-regulating in this respect. To a certain extent that is true.

Even when the signal is extremely weak it often varies from moment to moment between varying degrees of weakness. It is desirable to have some type of automatic control over those varying degrees of signal weakness, but it is not always desirable to have that control applied to the R-F amplifier tubes when the signal is extremely weak.

On the other hand, when the signal is quite strong it is often desirable to have as much AGC action as possible, especially in the more sensitive receivers. In that case it is desirable to have the AGC voltage applied to the R-F amplifier as well as to the I-F amplifier tubes. When the signal is strong AGC control on the R-F amplifier is more effective than on the I-F amplifier.

A clamper circuit for use with keyed AGC is shown in Fig. 19. A study of the circuit shows the main part of the circuit is quite similar to that of Fig. 17. The circuits are not identical, but they are quite similar.

The action of the 6AU6 keyed AGC tube in developing AGC voltage in Fig. 19 is much the same as that in Fig. 17, and so far as the AGC voltage for the I-F amplifier tubes is concerned the actions in the two circuits are almost identical.

But a closer study of Fig. 19 discloses the fact that AGC voltage for the R-F amplifier tube in the tuner is tapped off separately from that for the I-F amplifier tubes. The tap for the R-F tube AGC voltage is separated from that for the I-F tube AGC voltage by a 39K resistor.

Under normal operation the three resistors in series in the anode circuit of the 6AU6 constitute a voltage divider network. These are resistors R-1, R-2 and R-3.

Notice that R-3 is also a part of another voltage divider network consisting of R-3 and R-4. This second voltage divider network is between ground and B+ voltage of 325 volts.

Let us first direct our attention to point "A-1" in the circuit. That is the junction between R-2 and R-3. It is also the junction between R-3 and R-4. Furthermore, it is also the point at which the AGC voltage for the R-F amplifier tube is tapped off.

Let us suppose that the line between that junction point and R-4 is open temporarily. We can do this for the purpose of explanation. We would then find that the voltage developed across R-3 as the result of AGC voltage from the 6AU6 amounts to approximately 1 volt negative.

Now let us reconnect the line from R-4. Because that line leads to a B+ voltage it brings a positive voltage to the junction point we have designated A-1.

The exact magnitude of that positive voltage is determined by the ratio of resistance in R-3 and that in R-4. The diagram shows R-3 has a

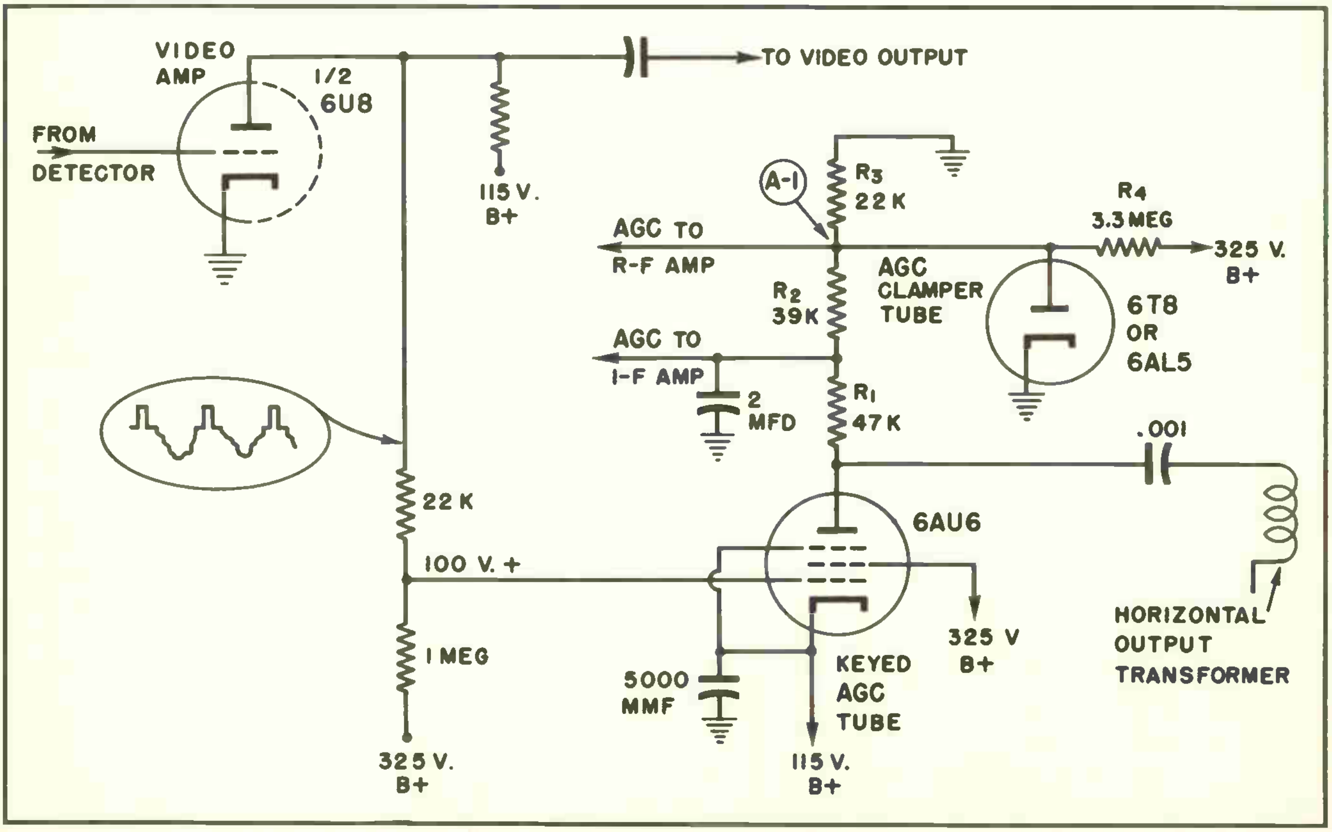

Fig. 19. Clamper circuit for keyed AGC.

resistance of 22K while R-4 has a resistance of 3.3 megohm. Thus, R-4 has a resistance about 150 times as great as R-3.

Because of these resistance ratios the line from R-4 brings a positive voltage to junction point A-1 amounting to approximately 3 volts. At least it would if it were not for the clamper tube.

The net result of combining the 3 positive volts from the R-4 line and the 1 negative volt from R-2 and the 6AU6 tube, is to make junction point A-1 normally about 2 volts positive.

However, the facts just stated fail to take into account one very important element. That is the action of the diode clamper, which is sometimes one-half of a 6AL5 and sometimes a diode section of a 6T8 miniature tube.

The internal resistance of a diode is very low. Even the two positive volts applied to the anode of the diode is sufficient to cause the tube to conduct.

And the tube does conduct. It conducts just enough so the positive voltage applied to R-4 actually divides across R-4 and the diode tube rather than across R-4 and R-3. This action has the effect of clamping the voltage at junction point A-1 to ground potential.

This all adds up to the fact that under normal conditions the voltage at junction point A-1 is the same as ground, and also means the AGC voltage applied to the R-F amplifier is zero.

The action described here is based on the very high resistance of R-4, and the fact that the internal resistance of the diode clamper tube is very low when it conducts.

Let us now take another look at the circuit in Fig. 19. We find that junction point A-1 is also in the anode circuit of the 6AU6 through the coupling of R-1 and R-2. This means that when the voltage pulses applied to the 6AU6 cause that tube to conduct, the voltage at junction point A-1 will become more negative. Just how negative that point becomes depends on the strength of the pulses applied to the 6AU6, which in turn depends on the strength of the R-F and I-F signals.

In action, sufficient negative voltage is developed in AGC circuits to reduce the sensitivity of both the R-F and I-F amplifier tubes. This is especially true when the incoming signal is strong, and the sync pulses are strong.

But when the incoming signal is weak there is not enough negative voltage developed in the series network in the anode circuit of the 6AU6 to make junction point A-1 negative. Thus, no negative bias is applied to the R-F amplifier tube. This maintains the R-F tube in a state of high sensitivity when the incoming signal is weak, but when the signal is strong AGC negative bias is applied to the R-F amplifier as well as to the I-F amplifier tubes.

It is not possible to describe all the several variations of the clamper circuit used with keyed AGC. However, most such variations are in the nature of modifications of the basic circuit rather than being fundamentally different. Usually a study of a diagram of a given circuit, with special attention paid to the values of the circuit components, and the amplitudes of the voltages, provides a clue to the exact manner in which the circuit operates.

Section 15. WHY AGC VOLTAGE IS NEEDED

Oddly enough, when television first came on the market it was not thought that any kind of automatic control would be necessary to control the level of the incoming signal as the AVC circuit in radio receivers had controlled the signal level in a radio. It was believed the conditions under which television would operate were so different from those under which radio receivers operated that any such automatic circuit would not be needed.

It merely goes to show what poor prophets even the most experienced engineers can be.

As a result of that line of thinking the earliest models of TV receivers did not incorporate any AGC or AVC circuits at all. Each stage of R-F amplification and each of the I-F amplifiers were made as sensitive as possible, and thus every effort was made to build up the signal as much as possible. All control over the magnitude of the signal was provided by the contrast control.

In the early model TV receivers, much as with the earliest radios, control over the signal strength was achieved by manual adjustment of the bias on the I-F and R-F amplifier tubes. It was several years before the contrast control was moved toward the later stages of signal amplification, and it found its place near the video detector or the video amplifier.

But it did not take long to discover that television signals were subject to peculiar variations of strength in matters utterly foreign to radio reception. Some of these peculiarities resulted from the very short wave-length of the signal, others resulted from atmospheric conditions, and others resulted from still other things.

It all added up to the fact that some form of automatic control over the strength of the incoming signal was necessary.

Probably the need for such automatic control was underscored more emphatically by what became known as "airplane flutter" than any other one thing. But other contributing causes of signal strength variations annoyed viewers in other viewing areas.

The peculiarly annoying condition known as "airplane flutter" was most pronounced near airports, but it was not completely unknown elsewhere. Reflections of high-frequency TV signals off speeding airplanes brought about a condition in a TV receiver in which the pattern on the screen became alternately very dark and very light. The illustration in Fig. 20 provides a clue to the cause of this trouble. The condition usually occurs when the airplane is above the signal and between the transmitter and receiver.

Similar reflections can bring about picture patterns that are called "ghosts." But at the moment we are not concerned with the matter of ghosts so much as *flutter*.

Ghosts develop when the path from the transmitter to the reflecting body (airplane) is *considerably* longer than that directly from the transmitter to the receiver antenna, such as reflection from beyond the receiver. *Flutter* occurs when the reflected path is only *slightly* longer than the direct path, and when the reflecting body is moving. (The subject of ghosts will be gone into more thoroughly in a later lesson.)

TV carrier signals, like all other radio signals,

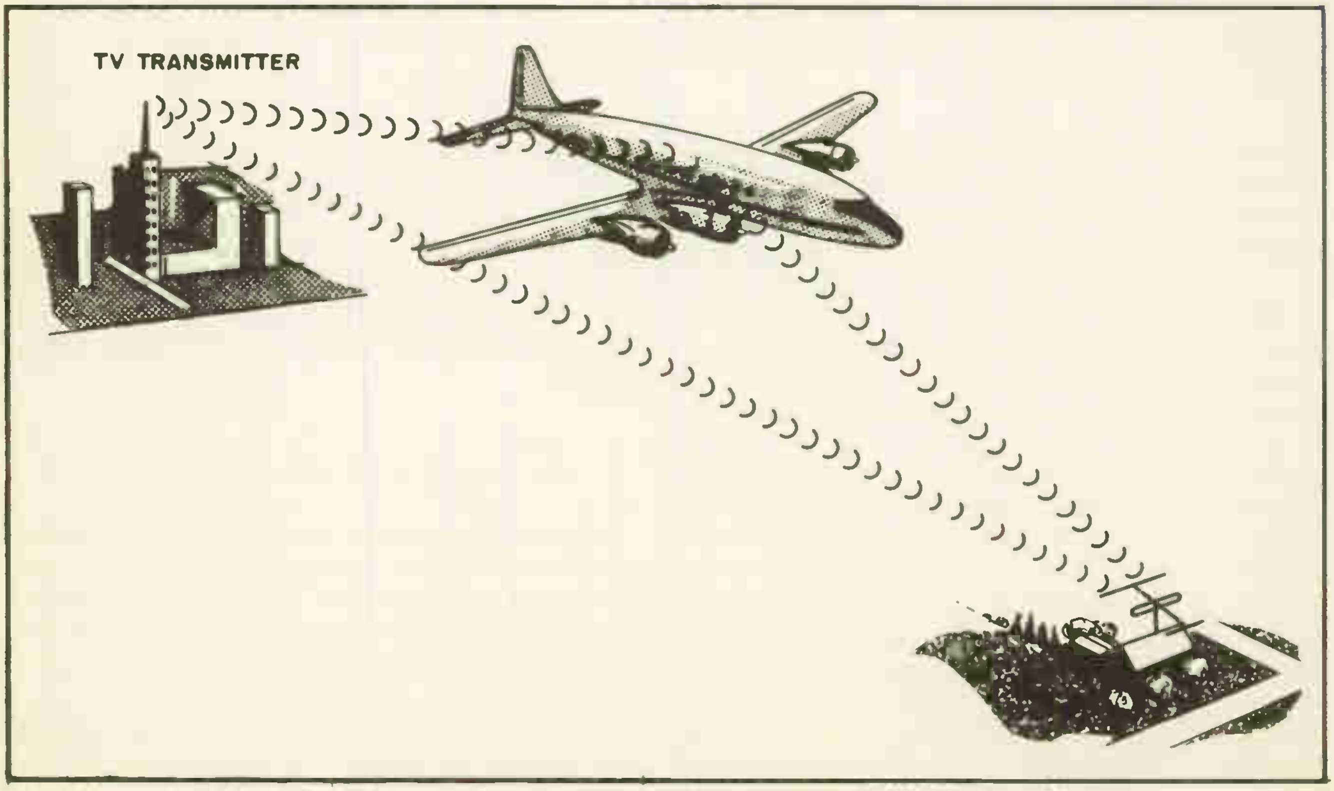

Fig. 20. Signal reflections from moving plane combine with direct signals from transmitter to produce "airplane flutter."

consist of cycles which are alternately positive and negative. This you well know, but we mention it here merely as a preliminary to our explanation of airplane flutter.

When a signal is reflected from a reflecting body, such as an airplane, it is inevitable that the path of the reflected signal is somewhat longer than that which travels over the direct path.

If a given signal leaves the transmitting antenna, part may go directly to the receiving antenna, as in Fig. 20, and part along a reflecting path. But both will be exactly the same signal, and both will have the same phase relationship at the instant they *leave* the transmitter.

Due to the fact the signal following the reflecting path takes a fraction of a microsecond longer to reach the receiving antenna it is entirely possible for the reflected signal to be in the positive half of a cycle at the same instant the direct signal is in the negative half of a cycle. When that occurs there is a tendency for the two signals to partially cancel each other, so the only signal strength which affects the receiver is the difference in strength between the two signals.

If the signal is being reflected from a moving airplane the distance the reflected signal has to travel varies from moment to moment.

As the plane flies through the sky the two signals cancel each other at one moment, then a moment later we have the opposite condition where both are going through their respective cycles together at the same time. Under the second condition the two signals supplement each other, and the total signal applied to the receiver is much stronger than normal. This makes the picture on the screen during that moment very strong and very brilliant.

As the airplane continues to fly its course the path of the reflected signal continues to change. The speed with which the path changes depends on the speed of the plane, the frequency of the TV signals, the direction in which the plane is flying, and several other variables.

But in all cases, the strength of the TV signal which actually reaches the R-F tuner section of the receiver varies from one moment to the next. Sometimes the variations are rapid. In fact, it is possible for the signal strengths to change so rapidly the eye cannot follow them. But those are not any problem to the viewer or the serviceman.

At the other extreme, if the course of the plane is just right, it may take several seconds for the picture strength to change from extremely high level to the extreme low level. In this case the variation in the level of the picture may be so slow the viewer is not aware of it, or he may attribute the variation to some other cause.

It is those cases in which the signal level changes fairly rapidly, going through the light-dark-light cycle once every second or less, that are troublesome.

A television receiver which has a properly designed AGC circuit is able to hold the signal level at the detector reasonably steady, and airplane flutter is not a matter of concern.

Turbulent atmospheric conditions in mountainous areas also affect the signal strength which reaches the antenna of a TV receiver. The exact nature of such disturbances is not fully known, although it is known that some types of atmospheric conditions provide a better reflective surface for high-frequency TV signals than other conditions.

When such atmospheric conditions are undergoing rapid changes they often affect the strength of the signal which reaches a given receiver antenna. But if the receiver is properly equipped with a good AGC circuit the viewer is often not aware the signal reaching his antenna is undergoing changes in strength.

Section 16. CRYSTAL DETECTORS

In the very earliest days of radio, even back in the so-called "wireless" days, crystals were used almost universally as detectors. Certain types of natural crystals, such as galena, silicon, germanium and others had the ability to pass an electrical current in one direction, but restrict its flow in the opposite direction.

This peculiar electrical property was just what was needed to rectify the high-frequency R-F signals used in the transmission of radio signals, and thus make it possible to apply the signals to earphones.

When vacuum tubes came into use crystals lost their popularity as rectifiers. The new vacuum tubes could amplify the signal at the same time it was being rectified. Since amplification was vitally important crystals soon lost favor, and little was heard of them for many years.

During world war II germanium crystals began to stage a comeback. They were used in many radar receivers, in which they served as a mixer. The incoming R-F radar signals, together with signals from a high-frequency internal oscillator, were both fed into a germanium crystal. The action of the germanium crystal served to mix the two frequencies together so it became possible to tap off the difference frequency, so it could be fed to an I-F amplifier.

Research into germanium and silicon crystals continued after the war. One important side-product of that research was the development in 1948 of the first practical transistor. But of more immediate importance to the great television industry was the development of newer, and more effective, types of diode crystals which could be used in the video detector circuits.

Basically, there is little difference between the germanium diode crystals used as video detectors in modern television receivers and those used so many years ago as detectors in the early-day wireless receivers. But from a standpoint of efficiency, and controlled quality and reliability, those used today are far superior.

There are several diode crystals which are able to do a good job as a video detector. The one that seems to be most favored by design engineers is the 1N64.

The 1N64 is used not only as a video detector in many receivers, but as an R-F mixer in many UHF TV tuners. We go into much greater detail concerning the use of crystal diodes in UHF tuners in a later lesson, one which is devoted solely to that subject.

There is little difference in the signal circuit of a crystal diode and that of a vacuum tube diode. In general, the crystal diode introduces less stray capacitance into the signal circuit, therefore the load resistance can be somewhat higher than that used with a vacuum tube diode. Despite the higher

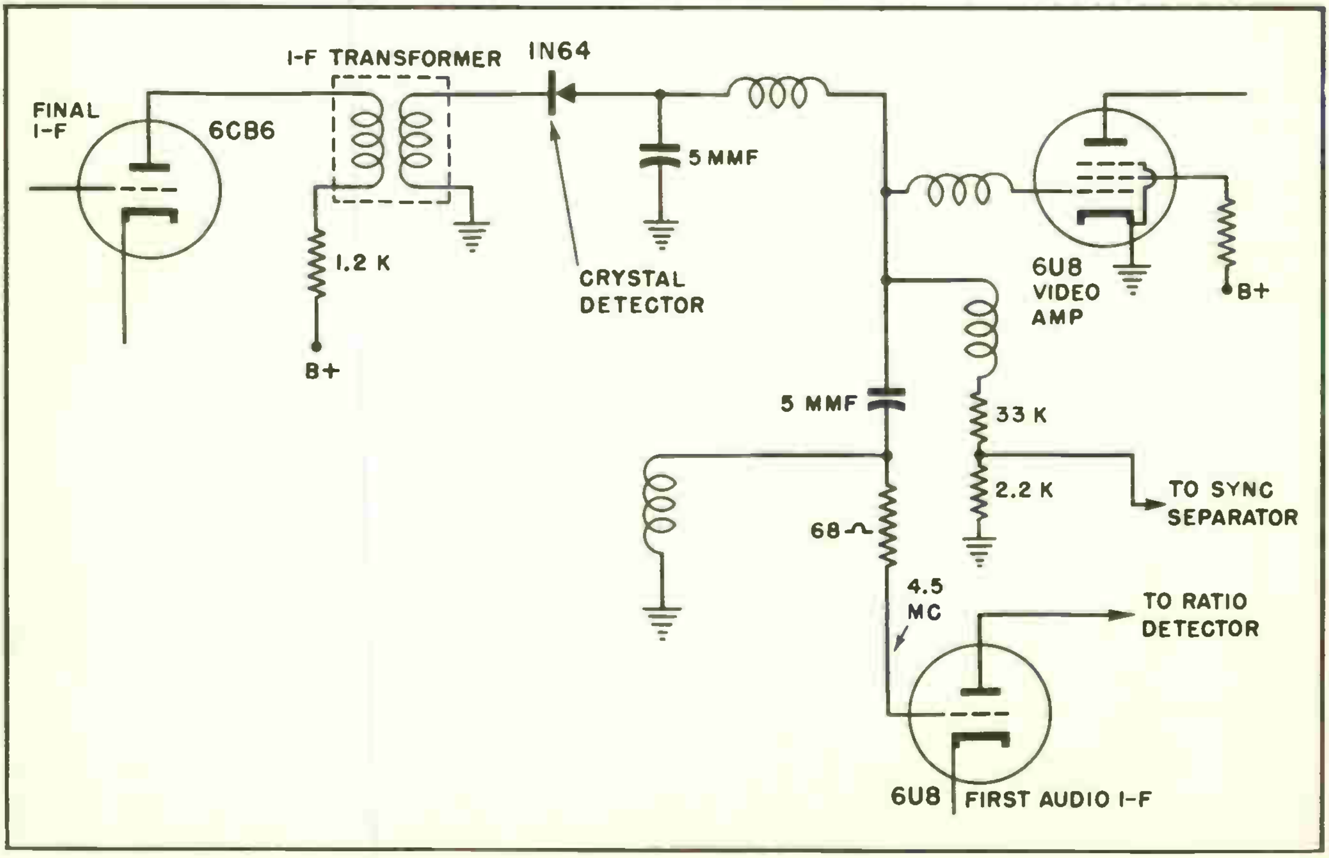

Fig. 21. Circuits surrounding crystal detector.

internal resistance of the crystal diode, its ability to take a slightly higher load resistance makes it possible for the crystal to deliver a stronger signal in some cases.

The principal advantages of using a crystal diode rather than a vacuum tube diode as the video detector are matters of economics. The crystal diode is far smaller than even the smallest vacuum tube; it is easier to install, and it requires no filament power. Barring accident it lasts almost indefinitely; much longer than a vacuum tube. In addition to these advantages, the original cost is often less than that of installing an equivalent vacuum tube.

A study of the circuit in Fig. 21 shows the similarity between circuit elements in a video detector which uses a crystal diode and one in which a vacuum tube is used. The circuit shown is one used in a Stromberg-Carlson receiver, but it is typical of those found in most other TV receivers which use the crystal.

A slightly different arrangement has been followed by Zenith in some of their receivers. The circuit in Fig. 22 shows some of the details of the crystal detector they use in their model 19K20.

The major difference between Zenith design and that followed by other manufacturers is in the physical features rather than electrical ones. Zenith builds its final I-F transformer, its crystal video detector, and its detector circuits as a completely integrated unit. This has been made possible by the fact the crystal requires no filament supply, thus can be mounted anywhere.

Service on the detector section on one of these models consists of merely removing the entire unit from the receiver, then replacing it with an identical unit built by Zenith. This means the specific part must be purchased from Zenith, but the actual servicing is quite simple.

Franchised Zenith dealers and service companies enjoy a genuine advantage in this respect. Specialized parts are not readily available to anyone except franchised representatives. This makes it difficult for outsiders to do many types of service work on Zenith products, but makes it very convenient for those who have a franchise.

Section 17. WHERE THE DETECTOR SIGNAL GOES

Output signals from the video detector have several destinations. In this respect the video detector differs from its counterpart in a radio receiver.

The principal component of the video detector, of course, is the camera signal which goes through the video amplifier to the picture tube. But that is only a part of the signal which appears at the output of the video detector.

The block diagram in Fig. 23 gives a pretty good idea of the various kinds of signals found in the output of the video detector. In addition to the camera video signal for the picture tube there are the sync pulses for the sync separator circuits, the 4.5 mc sound I-F signal for the sound ratio detector, and the signals for the AGC circuit.

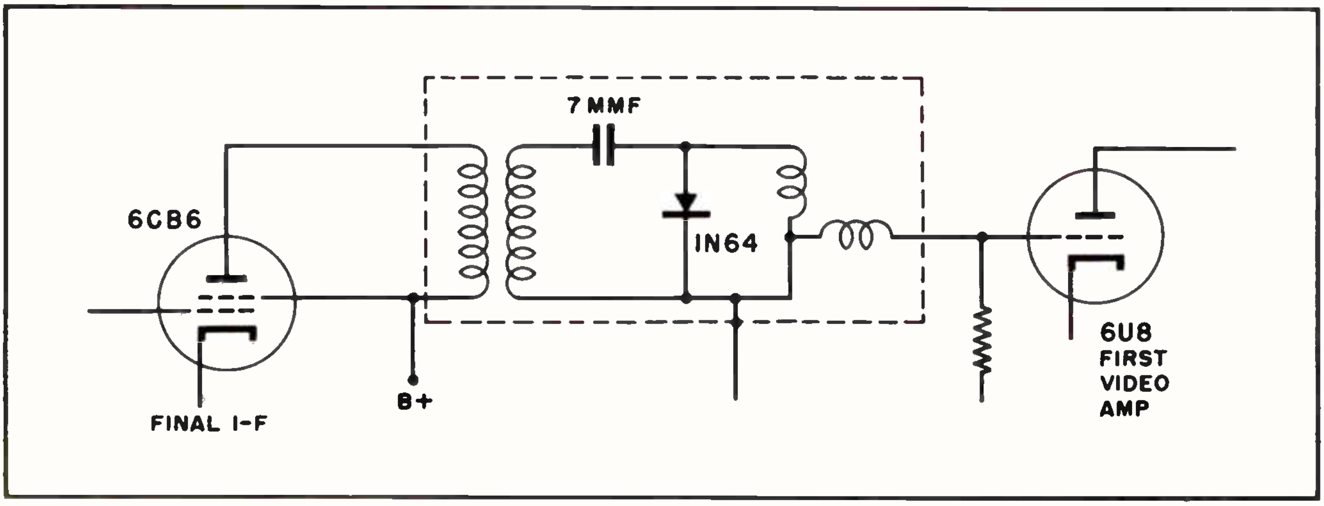

Fig. 22. Crystal detector in Zenith receiver.

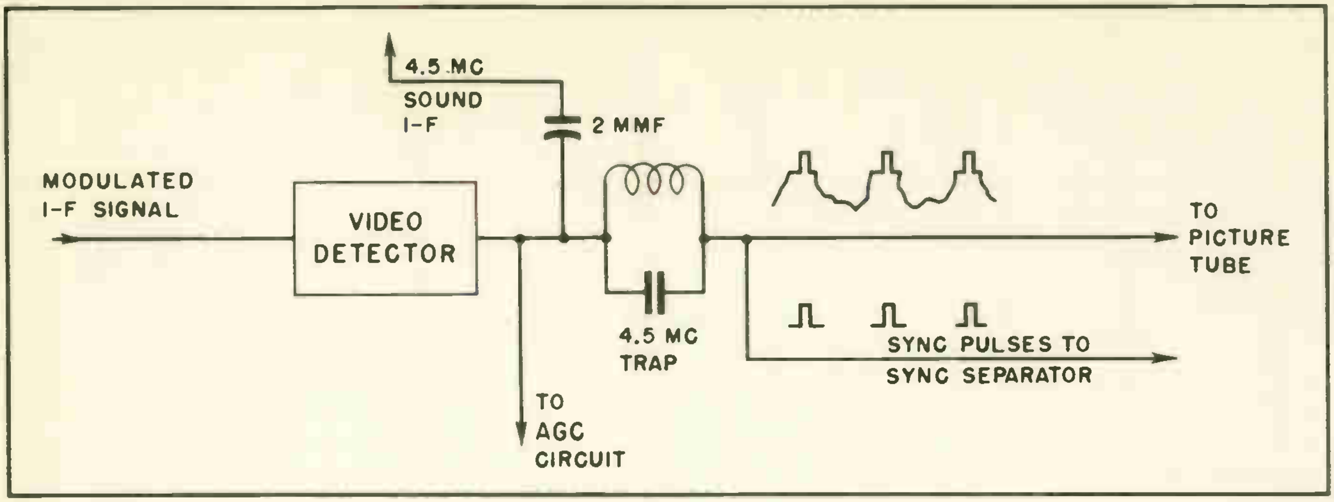

Fig. 23. Signals at output of video detector.

These signals are not always separated from each other in exactly the manner shown by the block diagram. The AGC signal, for example, may be tapped off directly at the output of the video detector, or it may be tapped off a later stage of the video amplifier. Much the same is true of the synchronizing pulses for the sync separator circuit.

We have not yet gone into the sync separator circuits. They are the subject of a lesson immediately ahead of us. But that does not keep us from mentioning them at this time.

The manner in which the sound is separated from the other signals depends to a considerable extent on the type of I-F amplification used in a given receiver. There are two general systems in common use for amplifying the I-F signal. They will both be described and explained in a later lesson which takes up the subject of I-F amplifiers. One system is called the *intercarrier* system of I-F amplification. The other system has had several names, but the one which seems to find the most favor at this time is *split-sound* system of I-F amplification.

When the intercarrier system of I-F amplification is used the sound I-F signal has a frequency of 4.5 megacycles, and is tapped off the circuits which follow the video detector.

The favorite method is to tap off the sound I-F immediately following the video detector by inserting a 4.5-megacycle trap in the circuit to the first video amplifier. The sound I-F signal is tapped off by using a very small capacity capacitor. The coupling capacitor rarely has a capacity greater than 5 mmfd. and far more often it has a lower capacity. A capacity of 2 mmfd. is favored by many designers.

When the split-sound system of I-F amplification is used the sound I-F is separated from the video I-F in one of the I-F amplifiers preceding the video detector. Often it is tapped off immediately following the tuner. All this will be explained in detail in the later lesson on I-F amplifiers.

Section 18. FRINGE AREA CONTROL OVER AGC ACTION

Because of the newer tubes which are available, tubes which have exceedingly high transconductance, and because of the greater sensitivity of the better receivers, it is often desirable to incorporate in TV receivers provision to adjust the AGC to provide best reception in the particular locality where the receiver is to be used.

For example, a receiver which is to be used within a few miles of a powerful transmitter would not need nearly the same degree of sensitivity as one which is used 100 miles from the nearest transmitter. In fact, the powerful signal would probably overload the receiver circuits and cause poor reception. Some manufacturers are adding AGC adjustment controls to the other controls which are already mounted on the chassis.

These AGC adjustments are given a variety of names by their respective manufacturers. Some

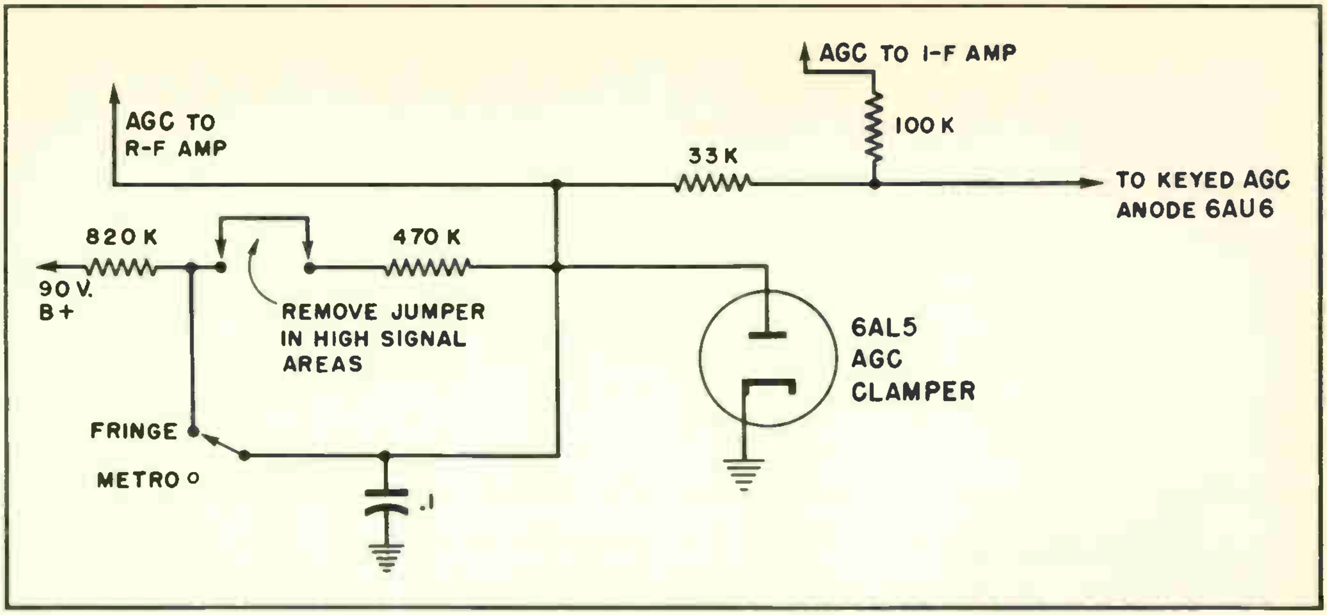

Fig. 24. Adjustments for AGC action.

are named "Sensitivity Adjustment," others are called "Fringe Area Control," still others are merely marked "Local-Distant-Fringe." Some are more properly marked "AGC Adjustment."

Some of these controls are in the form of a two-way or three-way switch. Some involve the use of a jumper across a terminal mounted on the outside of the chassis. More frequently the adjustment is in the form of a potentiometer.

The Andrea Model CO-VL-19, built by the Andrea Radio Corporation in New York, uses a combination of two-way switch and jumper. The switch is mounted on the back panel of the chassis. One position is marked "Fringe," the other is marked "Metro," meaning that when the receiver is used in metropolitan areas the switch should be in that position. Fig. 24 shows details of the AGC circuit.

When the jumper is in place, and the switch is thrown to the "Fringe" position, the clamper tube controls the sensitivity of the R-F amplifier in the same manner described earlier in this lesson.

In strong signal areas, such as the metropolitan districts near TV transmitters, there is no need to increase the sensitivity of the R-F amplifier. If the receiver is quite sensitive such sensitivity is not desirable in metropolitan areas. In that case the jumper is removed, and the switch thrown to the "Metro" position. When that is done a strong negative bias remains on the R-F tube whenever the signal is strong.

In plain words, in fringe areas the AGC voltage is removed from the first R-F amplifier. In strong signal areas, AGC bias is applied to the first R-F tube just as it is to the I-F amplifier tubes.

Crosley approaches the problem of controlling the sensitivity of their receivers in a slightly different manner. The circuit in Fig. 25 shows how they control the AGC in their model DU-17CDB.

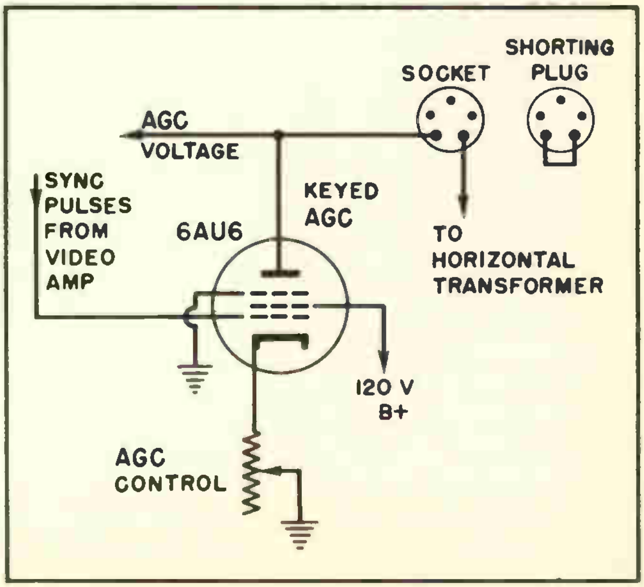

Fig. 25. AGC control at keyed tube.

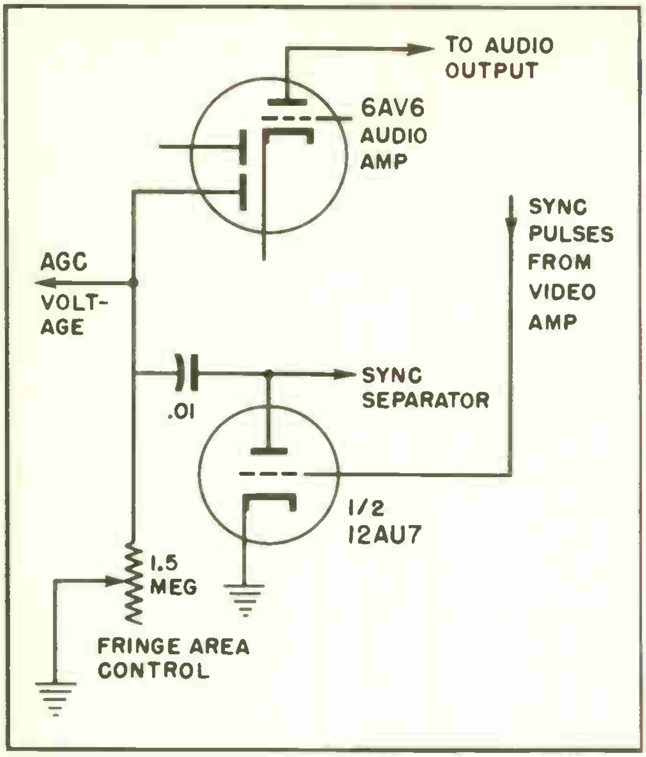

Fig. 26. Fringe area control on Crosley.

There is a double control, in which respect their solution resembles that used by Andrea. But both controls are incorporated directly in the keyed AGC tube.

One of the controls consists of a "shorting plug." It fits into a five-prong socket mounted on the rear panel of the chassis. When the plug is inserted in the socket it provides an electrical connection, through a jumper on the plug, between the horizontal transformer and the anode of the AGC tube. That provides a path for the positive pulses to the anode of the AGC tube.

When the plug is removed from the socket no positive pulses from the horizontal transformer can reach the anode of the keyed AGC tube, thus no AGC voltage is developed. The plug is removed in fringe areas to provide better sensitivity.

Additional control is exerted over the AGC tube to control the level of the AGC voltage. That is provided by the rheostat in the cathode circuit of the AGC tube. By adjusting the resistance of the rheostat it is possible to adjust the level of the AGC voltage.

Emerson Radio and Phono. Corporation uses a different method for controlling the level of their AGC voltage for improving fringe area reception. It is used in those receivers which use ordinary diode AGC circuits.

The diagram in Fig. 26 gives a pretty good idea of how the "fringe area control" works in those receivers. The control consists of nothing more than a high-resistance rheostat connected between the AGC line and B minus. By reducing the resistance of the rheostat the voltage of the AGC circuit can be reduced, thus increasing the sensitivity of the R-F and I-F amplifier tubes.

The circuit is modified still further in some models by using an "off-on" switch which grounds the AGC circuit completely. In other models the circuit is modified by including a resistance-capacitance network which can be cut in or out of the AGC circuit by means of a plug and socket arrangement. This plug and socket arrangement is not identical with that used by Crosley, but the electrical principles are fairly similar.

RCA has a form of AGC control in some of

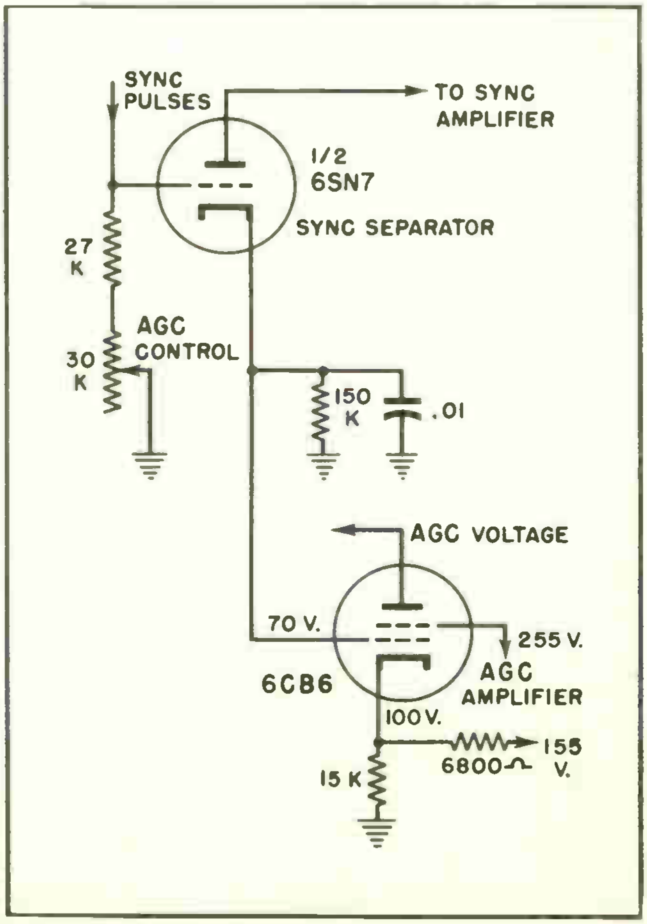

Fig. 27. Indirect AGC control used by RCA.

their models, including model 17T150 and other models similar to it, which is highly indirect in its action.

Control pulses to the control grid of the AGC amplifier tube are fed from the cathode of the horizontal sync separator tube. The magnitude of those pulses can be controlled by adjusting the bias resistance in the grid circuit of the sync separator tube. This is shown in **Fig. 27.**

The anode of the AGC amplifier tube, which is usually a 6CB6 pentode, supplies the AGC voltage for application to the R-F and I-F amplifier tubes. The AGC control is mounted on the rear panel of the chassis.

NOTES FOR REFERENCE

The video detector in a television receiver performs much the same function as a detector in an AM radio.

The video detector is always a diode detector and may be either a vacuum tube diode or a crystal diode.

Basic action of the video detector is to rectify the I-F carrier, then tap off the modulating component.

In contrast to the situation in a radio receiver, the phase of the composite video signal following the video detector is always important.

The correct phase of the composite video signal at any given stage depends on the purpose for which the composite signal is to be used in that stage, and the manner in which the signal is applied.

The load resistor for a video detector may be inserted in the anode circuit of the diode tube, or in the cathode circuit.

Load for the video detector is usually a resistor.

Many television receivers use the metal of the chassis for the B — return circuit. But that is not universal practice. It is always wise to examine the circuits to determine if the chassis is also the ground, or B—, before starting testing procedures.

If proper phasing of the composite video signal is not observed it may have the wrong phase when applied to the picture tube. In that case there will be a *negative picture* instead of a positive one. The picture will resemble a photographic negative.

The composite video signal undergoes a 180° phase reversal each time it passes through a stage of amplification.

Automatic gain control in a television receiver serves the same general purpose as an automatic volume control on a radio receiver.

A TV AGC circuit is not identical with a radio AVC circuit.

An AGC circuit must be capable of responding to differing levels of R-F signal amplitude, yet should not be affected by differing *average* levels in the camera signal.

Keyed AGC is the most desirable circuit for holding the signal to the same level of intensity at the video detector, but is more costly than others. While keyed AGC is reliable, and performs excellently, it is not used in some modern receivers because it requires an extra tube.

Keyed AGC works on the principle that the peak tips of the sync pulses must all have the same level of amplitude. Any tendency for the amplitude of those peaks to vary in amplitude sets up voltage reactions in the keyed AGC circuit which brings the average amplitude back to what it should be.

Should the strength of the I-F carrier signal weaken slightly to reduce the amplitude of the sync pulses the keyed AGC circuit acts to reduce the negative bias on the I-F amplifier tubes, and thus increase the amplifying ability of those tubes.

When the I-F carrier becomes a little stronger than normal the peaks of the sync pulses acquire slightly greater amplitude. The keyed AGC action counteracts that tendency, and reduces the amplitude to the normal level.

Action of a keyed AGC circuit is such that a pulse from the video signal is applied to the control grid of the AGC tube simultaneously with another pulse fed back from the horizontal deflection circuit. Strength of the pulse from the video circuit determines the level of AGC biasing voltage.

Details of keyed AGC circuits used in some TV receivers may vary somewhat from the standard circuit, but all work on the principle of maintaining the peaks of the sync pulses at the same level in the video amplifier circuit.

To provide good AGC action under normal signal conditions, yet retain high sensitivity in the R-F circuit when the signal is extremely weak, special *clamping* circuits are used to modify the keyed AGC circuit.

A clamping circuit acts to remove AGC negative biasing voltage from the R-F amplifier tubes whenever the incoming signal strength falls below a given level. It is especially helpful in receivers used in fringe areas.

Airplane flutter is reduced, or eliminated, by a properly functioning AGC circuit.

Airplane flutter is caused by signals from a transmitter reaching the receiver along paths of different length. Because one portion of the signal travels a longer path than the other the two signals may coincide in phase, or may oppose each other.

When two portions of the same signal coincide in phase when they reach the receiver their signal strengths add together, and the signal received is very strong.

If two portions of the same signal are out of phase with each other when they reach the receiver they tend to oppose each other, and the received signal is weaker than if only one of the signals reached the receiver.

This matter of reflected signals from the same source traveling different paths is what accounts for the so-called "hot spots" and "dead spots" in television reception.

When two or more signals, one direct, the others reflected, reach a TV antenna in phase with each other the total signal strength applied to the antenna is reinforced and strengthened. The physical location where those signals coincide in phase is known as a TV "hot spot" because the antenna picks up a very strong signal at that particular location.

When two or more signals reach a TV antenna so their instantaneous phases counteract, or neutralize, each other, the signal on the antenna is weak. Sometimes it is completely missing. Such locations are known as "dead spots" insofar as reception is concerned.

Signal "hot spots" and signal "dead spots" are frequently located within a few feet of each other. This accounts for the fact that moving a TV antenna as little as a few feet one direction or another often greatly improves TV reception.

It may be completely impossible to pick up a TV signal at a given location, but moving the antenna only a few feet often brings in a strong signal. This apparently strange situation is accounted for by the fact TV signals are easily deflected and reflected, and two or more signals from the same transmitter reach the receiver along differing paths so their phasing may aid or oppose each other.

Crystal diodes do as good a job of demodulating the video signal as vacuum tube diodes.

Crystal diodes are widely used as video detectors in modern TV receivers.

Crystal diodes have the advantage of compactness, being inexpensive and dependable, and requiring no filament heating current.

Circuits used with crystal detectors are more simple than when tubes are used.

The most widely used crystal diode is the 1N64, but other types perform equally well.

The output of the video detector contains the composite video signal for the picture tube, the sync separator circuit, signals for the AGC circuits, and in intercarrier receivers it has the 4.5-megacycle sound I-F signal.

In intercarrier receivers the signal containing the audio modulations is delivered to the audio circuits in the form of a modulated 4.5-megacycle difference signal.

Modern TV receivers are so sensitive that in strong signal areas they tend to "overload," and distort the picture, unless they have effective AGC action.

The AGC action is so strong in some TV receivers it must be modified in fringe areas to make the receiver more sensitive.

Many receivers incorporate controls to adjust the AGC action to fit the need in the locality where they are used. These are usually mounted on the back panel of the chassis.

Note: Don't be troubled if you see B minus, B-minus, B− or B plus, B-plus and B+ used interchangeably. They are sometimes written one way then the other and we want you to get accustomed to it.

NOTES

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SYNC SEPARATOR CIRCUITS

Contents: Purpose of Sync Separator Circuits — Importance of Having Sync Circuits Operate Perfectly — Types of Separator Circuits — Separating Pulses from Composite Signal — Diodes as Separator Tubes — Combining Separator Action with D-C Restorer — Time Constants — Rates of Charge — Calculating Time Constants — Time Constants for Discharging Capacitors — Types and Dimensions of Sync Pulses — Separating the Horizontal Sync Pulses — Separating the Vertical Sync Pulses — How Integrator Capacitor is Electrically Prepared for Vertical Pulses — Practical Separator Circuits — Modified Separator Circuits — Other Variations in Sync Separator Circuits — Servicing Sync Circuits — Notes for Reference.

Section 1. INTRODUCTION

In the lesson on video detectors we explained that several types of information were contained in the composite video signal at the time the signal left the detector. In addition to the picture information from the camera there are the synchronizing pulses.

The synchronizing pulses consist of two types. One is primarily intended to synchronize the action of the vertical deflection system in the receiver with the movement of the vertical deflection system in the camera. The primary purpose of the other is to synchronize the horizontal circuits of the receiver with those in the camera.

In addition to the horizontal and vertical sync pulses, the composite signal also includes the equalizing pulses.

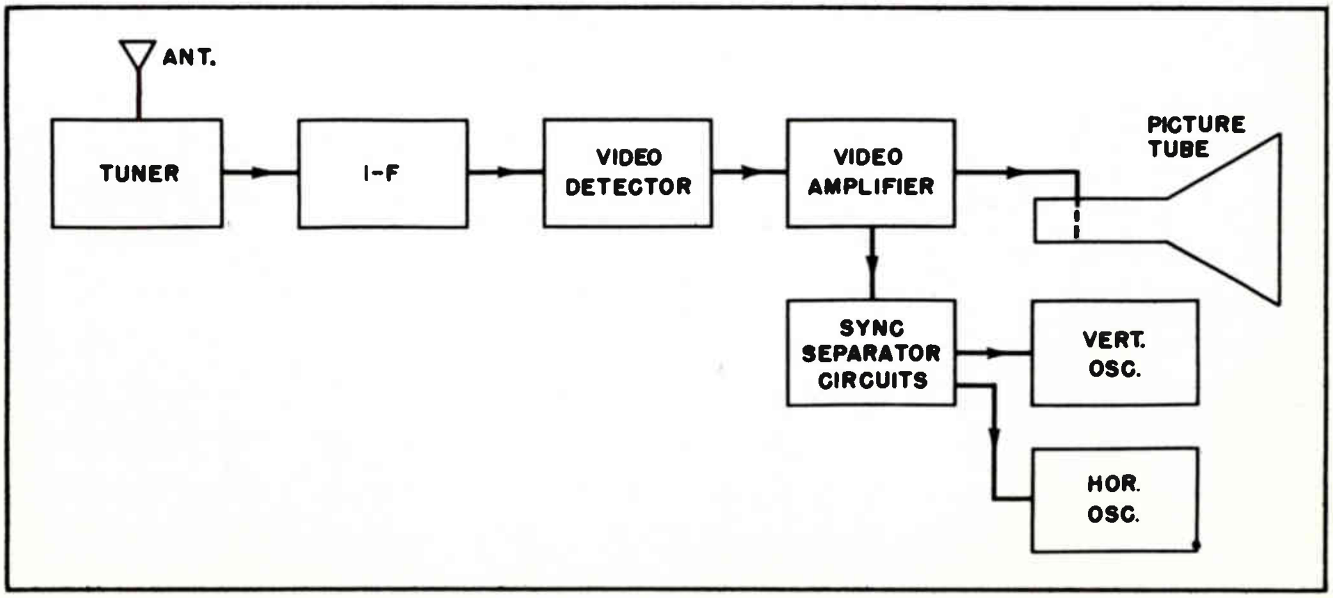

Figure 1. Electrical location of Sync Separator circuits with respect to other circuits

Sync pulses perform other functions besides those relating to the deflection circuits. The short horizontal sync pulses, for example, are fed into the D-C restorer circuit in some receivers to establish the D-C signal level. They are also used to develop AGC bias voltage in receivers with a keyed AGC circuit.

Some idea of how the sync separator circuits are positioned with respect to other electrical circuits is shown by the block diagram in Fig. 1. The purpose of the block diagram is to show the relative *electrical position*, but this does not necessarily mean the physical position of the sync separator circuits is so close to the video amplifier circuits as the diagram would indicate. In most cases they are not so close.

The arrangement shown in Fig. 1 is the one most frequently followed when the TV receiver uses one or more stages of video amplification. The sync pulses are sometimes tapped off between the video amplifier and the input to the picture tube, and sometimes tapped off between the stages of the video amplifier. Much depends on the individual ideas of the designer of the receiver, and the phasing of the signal.

In those receivers which have no video amplifier stage the sync pulses must be tapped off immediately following the detector stage. This is indicated in the block diagram in Fig. 2.

Section 2. PURPOSE OF SYNC SEPARATOR CIRCUITS

Although sync separator circuits are often discussed among television men when talking about the various types of circuits in TV receivers, some technicians continue to be somewhat hazy as to the exact job these circuits play. This is surprising, especially since they perform such an important function.

The composite video signal carries all the electrical information to enable a television receiver to reproduce a scene viewed by a camera. This fact has been discussed at length in previous lessons.

Included in the information carried by the composite video signal is the constantly varying amplitude of the camera signal, plus the regularly spaced horizontal synchronizing pulses. The varying amplitude of the camera signal provides the electrical information needed by the picture tube to reproduce the varying levels of light intensity at all the many individual areas on the face of the screen. But at regular intervals the camera signal is blanked by the horizontal blanking pulse, then the synchronizing pulse comes riding through on top of that blanking pulse.

At the moment, the subject of our attention is the synchronizing pulses, and the manner in

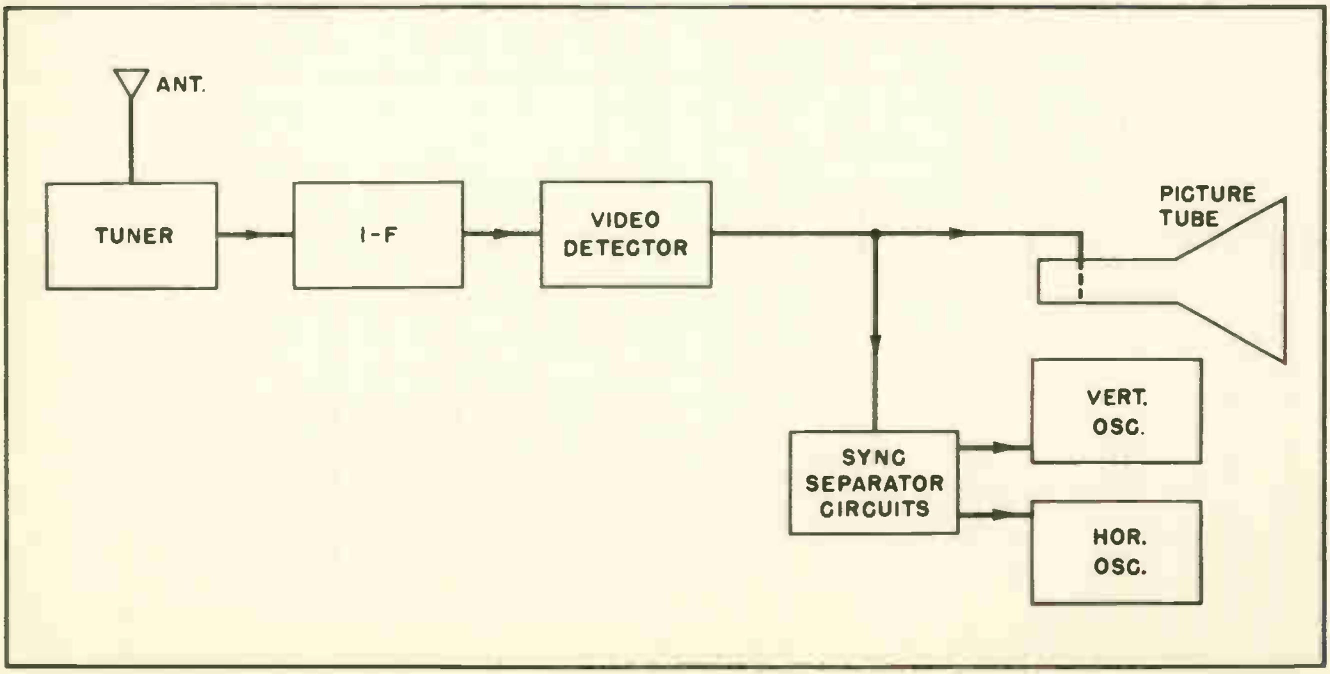

Figure 2. Electrical position of Sync Separator when there is no Video Amplifier.

which they are separated from the other voltages which make up the composite video signal. Yet we are equally interested in the vertical blanking pulses and the vertical synchronizing pulses.

Basically, the purpose of the sync separator circuits is to separate the sync pulses from the camera video signal. Often, that action is combined with other actions, but at the moment our interest centers on the action which separates the sync pulses from the other signal elements.

The sync separator tube may be a diode, a triode or a pentode. It may be a tube whose only function is to separate the sync pulses from the composite video signal, or it may be a tube which performs some other function at the same time it separates the pulses.

In most cases the sync separator tube is one which is so biased that the normal variations of the camera video signal do not affect the tube, and do not cause any variations in the anode current of the tube. The tube is usually biased in such manner that only the peak voltages of the sync pulses affect the tube sufficiently to cause changes in the anode current.

Sometimes the sync pulses are fed to the control grid of the sync separator tube. In other circuits the sync pulses are fed to the cathode of the separator tube. In still other variations the circuit is so designed that the composite signal is fed to the anode of the separator tube.

The exact manner in which the composite signal is introduced to the separator circuit depends on the ideas of the designers, and the other possible functions of the circuit.

Section 3. IMPORTANCE OF HAVING SYNC CIRCUITS OPERATE PERFECTLY

You recall that in our earlier lessons we described how the sync pulses are added to the camera signal at the camera. They are added for the purpose of maintaining the deflection circuits in the receiver in exact synchronism with similar circuits in the camera.

In this connection it is worth emphasizing the importance of *exact synchronism*. If the vertical movement of the deflection system in the receiver is not exactly in step with the vertical movement in the camera the reproduced picture will not be right.

If the vertical circuits in the receiver are not in step with those at the camera the picture frames tend to slip upward, or downward. Instead of the successive frames of the picture being superimposed upon each other they are slightly displaced.

Lack of synchronism in the horizontal circuits is even worse. Unless the receiver circuits are perfectly synchronized with those at the camera there will be no picture at all, or it will be so distorted it makes little sense. The horizontal lines contain the basic picture information, and if they are not placed on the screen in the proper sequence, and at exactly the correct position, they make no sense.

Under some sets of conditions it is possible for a picture to be reproduced on the receiver screen even when the sync circuits are not functioning. But it is a most trying experience.

For that to occur the horizontal oscillator must be running free at exactly 15,750 cycles per second, and not a cycle or two lower or a cycle or two higher. And the vertical oscillator must also be functioning at exactly 60 cycles per second.

Even so, the viewer must sit with his fingers on the horizontal hold control and the vertical hold control. Any tendency for the picture to roll vertically, or to *tear* horizontally must be instantly corrected by a slight adjustment of the individual controls. Naturally, this is most unpleasant, and is almost impossible unless the oscillator circuits are adjusted for the exact sweep frequencies.

In most cases, loss of synchronizing pulses destroys the picture. If the vertical pulses fail to come through the picture rolls up or down. If the horizontal pulses are lost the picture tears badly, or diagonal bars appear, and often there is nothing but a blur.

Section 4. TYPES OF SEPARATOR CIRCUITS ETC.

The exact details of all the sync separator circuits used in television receivers are too much to describe in a course such as this. This is because each manufacturer has his own ideas how such circuits should be designed. The total number of combinations which can be created is so large as to be almost uncountable.

Despite this, the basic fundamentals of sync separator circuits are relatively simple, and by describing the manner in which they work it is easy to understand any specific circuit. This is true despite the fact the circuit may be different from anything you have previously run into.

The first function of a sync separator circuit is to separate all the synchronizing pulses from the composite video signal. A circuit similar to that shown in Fig. 3 can accomplish that purpose very well.

Once the synchronizing pulses have been separated from the composite video signal they must undergo another separation. They must next be separated into two groups. The horizontal sync pulses must be separated from the vertical sync pulses.

This calls for two differing types of separating circuits. A block diagram of how this is accomplished is shown in Fig. 4.

The circuit in Fig. 3 is able to separate the sync pulses from the camera signal because the B+ voltage on the anode of the tube is deliberately kept quite low. The relatively low amplitudes of the camera signal voltages are not strong enough to affect the anode current of the tube. Therefore, variations in the voltage level of the camera signal does not cause equivalent variations in the anode current.

In plain words, the tube circuit is not capable of accepting and amplifying the low-amplitude voltages of the camera signals.

But the sync pulses have a higher voltage amplitude. When the sync pulses strike the control grid of the tube they cause pulses of current to flow in the anode circuit.

The result of this action is to separate the synchronizing pulses from the composite video signal.

But the vertical sync pulses and the horizontal sync pulses are still mixed together. They must be passed through special filter circuits so they can be separated from each other. This is indicated in the block diagram in Fig. 4.

The vertical synchronizing pulses, needed to synchronize the vertical deflection circuit, are filtered through a special circuit which is called an *integrating* circuit. The horizontal synchronizing pulses are passed through a differing kind of filter network called a *differentiating* circuit.

The integrating circuit passes the vertical sync pulses, but acts as a bar to prevent passage of horizontal sync pulses. Only the vertical sync pulses pass through the integrating circuit.

On the other hand, only horizontal sync pulses can pass through the differentiating circuit. Hori-

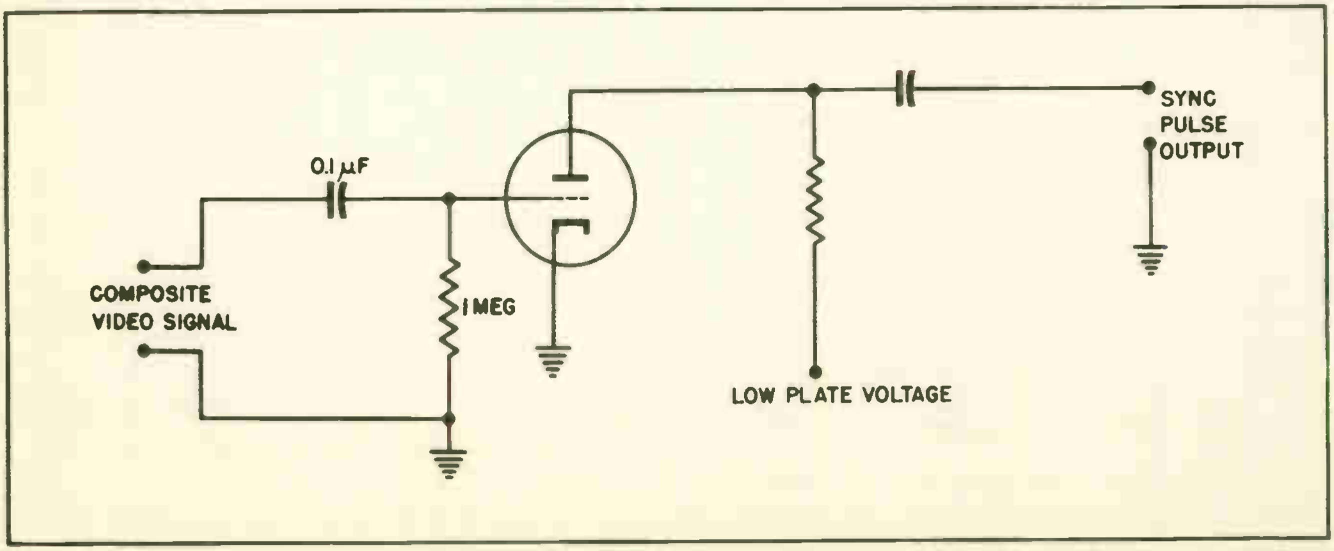

Figure 3. Sync Separator circuit used in early model receivers.

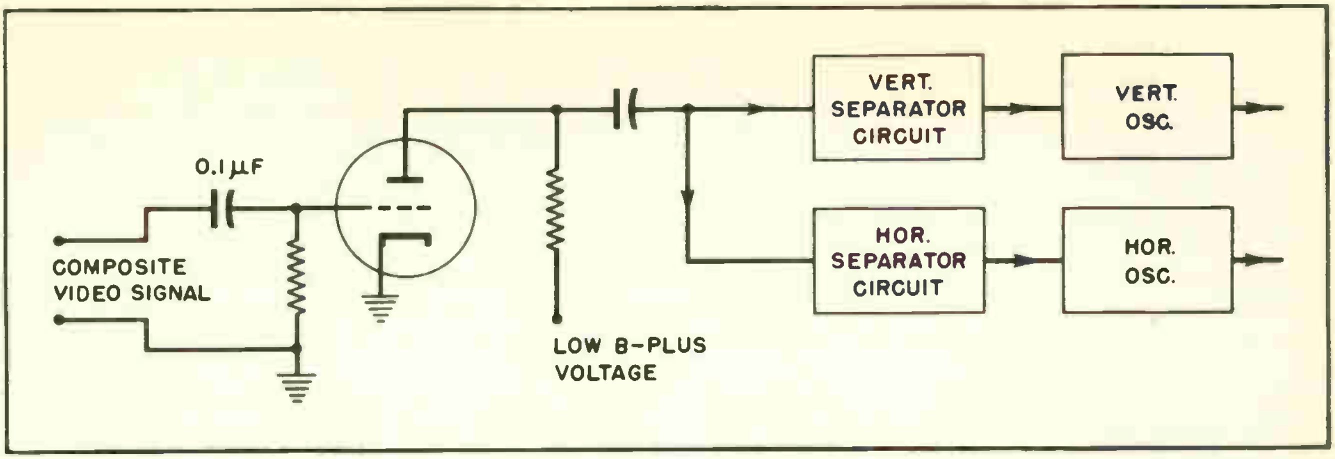

Figure 4. Separating sync pulses from Composite Signal, then into separate groups.

zontal sync pulses pass through, but the vertical sync pulses are barred.

Section 5. SEPARATING PULSES FROM COMPOSITE SIGNAL

The first job of the separator circuits is to separate sync pulses from the camera signal. A circuit like that shown in Figs. 3 and 4 was the one originally used for this purpose.

In action the separator circuit is little different from an ordinary clipper circuit. It is also much like the circuit sometimes used to restore the D-C component of the video signal.

In most cases it is self-biased. In the case of a triode, such as the one shown in Figs. 3 and 4, the self-biasing is accomplished by a form of grid-leak bias. When so used only the peak voltages of the sync pulses are strong enough to cause the tube to conduct.

In some cases, however, the signal is fed to the cathode of the triode. This is explained later in the lesson.

Very often the voltage of the sync pulse at the time it is applied to the grid of the triode separator tube is great enough to drive the grid slightly positive at the peak of the pulses. This has the effect of attracting electrons to the control grid where they are trapped behind the grid-leak resistor. After the sync pulse has passed the presence of the trapped electrons is such as to bias the tube so that the camera signal has no effect on the tube.

This matter of self-bias through the action of a grid-leak bias has been described in previous

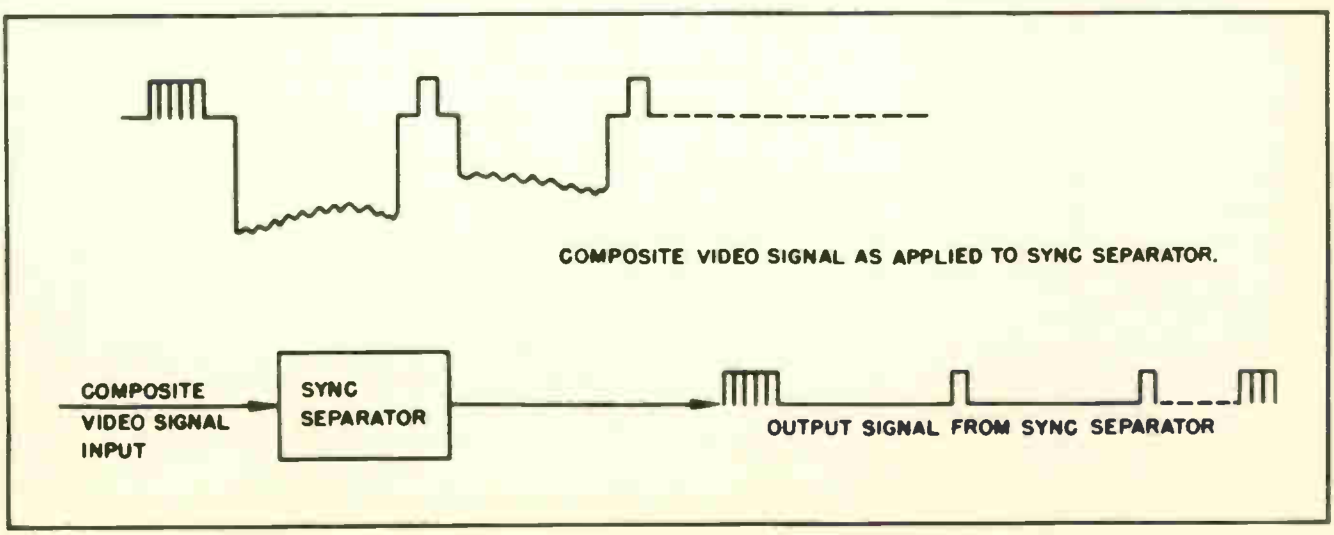

Figure 5. Separating sync pulses from Composite Signal.

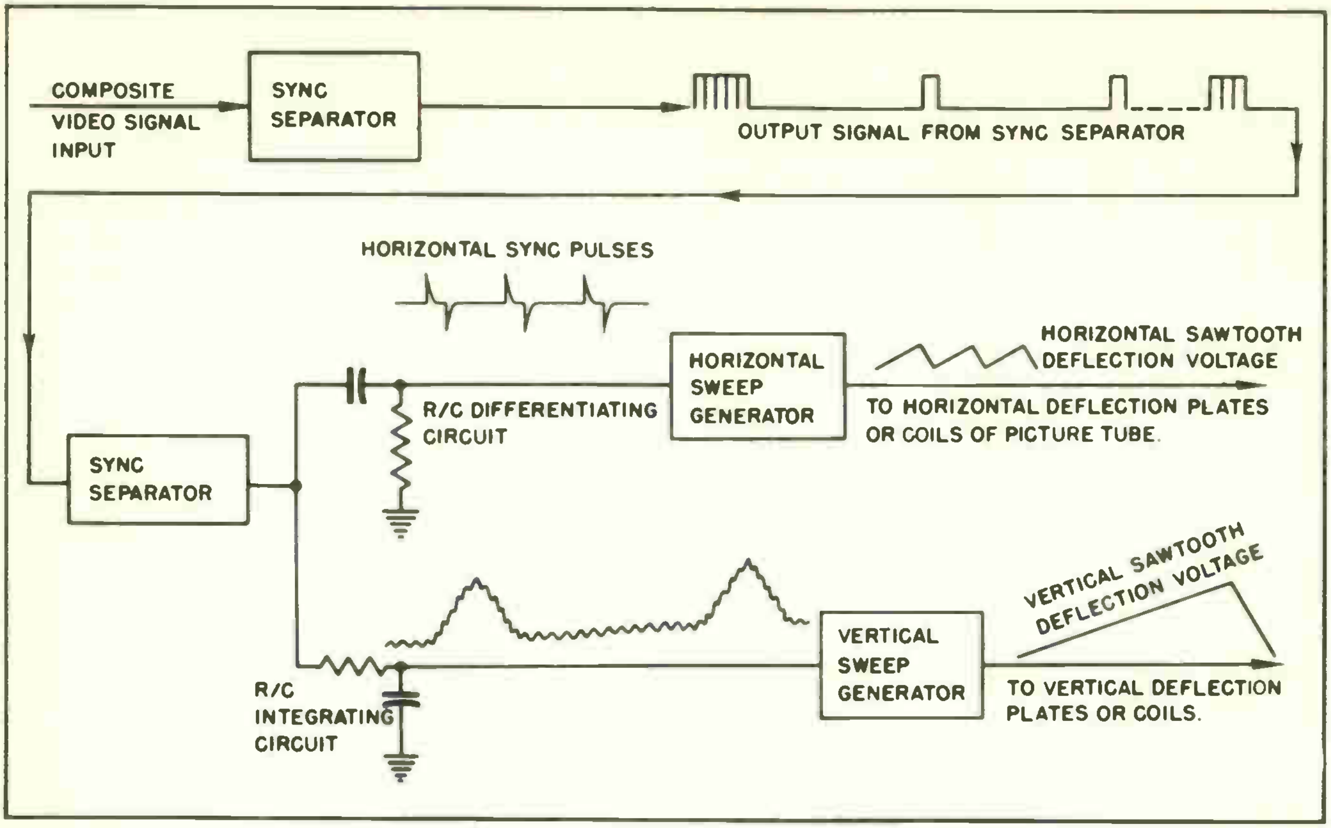

Figure 6. Separating sync pulses into horizontal pulses and vertical pulses.

lessons. Nevertheless, since it plays such an important part in the action of a separator circuit we are justified in touching on it again, at least briefly.

The voltage on the grid of the tube, and the way the voltage appears on the characteristic curve, is shown in Fig. 7. The composite video signal must have a polarity so the peaks of the pulses represent the most positive part of the signal. This is the same polarity a composite signal must have when it is applied to the cathode of a picture tube.

The peaks of the pulses drive the grid of the tube slightly positive. This is shown on the graph in Fig. 7. Momentary presence of the positive voltage on the control grid causes the tube to pass a pulse of current into the anode circuit, and also causes the grid to attract a few electrons to the grid itself.

Electrons which are attracted to the grid are trapped there. The only escape is through the grid-leak resistor shown in Figs. 3 and 4. This places a fairly high negative bias on the tube, a bias high enough to prevent the camera signal having any effect on the tube. Presence of that bias voltage prevents any current flowing as a result of the camera signal.

The only signal which appears in the anode

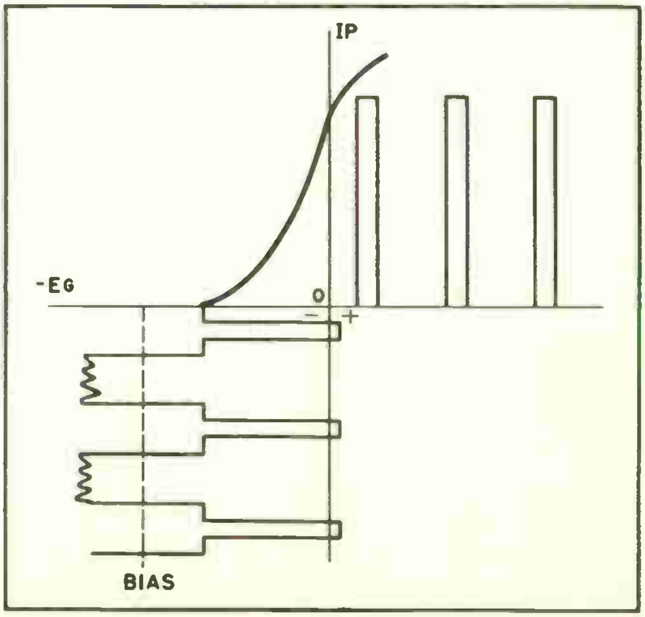

Figure 7. Graph of Input and Output Voltages of Sync Separator circuit.

circuit of the tube are the series of synchronizing pulses.

Since the camera signal cannot pass through the tube because of the high negative bias on the control grid, and the only signals which appear in the anode circuit are the synchronizing pulses, the net action of the circuit is to separate the sync pulses from the composite signal.

It should be noted that this circuit, because of its self-biasing feature, responds to signals of any strength. Strong signals cause the tube to increase its bias, and thus kill the stronger camera signal. Weak signals do not cause the bias voltage to rise so high, thus the tube is able to pass weaker sync pulses.

The action of the self-biasing feature is such that the negative voltage on the control grid is always just right to prevent the passage of camera signals, yet is also just right to permit the peaks of the sync pulses to cause current pulses to appear in the anode circuit. These are problems for the engineer, but it is well for you to have some understanding of the reason why certain component values have been chosen.

Section 6. DIODES AS SEPARATOR TUBES

While it is almost hopeless to explain the details of all the variations of sync separator circuits, we can examine some of them. We will pay most attention to those which are most common.

There is one feature which is found almost universally in all circuits intended to separate the sync pulses from the composite video signal. That is the fact all are self-biasing.

In Fig. 8 a diode tube is connected so a composite signal with positive polarity can be applied to it. In this connection it should be remembered that a signal can be fed into the diode's anode, as in Fig. 8, or into its cathode. In this respect we find a situation similar to that we met when we were studying D-C restoration.

The composite signal is applied to the anode of the diode tube in Fig. 8. Presence of the strong positive voltage pulse causes the diode to conduct, thus charging coupling capacitor C. The negative charge on the coupling capacitor prevents the camera voltages of the composite signal affecting the diode. The camera voltages never attain sufficient amplitude to overcome the negative voltage.

The negative charge on the coupling capacitor gradually leaks off through resistor R, but not rapidly enough to reduce the negative voltage to such value the camera signal can make the tube conduct. Action of the capacitor and resistor maintains the negative voltage on the anode at all times except when the strong positive voltage of the sync pulses come along.

The positive voltage of the sync pulses is always stronger than the other portions of the composite video signal. Each pulse is strong enough to overcome the normal negative voltage on the anode, and cause the tube to conduct

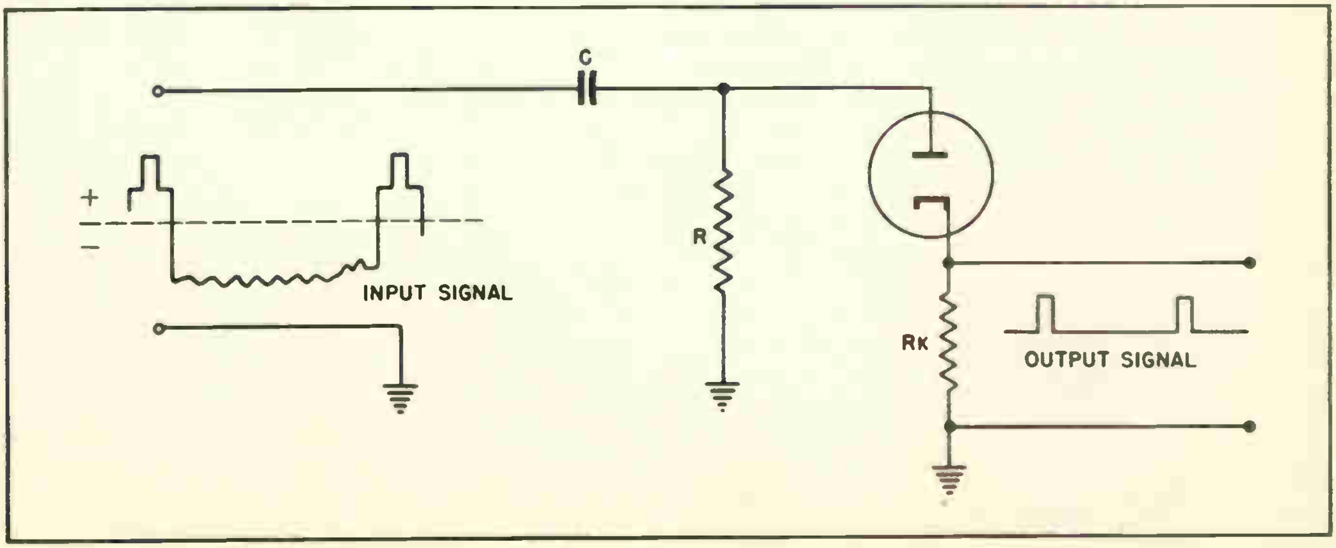

Figure 8. Diode Separator connected to accept positive signal at input.

again. Each incoming voltage pulse causes a pulse of current to flow through the diode.

The time/constant of the grid circuit biases the tube against the camera signal, but not against the pulses.

From this explanation it should be clear that the diode conducts only in a series of pulses. No current passes through it at any time except when a positive sync pulse is impressed on the anode.

The pulses of current which flow through the diode also flow through cathode resistor R_k in the cathode circuit of the tube. Whenever current flows through the resistor a voltage drop occurs across it.

This means that the series of sync pulses on the anode causes a series of current pulses to flow through the resistor, and that, in turn, causes a series of voltage drops to occur across the resistor. The voltage drops are present across the resistor only when current is flowing through it. Thus, a series of voltage pulses appear across the cathode resistor, but no evidence of the camera voltages appear.

For all practical purposes the sync pulses are separated from the camera signal by the circuit and tube.

Note the polarities involved. Positive voltage pulses are applied to the anode of the diode. Positive voltage pulses also appear across the cathode resistor. There is no inversion of the voltage polarity, such as takes place when a signal is fed into the grid of a triode, and when the output is tapped off the load of the anode circuit.

A different type of diode separator circuit is shown in Fig. 9. That form of circuit is used when the polarity of the composite signal is negative at the time it is fed into the separator circuit.

The action is similar to that which occurs in Fig. 8, except the polarities are reversed, and the current moves in the opposite direction.

A tube, especially a diode, can be caused to conduct in either of two ways—by placing a positive signal on the anode, or by placing a negative signal on the cathode.

Placing a positive voltage on the anode makes the anode more positive than the cathode. That is the condition which causes any vacuum tube to conduct. Placing a negative voltage on the cathode also causes the anode to be more positive than the cathode; and this, too, establishes the condition necessary to make the tube conduct.

A glance at the graph in the lower lefthand corner of the illustration in Fig. 9 shows that the peaks of the composite signal, and the sync pulses, are negative. When these are applied to the cathode of the diode the tube conducts in a series of pulses. It conducts only when the strong negative pulses are placed on the cathode.

The resistor and capacitor set up a bias network to establish a *positive* voltage on the cath-

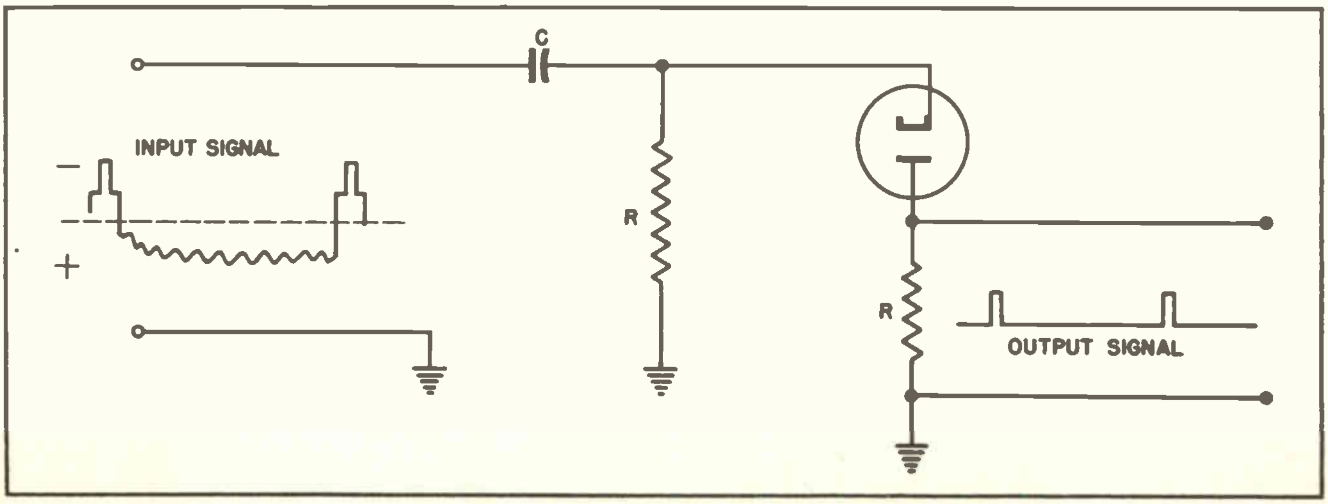

Figure 9. Diode Separator with signal fed to cathode.

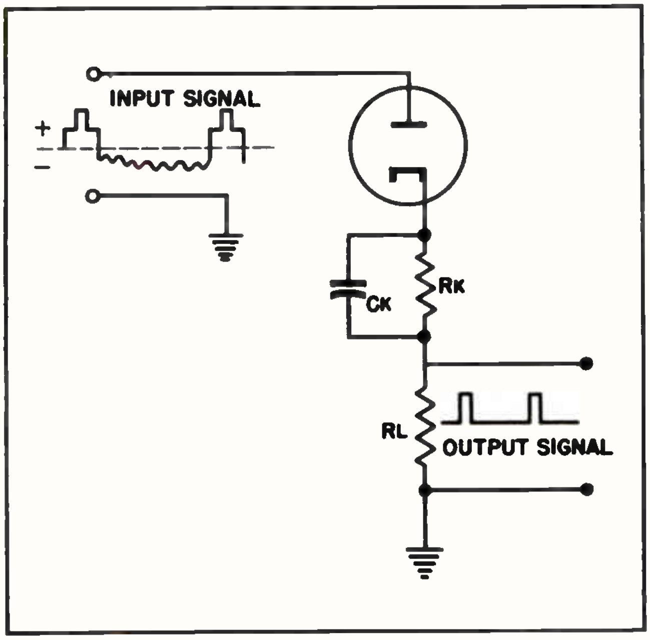

Figure 10. Bias voltage in Cathode Circuit when there is no Coupling Capacitor in anode circuit.

ode at all times except when the pulse voltages are actually present. This prevents the tube conducting under the influence of the lower-amplitude camera signal voltages.

All this causes the current in the anode circuit to flow in a series of pulses. The current flows in the anode circuit only when the strong negative pulses are present at the cathode of the diode.

Those pulses of current flow through the load resistor in the anode circuit. As they flow through the resistor they cause a series of voltage pulses to form across it. Thus, the sync pulses are separated from the camera signal component of the composite video signal.

One thing well worth noting in this connection is that the output pulses have the same voltage as those from the diode circuit shown in Fig. 8. This means the sync pulses from the circuit in Fig. 9 can be handled from that point further in exactly the same way as those from the circuit in Fig. 8.

In some cases it is desirable to couple the signal directly from the video amplifier into the separator diode without any intermediate coupling capacitor. When that is done it is necessary to provide the biasing circuit of the tube in the cathode circuit instead of the anode circuit, as in Fig. 8. This action can be accomplished by using a circuit like that shown in Fig. 10.

It is also possible to apply cathode bias when a triode is used. This is used in some receivers where there is some need to apply the composite signal directly to the grid without passing through a capacitor. Fig. 11 shows how that can be done.

Section 7. COMBINING SEPARATOR ACTION WITH D-C RESTORER

In a preceding lesson we mentioned that the same tube could be used as both D-C restorer and sync separator. In those receivers where the sig-

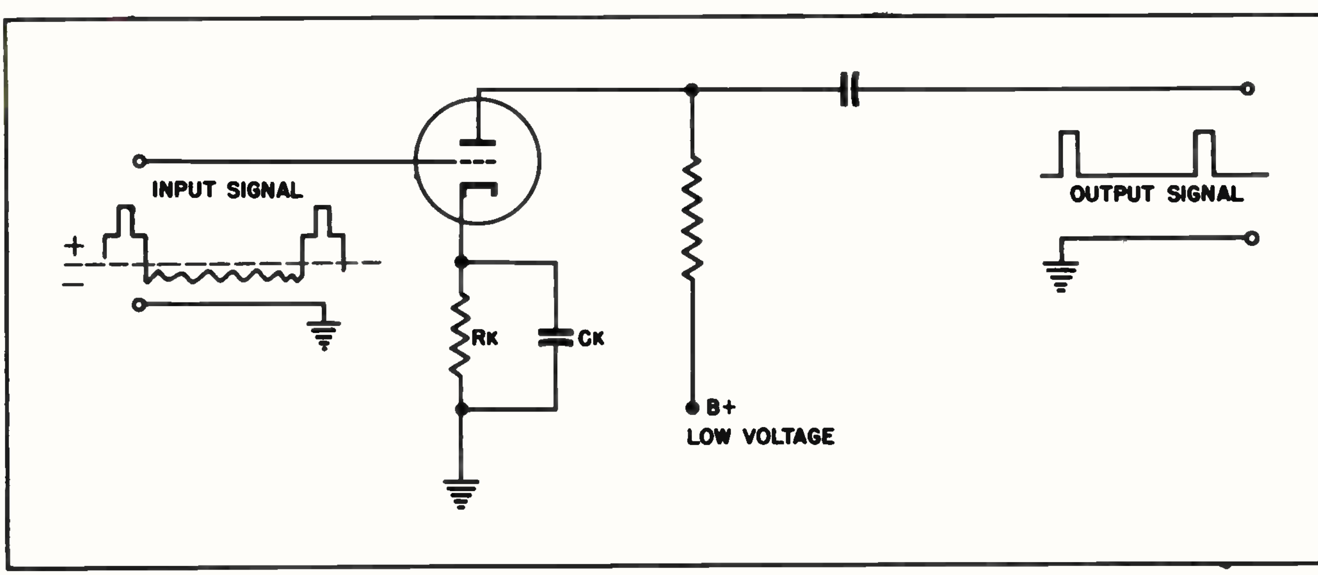

Figure 11. Bias voltage created in Cathode Circuit of Triode Separator tube.

nal is fed into the control grid of the picture tube such a combined circuit is very frequently used in modern receivers.

Most of the details of the circuit were explained in the lesson on D-C Restorers, and there seems little point in adding to them at this time. The diagram in Fig. 12 discloses the essential details.

This is a circuit RCA used in their model 6T54. That chassis was used in several of their other model TV receivers.

This circuit will also be found in hundreds of thousands of television receivers built by other manufacturers. It has been copied by those manufacturers who operate under RCA patents. One of the important reasons for studying RCA circuits is that they are found in receivers built by so many other manufacturers. (RCA licenses use of their patents to other manufacturers.)

Normally, the voltage on the cathode of the sync separator tube in Fig. 12 is about 1.2 volts positive. The voltage on the anode is about 5 volts positive. These low voltages prevent the tube conducting under most conditions, especially those times when only the camera signal is present.

When sync pulse voltages come along they are so strong they drive the cathode of the 12AU7 as much as 15 to 20 volts negative, possibly even more. It depends on the strength of the composite video signal.

When these sync pulse voltages are applied to the cathode of the 12AU7 they cause the tube to conduct. That causes a pulse of voltage to appear in the anode circuit, from which the pulse voltage is fed into another sync amplifier tube to make it stronger.

When the tube conducts it takes electrons away from the cathode, thus making the cathode slightly positive after the pulse has passed. The cathode is connected directly to the control grid of the picture tube through the 820K resistor. This means the positive voltage developed at the cathode of the 12AU7 is applied to the control grid of the picture tube. This voltage represents the restored D.C. voltage which is always necessary whenever the composite signal is fed to the control grid of a picture tube.

One other feature of this circuit which has not been previously mentioned is the fact that AGC voltage is also developed at the 12AU7 tube. The AGC voltage is developed on the grid circuit of the 12AU7.

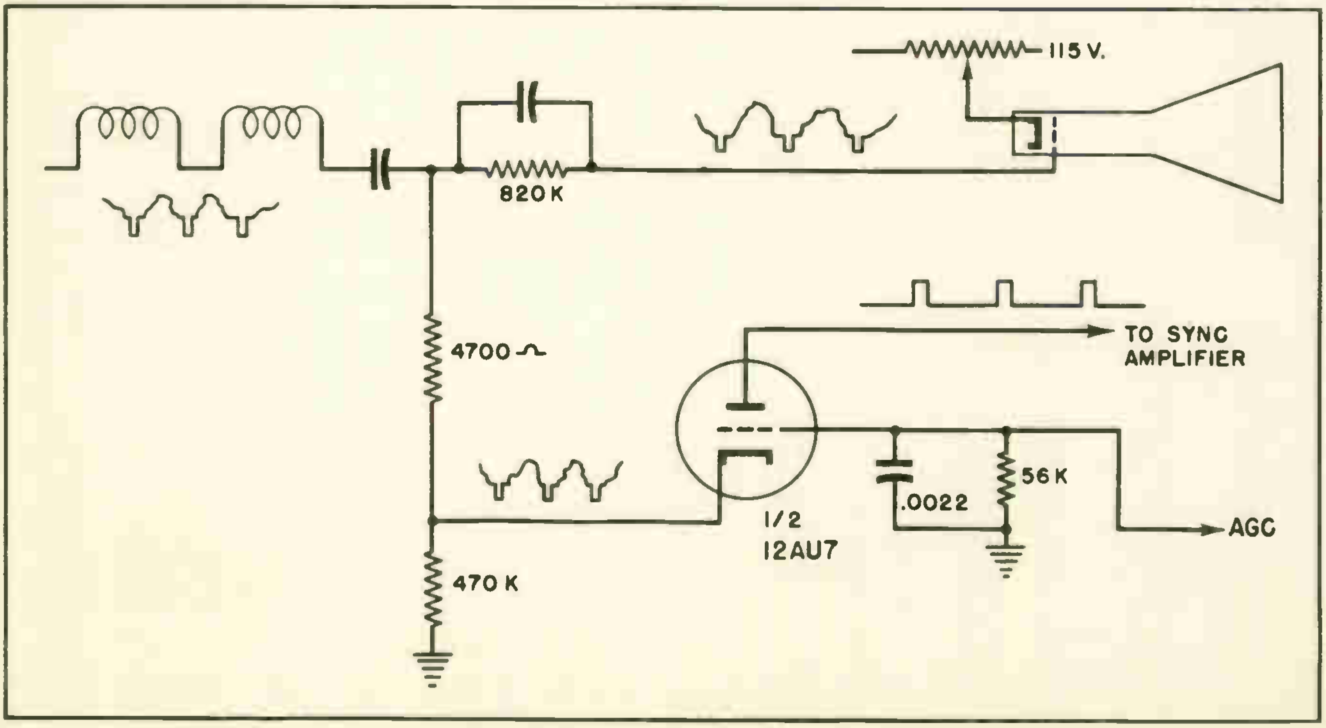

Figure 12. Combination Sync Separator and D-C Restorer.

In this circuit the control grid is not used for control purposes as is the normal custom. Instead, it is used to develop the AGC voltage. It acts very much as a small anode. When the cathode is driven negative it makes the grid positive with respect to the cathode.

When the cathode is driven negative by the presence of the negative sync pulse it makes the cathode negative with respect to both the anode and the control grid. This can be said another way: when the pulse voltage is present on the cathode both the anode and the control grid are positive with respect to the cathode. This means electrons will pass from the cathode to both the anode and the control grid.

The pulses which appear at the anode are passed along to another amplifier circuit. But the negative voltage, which develops on the control grid because of the presence of the trapped electrons after the signal pulse has passed, remains until they can leak off. They can leak off through the 56K resistor, but they cannot leak off very fast. So long as they remain they constitute a negative AGC bias for application to the control grids of the R-F and I-F amplifier tubes.

Section 8. TIME CONSTANTS

After the synchronizing pulses have been separated from the composite signal it is then necessary to separate the vertical sync pulses from the horizontal sync pulses. This action is accomplished by introducing the synchronizing pulses to special circuits which permit only one specific type of pulse to pass through.

These filtering circuits, one called a differentiating circuit and the other an integrating circuit, are circuits which have been carefully constructed with an eye to the time constants of each. One is specifically designed to have a very short time/constant, while the other is designed to have a longer time/constant. They include other special details, but these are the two most important.

In order to properly understand the matter of time constants, and thus understand how time constants play such an important part in TV work, it is well that we pause briefly to review this general subject. Time constants were introduced earlier in the course, but at that time we made no effort to go into the subject very deeply.

A long time ago, long before the science of electronics and radio and television became a reality, electrical men learned they could charge a capacitor by momentarily placing a voltage across the capacitor, then disconnecting the voltage source. All that is necessary is to connect the capacitor momentarily to a source of voltage.

Fig. 13 shows in rough outline the most common manner in which this ability to charge a capacitor can be demonstrated. The leads from the capacitor are merely touched to the opposite terminals of the battery for a moment, then disconnected. The charge placed on the capacitor by the voltage of the battery remains on the capacitor until it leaks off.

Just how long it takes that voltage to leak off depends on many factors. The important fact is that the capacitor remains charged after the source of voltage has been removed. The capacitor acts to store an electrical charge.

It is worthy of note that neither of the leads of the capacitor in Fig. 13 has any resistance, other than the negligible amount normally present in all conductors. It is fair to assume the resistance is probably less than 1 ohm.

The absence of resistance in the leads of the capacitor permits the capacitor to come up to a full charge just as fast as the current can flow into it—which is virtually instantaneous.

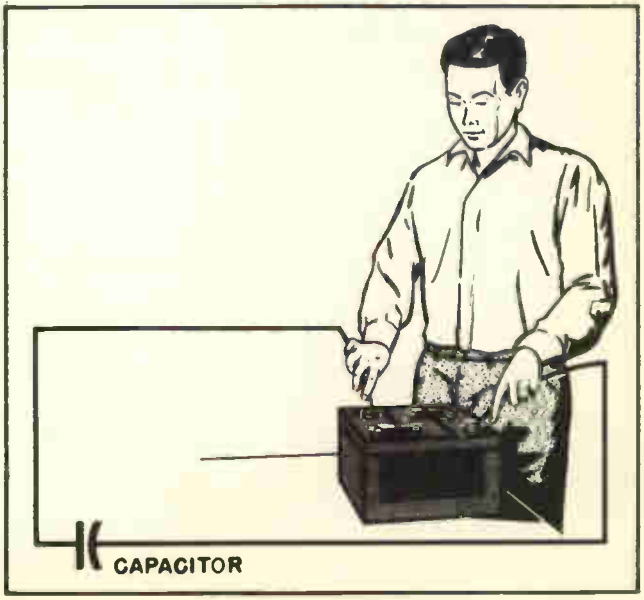

Figure 13. A capacitor can be charged by momentarily connecting voltage source.

After discovering that it was possible to charge a capacitor from a source of voltage, electrical men later learned that the charging process could be slowed down by inserting a resistor in one of the leads to the capacitor. This is illustrated in Fig. 14.

In Fig. 14 we find a capacitor connected in a series circuit with a battery. But in addition to these components there are also a resistor and a switch. The switch is inserted to provide a means for opening and closing the circuit.

When the switch is closed current can flow from the battery through the resistor to charge the capacitor. When it is opened the capacitor is disconnected from its source of voltage.

Now the interesting thing about a circuit like the one shown in Fig. 14 is that it takes longer for the capacitor to charge than was true when the set-up was like that in Fig. 13. The presence of the resistor restricts the flow of current so only a small amount can flow at any one time.

It is hard for us to visualize the flow of electricity through a conductor, and even harder for us to realize its physical movement into a capacitor. By using liquids for the purpose of example the action is made more clear to us.

In Fig. 15 a man is pouring liquid from a large container into a small one. The small container is filled very rapidly because there is no restriction on the movement of the liquid into it. The liquid pours into the small container as fast as it can fall.

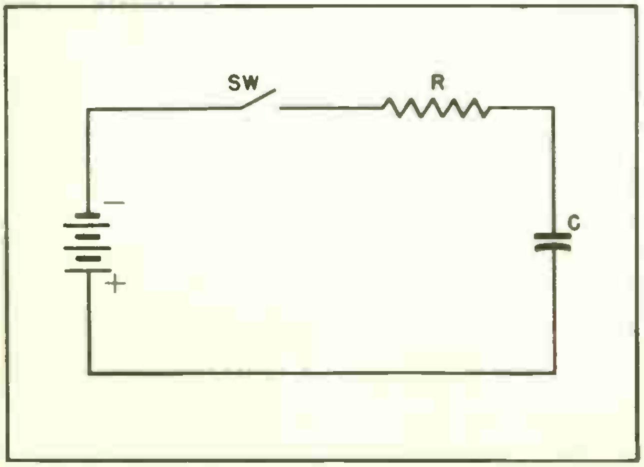

Figure 14. When a capacitor is charged through a resistor it takes more time.

Figure 15. Small container can be filled very quickly when liquid is poured in.

In the following illustration, in Fig. 16, we see a somewhat different set of conditions. A small container is again being filled with liquid supplied from a larger container. But in Fig. 16 the liquid must flow through tubing before it enters the small container.

The need for the liquid to flow through a small tube slows its movement quite radically. It takes far longer for the container to become full when the liquid must pass through the tubing than when it can be poured without using the tubing.

In both cases there is adequate liquid to fill the small container. But in one case it takes much longer for the container to become full than in the other.

There is not an exact similarity between the action of flowing liquid and that of electrons moving into a capacitor, but there is sufficient similarity for this illustration to make the action understandable.

This example can be carried even further. If the small container into which the liquid is passed is made still smaller it can be filled more quickly. This is true regardless of whether the liquid is poured in, or is permitted to pass through the tubing.

On the other hand, if the container is made larger it takes longer for the liquid to fill it. This is also true regardless of whether the liquid is poured in or permitted to flow through the tubing.

A difference in the size of the tubing also affects the length of time it takes to fill the container with liquid. If the diameter of the tubing is smaller it takes longer for the liquid to pass through, and thus takes longer to fill the container.

On the other hand, if the size of the tubing is larger the liquid passes through it more rapidly. In that case the container is filled more rapidly.

All of which brings up some interesting speculations, and for the purpose of illustration they are directly in line with the matter of electrical time/constants.

The length of time it takes to fill the container with liquid depends on several factors which are immediately obvious. One factor is the size of the container. The larger the container the longer it takes to fill, and the smaller it is the less time required to fill it.

Another factor is the size of the tubing through which the liquid flows. The larger the tubing (the less the resistance) the quicker the liquid can flow, and the shorter the time it takes to fill the container. The smaller the tubing (the more resistance) the longer time that is needed to fill it.

These actions with the liquid, the tubing and the container are almost exactly like the actions of a capacitor and a resistor in handling electrical current flow in a time/constant circuit. The larger the capacitor the longer it takes to acquire a charge. The smaller the capacitor the quicker it can charge up.

Resistance of the resistor is equally important. The greater the resistance, like the smaller the tubing, the longer it takes the capacitor to acquire a charge. On the other hand, the less the resistance, like the larger the tubing, the quicker the capacitor can be charged.

In a time/constant circuit the electrons to charge the capacitor are caused to flow through the resistor. The capacity of the capacitor and the resistance of the resistor both have an important bearing on the exact amount of time needed to charge the capacitor.

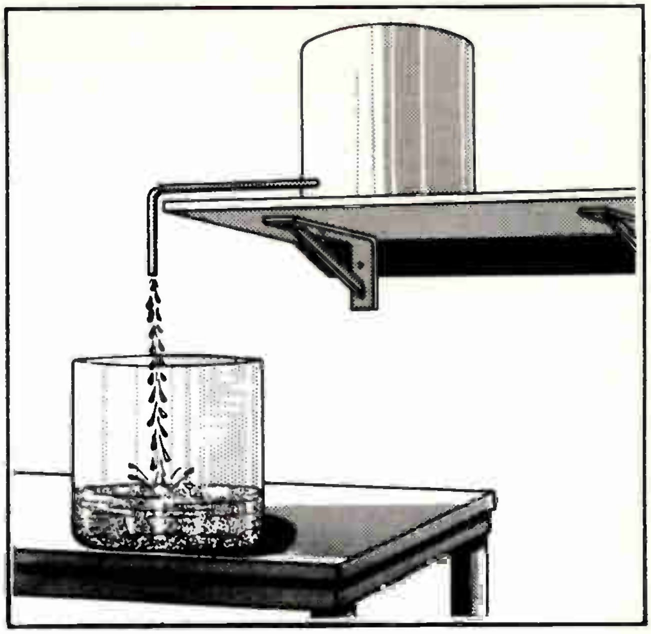

Figure 16. When flow is restricted by small tube it takes much longer to fill container.

Because a definite relationship between the size of capacitors and resistance of resistors, and their effect on the time it takes to charge the capacitor, have become known through years of experimentation, it is now possible to set up a time/constant circuit to measure any given length of time. One of extreme accuracy can be set up for any purpose.

Section 9. RATE OF CHARGE

When a capacitor is being charged it does not charge up to full charge at the same rate during all the various intervals of the charging action. For example, when there is no charge on the capacitor—when it is completely discharged—electrical current can flow into it at a very high rate.

But as electrons move into the capacitor they create a counter-voltage which acts against the additional electrons which follow. This means that after some degree of charge has been placed on a capacitor it does not continue to charge at the same fast rate. In fact, the rate of charging slows down very materially.

By the time the capacitor is half-charged—that is 50% charged—the counter-voltage is half as great as the charging voltage from the source. By the time the capacitor is 60% charged the movement of electrons into the capacitor begins to slow down, and by the time it is 70% charged the movement of current into the capacitor has slowed considerably.

As the charge passes 80% the movement of electrons into the capacitor is still slower, and the capacitor is continuing to charge at a much slower rate than when the charging action first started. After the capacitor is 90% charged the continuing charge is very slow. It takes much longer for the capacitor to charge from 90% of full charge to 95% of full charge than from zero charge to 50%.

From 95% of full charge onward the charging rate is very slow, and somewhat erratic. A capacitor that took only 10 microseconds to charge from zero to 50% may take 1000 microseconds or more to charge from 95% to 98% of capacity. And, as the charging action continues the rate of charging is ever slower. Each additional percentage point of full charge adds still more to the counter-voltage, making it still harder for any additional charge to build up on the capacitor.

There is some disagreement as to exactly how long it takes a capacitor to charge from 99.5% of full charge to a completely full charge. There are some scientists who claim that a full charge cannot be attained, but others equally famous insist a capacitor can be fully charged. But all

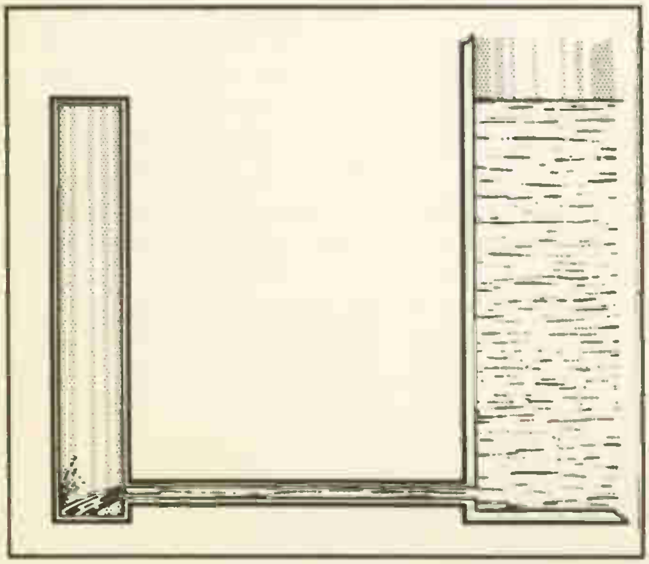

Figure 17. When small container is empty liquid rushes through connecting tube very fast.

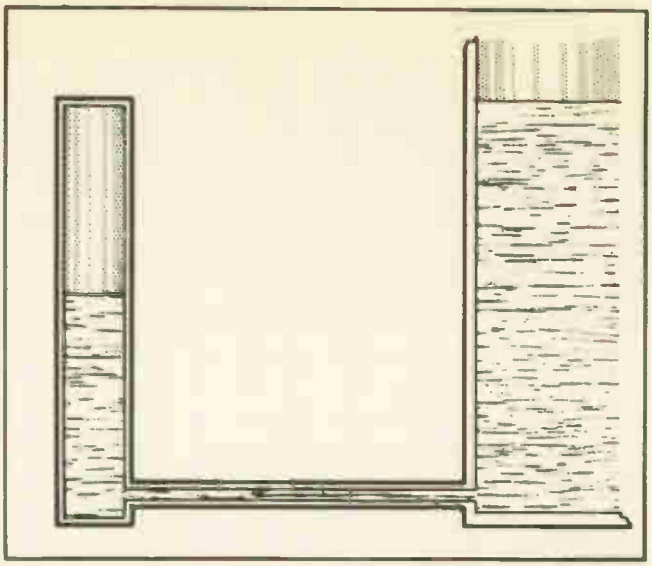

Figure 18. As liquid fills container it creates back-pressure, thus slowing passage of liquid through tube.

agree that the final few percentage points of full charge come very, very slowly.

If this action of a capacitor during the charging cycle is not entirely clear perhaps it would be wise to resort once again to our analogy of liquid filling a container. In Fig. 17 we have a tall cylindrical container which is connected by a tube with a large tank. For purposes of our explanation we can think of the liquid in the tank as being inexhaustible, and that removal of liquid to fill our elongated container will not lower the level of the liquid in the tank.

When the tall container is empty, and the tube to the tank is open, liquid passes through the tube into the container with a rush. It flows at a high rate, the exact rate being governed by the pressure in the tank behind it, and the resistance of the tubing through which it flows.

However, the liquid does not continue to flow at this same high rate. As the liquid rises in the container, as shown in Fig. 18, it builds up a back-pressure of its own. The higher the liquid level climbs the slower it flows through the tube from the large tank.

By the time the liquid has risen in the container as high as shown in Fig. 19 it is almost as high as the level of the liquid in the large tank. The back-pressure of the liquid in the container is nearly as great as that of the liquid in the tank.

This means there is so little difference in the two counter-acting pressures that little force is placed on the liquid to continue flowing through the tube. Some liquid does continue to flow through the tube, but it flows very slowly.

As the liquid continues climbing slowly in the container, closer and closer to the level of the liquid in the tank, it climbs ever more slowly. During the last few fractions of an inch it will climb so slowly that the most careful observer will be unable to notice the increasing height.

Most high school students have conducted experiments similar to this as a part of their school work. Even those who have not conducted formal experiments in school have observed them as a part of their everyday lives. If you have not observed this phenomenon it might be well for you to set up such an experiment for your own satisfaction. It will help tremendously in understanding the electrical action which takes place in an electrical time/constant circuit.

The rise of voltage during the charging action of a capacitor can be graphed. One method of doing so is shown in Fig. 20.

Two graphs are shown in Fig. 20. One is for the rise of voltage across the capacitor as it is being charged. The other is the flow of current into the capacitor as it is being charged.

Assuming the capacitor to be completely discharged before the switch of the circuit is closed we have a condition in which the voltage across the capacitor is zero. If the switch is then closed there is no voltage across the capacitor to act against the movement of current into the capacitor. The result is that current flows into the capacitor with a rush.

Technically speaking, the current flow is at maximum the instant the switch is closed.

However, the very instant any electrons in the current stream move into the capacitor they react instantaneously to begin setting up a counter-voltage. During the initial charging period current continues to move into the capacitor quite freely because the external voltage of the source —the battery—is much greater than the counter-voltage inside the capacitor. But as current continues to flow into the capacitor the counter-voltage continues to increase until it reaches important proportions.

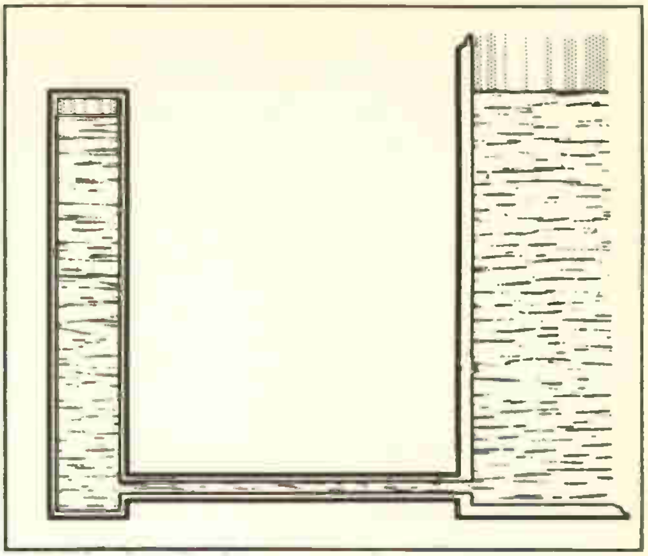

Figure 19. As liquid almost fills small container it creates so much back-pressure that additional liquid barely trickles through tube.

Even more important than the current graph is the one showing the rise of the counter-voltage within the capacitor. That is shown by the upper graph in Fig. 20.

Note that the counter-voltage rises quite steeply during the first charging period. Then, as the capacitor acquires approximately 50% to 60% of full charge the curve of the graph keeps bending more and more toward the horizontal. It takes longer and longer for the voltage to rise any given percentage of full charge.

By the time the capacitor has become approximately 70% charged the graph is slanting so far toward the horizontal that it is difficult to note any given amount of rise with respect to any given amount of time.

Because of these factors electrical men rarely make use of the charging action during the latter part of the voltage rise. To be exact, they utilize only the first 63% of the charging voltage. They base all their calculations on the time it takes a capacitor to charge to 63% of full charge. They ignore the latter part of the charging cycle as though it did not exist.

In designing a timing circuit of any kind engineers are interested only in creating a device which will accurately measure the time it takes some definite action to take place. Mechanical engineers who design door-closers create a device which consists of a cylinder into which is inserted a piston. A small hole in the piston permits air or oil or some other liquid to pass through. Size of the hole determines the length of time required to close the door.

Other mechanical engineers create shock absorbers for automobiles. They are built on much the same principle. The time it takes for the piston of the shock absorber to move in or out is determined by the size of a small hole through which liquid can pass. It is all a matter of time-delay.

In electrical work the necessity regularly arises for a circuit which can measure time, or which responds to electrical pulses of definite time length. Such circuits can be created by properly arranging one or more capacitors in relationship with one or more resistors.

Section 10. CALCULATING TIME CONSTANTS

Returning to the electrical circuit at the top of Fig. 20 we see the capacitor being charged through the resistor under the pressure of the voltage of the battery. The charging action begins when the switch is closed.

In that illustration we have shown the voltage as 100 volts. This has been done as a matter of convenience, but the applied voltage has little to do with the relative voltage relationships which are present in a time/constant circuit. The voltage will rise to a given percentage of full charge within a given interval of time. It will rise to that pre-determined percentage of full charge within exactly that period of time, regardless of the amount of voltage impressed on the circuit.

To make this a little more clear let us look at the action from a different point of view. In the circuit shown in Fig. 20 the applied voltage is shown to be 100 volts. In this particular case the voltage across the capacitor will rise to 63 volts within a given period of time. That period of time is determined solely by the value of the capacitor and the value of the resistance.

If 200 volts were applied to the same identical circuit the voltage across the capacitor would rise to 126 volts (63% of 200 volts) within exactly the same period of time it took the voltage to rise to 63 volts when 100 volts were applied.

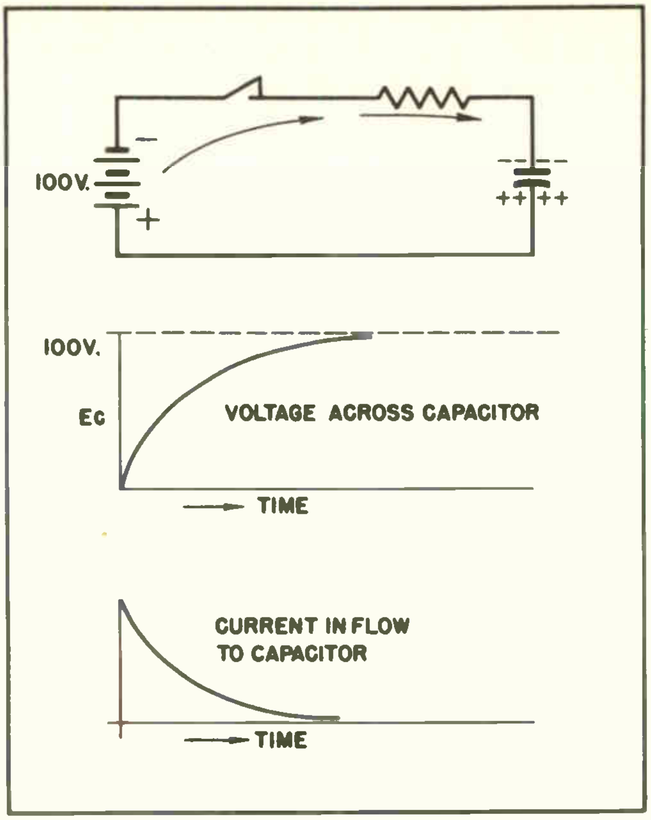

Figure 20. Graphing voltage rise, and current decrease, during charging of capacitor.

This can be carried to any extreme. Regardless of what voltage is applied to the circuit from a source, the voltage across the capacitor will rise to 63% of full charge within that definite interval of time, and that interval will be the same in all cases regardless of the applied voltage.

The interval of time required to charge the capacitor to 63% of full charge is determined solely by the capacity of the capacitor and the resistance of the resistor.

Now let us look into the controlling factors which govern the exact length of time involved in any given combination of resistors and capacitors.

It is always desirable to make our calculations as simple and easy as possible. That has been done in the case of time constants, and the calculations involved with them have been reduced to the most simple degree possible.

The first approach to this problem by electrical men was a series of experiments. It was necessary to know just what combinations of resistors and capacitors would add up to a given interval of time.

Experiments showed that when a capacitor with a capacity of 1 mfd. is charged through a resistance of 1 megohm the capacitor would charge to 63% of full charge during the period of 1 second. Fortunately, here were a group of factors easy to handle.

The basic factors were 1 mfd., 1 megohm, and 1 second. No fractions or decimals were involved.

Smaller capacitors would shorten the timing interval. Larger capacitors would lengthen it.

By the same line of reasoning, smaller values of resistance would shorten the timing interval. Higher values of resistance would lengthen it.

These factors can be set up in a formula so they can be easily remembered. Basically, the time interval is equal to the product of the capacity in microfarads and the resistance in megohms. When those two factors are multiplied together it gives the time interval in terms of seconds. As a formula the arrangement looks something like this:

$$\text{Time (sec.)} = \text{C(mfd.)} \times \text{R(megs.)}$$

Perhaps an example or two will show how this formula is applied, and demonstrate its simplicity.

Suppose we want to know the time constant of a circuit consisting of a .5 mfd. capacitor and a 200,000-ohm resistor. The first step is to reduce both values to microfarads and megohms. The capacity is already expressed in that form, but the resistance must be changed to 0.2 megohms.

When the problem is set up for solution it will look something like this:

$$T = .5 \text{ X } .2$$

When they are multiplied together, we find that .5 times .2 equals .10. This is the same as 0.1 second. Which means that a circuit consisting of a .5 mfd capacitor and a .2 megohm resistor would have a time constant of 1/10 of a second.

To be a little more precise, it means a circuit consisting of those two circuit components would cause the capacitor to charge 63% of full voltage within 1/10th of a second after the voltage has been applied to the circuit.

This same line of reasoning holds true for any given values of resistance or capacity. Had the capacitor had a capacity of .0022 and the resistor had a resistance of 47,000 ohms, the time/constant would have been calculated in exactly the same manner.

The first step would be to reduce both values to terms of microfarads and megohms. In this case the capacitor is already rated in microfarads, but the resistor must be converted to megohms. In terms of megohms the resistor is .047 megohms.

With these values before us we insert them in our formula, then solve the problem:

$$T = .0022 \text{ X } .047.$$

Multiplying the capacity by the resistance we come up with the numerical value of .0001034. This can be readily converted into microseconds, which are more convenient when working with small fractional parts of a second. In this case .0001034 seconds is equal to 103.4 microseconds.

All of which means that an electrical circuit consisting of .0022 mfd. and 47,000 ohms of resistance has a time constant of 103.4 microseconds. It is as easy as that.

While we are on this subject there is no reason why we cannot give you another example or two so you can become somewhat better acquainted with this subject. The matter of time constants is important. So many circuits in television receivers are specially designed to work within definite time limits.

Among these are the sync separating circuits we are discussing in this lesson, some types of circuits used in connection with AGC networks, delay networks in color television, and the timing elements used in multivibrators and other deflection oscillators. Failure to acquire an active understanding of time constants of electrical circuits will definitely handicap you when you tackle the more advanced subjects later in this course.

What occasionally fools some technicians when working with time constants is the necessity for observing the correct terms of the capacitor and resistor values. The capacitor must be rated in microfarads, and the resistor in megohms.

Suppose we consider a circuit in which there is a 1500 mmfd. capacitor and a 4700-ohm resistor. This is not an unusual television circuit. It is found rather frequently.

The first step is to convert micromicrofarads into microfarads, and the ohms of resistance into megohms. It is scarcely necessary to explain that 1500 mmfds. is exactly the same as .0015 mfd. That is something you learned in one of the earlier lessons. And no doubt you already know that 4700 ohms is the same as .0047 megohm. That was also explained previously.

So, once we have converted the values of the resistor and capacitor into terms of microfarads and megohms there is little to do except put them in the formula and work them out. That is done like this:

$$T = .0015 \times .0047.$$

When the arithmetic is worked out by multiplying the two values together we come up with

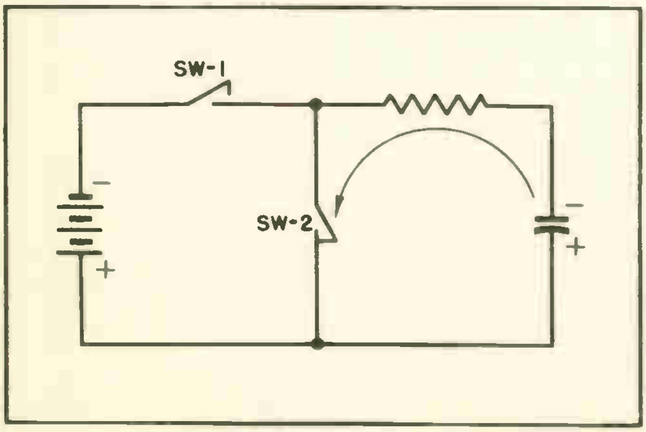

Figure 21. Circuit for observing action during discharge cycle.

the value of .00000705. This is the time in seconds. To convert that into microseconds we merely multiply it by 1,000,000 and come up with 7.05 microseconds.

All of which means that an electrical circuit in which a capacitor rated at 1500 mmfds is charged through a resistance of 4700 ohms the time constant amounts to 7.05 microseconds. There is nothing involved except simple arithmetic.

The same steps should be followed in working out the time constant of any circuit.

Section 11. TIME CONSTANTS FOR DISCHARGING CAPACITORS

So far we have directed our attention to those conditions where a capacitor is being charged through a resistor. Such circuits are very common.

Equally common are those in which the timing action occurs during the *discharge* of a capacitor. At first glance this might seem to be more complicated. Actually, the procedure for calculating the time constant is exactly the same.

In a timing circuit of this kind no effort is made to follow the discharging pattern all the way to complete discharge any more than the *charging* pattern is followed all the way to complete charge. Instead, timing action occurs during the interval between the *beginning* of discharge and the point where the capacitor is 63% discharged.

This action can be understood somewhat better by observing the circuit in Fig. 21. There we have a circuit very similar to the one in Fig. 20. The only difference is that in Fig. 21 a special discharging path is provided through switch SW-2.

The capacitor is first charged by closing switch SW-1 while switch SW-2 is open. Once the capacitor is charged switch SW-1 is opened. After SW-1 is opened the capacitor will retain its charged condition.

To observe the discharging action switch SW-2 is closed. When that is done a discharge path is provided through the resistor and SW-2. The capacitor will discharge; the length of time it

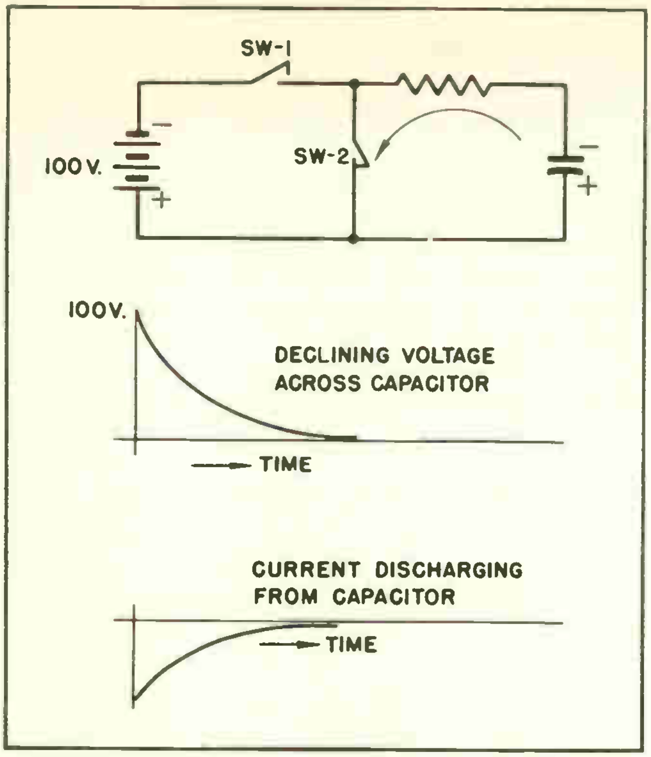

Figure 22. Graphing voltage decline as capacitor discharges.

will take is determined by the capacity of the capacitor and the resistance of the resistor.

The decline of the voltage across the capacitor can be observed somewhat better by studying the graph in Fig. 22. A comparison of the voltage graph in Fig. 22 with that in Fig. 21 shows the shapes are the same, except they are reversed.

The important point is that the voltage declines quite rapidly during the early part of the discharge, then slows the rate of decline during the latter part of the discharge.

Just as only the first 63% of the charging voltage is normally used when the charging action of a capacitor is used for timing, so, a similar situation prevails when the discharging action of a capacitor is used for that purpose. The portion of the voltage drop between the beginning of a discharge and 63% of full discharge is all that is used.

The formula for calculating the time constant is exactly the same. The time in seconds is equal to the capacity in microfarads multiplied by the resistance in megohms.

For example, in the case of our 1500 mmfd capacitor and 4700-ohm resistor, we work out the time constant in exactly the same way.

$$T = .0015 \text{ X } .0047 = .00000705 \text{ seconds.}$$

The time constant for any other resistance/capacity circuit is worked out in the same way. The time in seconds is always equal to the capacity in microfarads multiplied by the resistance in megohms. The value of the applied voltage is not important insofar as the timing action is concerned. A voltage of 20 volts will charge a capacitor to 63% of full voltage in exactly the same time an applied voltage of 400 volts will charge the capacitor to 63% of full voltage.

When the applied voltage is high the capacitor will charge faster, but it takes longer to charge. When it is lower the capacitor charges more slowly, but it does not charge to so high a voltage.

In either case the capacitor is charged to within 63% of full voltage in exactly the same time. It is this factor which makes these R/C timing circuits so valuable.

Section 12. TYPES AND DIMENSIONS OF SYNC PULSES

After the synchronizing pulses have been separated from the composite video signal the next step is to separate the vertical pulses from the horizontal pulses. As was indicated earlier in this lesson, that action is accomplished by special filtering circuits, one of which has a very short time constant, and the other has a much longer time constant.

To be precisely accurate, there are actually three types of pulses at the output of the first separator tube. These are the horizontal sync pulses, the vertical sync pulses, and the equalizing pulses. The equalizing pulses were mentioned in earlier lessons, but little was said about them at that time. The arrangement of the various pulses at the output of the sync separator tube is shown in Fig. 23.

From the fact we have mentioned it so many times in previous lessons you know the horizontal oscillator goes through 15,750 complete cycles during the period of one second. You also know that the total elapsed time required for the electron beam to sweep across the screen and back in one complete cycle is quite generally designated as *H*. This has been mentioned in previous lessons.

All of which boils down to the fact that *H* is equivalent to 1/15,750th of a second, or 63.5 microseconds.

In Fig. 23 we have shown the relationships of each of the various pulses to all the others. Dimensions in time of the pulses, and their separations from each other, are given in terms of percentage of *H*.

At the extreme left end of the diagram we show the elapsed time between the beginning of one horizontal sync pulse and the beginning of the following one. That is indicated as *H*, since it is a complete horizontal cycle; but it is also indicated as being 63.5 microseconds.

The widths of the horizontal sync pulses are quite narrow. In terms of comparison with other parts of the cycle they amount to 8% of *H*, meaning that in terms of time the total existence of one of those pulses amounts to 8% of the time required for the horizontal sweep to go through one complete cycle.

We want to call your attention again to the equalizing pulses. A study of Fig. 23 shows they are only half as long, in point of time, as the horizontal sync pulses. Measured in terms of *H* they are only 4% of *H*. But they are spaced only half as far apart as the horizontal sync pulses. During the time they arrive at the receiver they come in twice as often as the horizontal sync pulses, being spaced at ½*H* apart.

Six vertical sync pulses are shown in Fig. 23. The vertical sync pulses also arrive twice as frequently as the horizontal sync pulses, but *only* during the short space of time in which six of them are arriving.

This can be said in another manner. The vertical sync pulses arrive in a group. But when they do arrive they come twice as frequently as the horizontal sync pulses, arriving at the same rate as the equalizing pulses.

Contrasting with the equalizing pulses, each of the vertical sync pulses is much longer. In fact, the vertical sync pulses are so long that one scarcely ends before another arrives.

The six vertical sync pulses cover a total period, in point of time, amounting to 3H, or 190.5 microseconds. Some persons view the vertical sync pulses as actually being one long pulse broken in several places by short serrations (notches). In view of the function of the vertical sync pulses that is probably the most nearly accurate way of looking at them.

Some technical books describe the vertical sync pulse as being one long sync pulse divided into six parts by serrations.

Section 13. SEPARATING THE HORIZONTAL SYNC PULSES

Various methods are used to separate the

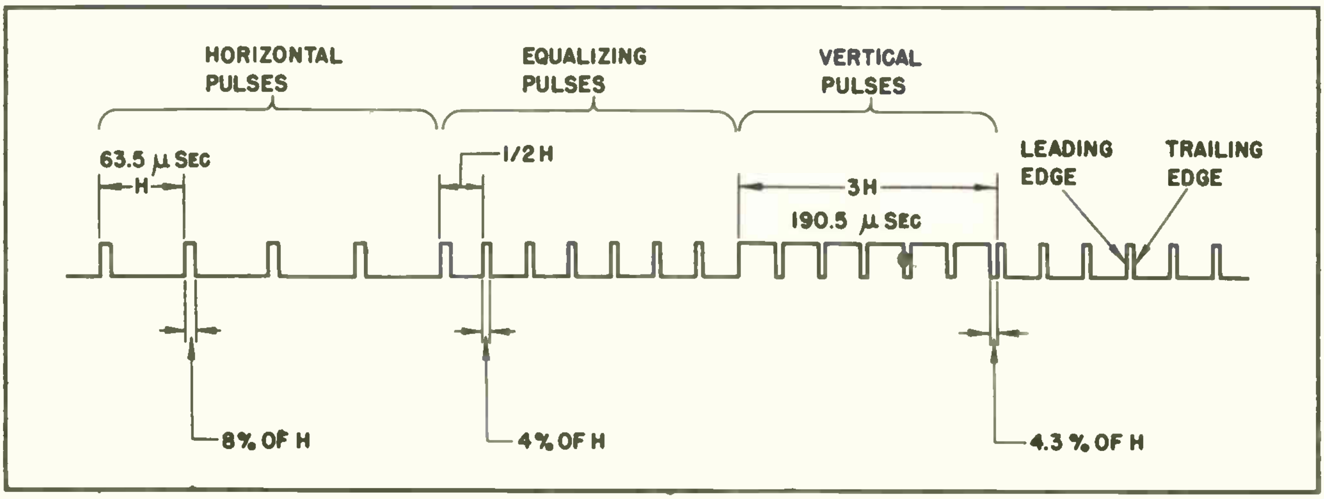

Figure 23. Types of pulses after separation from Composite Video Signal.

various pulses from each other. The first step often is to separate the horizontal sync pulses from the others. To do this a differentiating network must be set up.

A differentiating circuit is merely a high-sounding name for a special filter circuit which has a short time constant. Such a circuit responds to short-lived pulses of voltage, but are not additionally affected by pulses which are longer than usual.

Actually, a differentiating circuit, such as those used in television circuits, is one that is affected by the rising voltage at the front edge of a voltage pulse.

The diagrams in Fig. 24 are intended to give what amounts to a slow-motion view of a differentiating circuit in action. There is a sharply rising voltage *pip* at the output of the circuit each time the input voltage rises sharply. This is as true for the front edge of the vertical pulses as for the horizontal pulses. This action keeps the horizontal sweep synchronized during the period in which the vertical pulses are present.

In Fig. 24 the incoming signal has the waveform of a square-wave signal. This is the shape of most sync pulse voltages. The voltage rises sharply at the front edge, maintains that amplitude of voltage for a period of time without material variation, then falls abruptly to zero.

The differentiating circuit in Fig. 24 consists of a .001 mfd capacitor and a 100,000-ohm resistor. The time-constant of such a combination would amount to .0001 second, or 100 microsecond.

The square-wave signal has a frequency of 100 cycles per second. This means it goes through a complete cycle during the passage of .01 second of time.

Thus, each cycle of the incoming signal is 100 times as long as the time constant of the differentiating circuit. The differentiating circuit responds to the square-wave signal, but the square-wave is not reproduced at the output of the differentiating circuit.

The graphs under the diagram describe somewhat better than words the nature of the electrical action which takes place in the circuit.

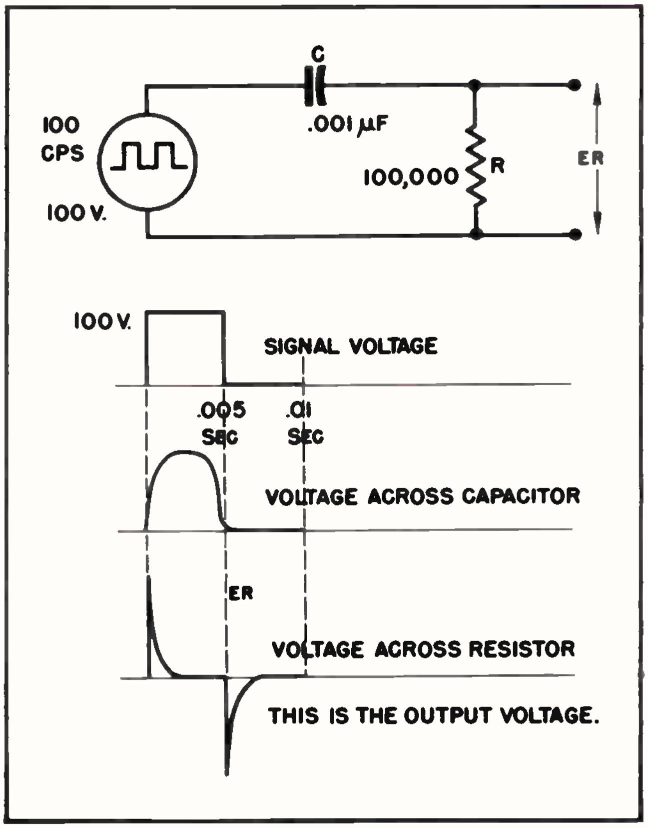

Figure 24. Action in a differentiating circuit when a low-frequency square-wave signal is applied.

When the voltage rises sharply at the front edge of the incoming square-wave it is impressed on the .001 mfd. capacity. The rising voltage of the square-wave pulse causes the voltage at the output of the capacitor to rise sharply as the voltage on the input side rises.

After the voltage rises to its maximum on the input side of the capacitor it levels off. It continues at that peak amplitude for approximately .0055 second of time.

However, the voltage at the output of the capacitor cannot be maintained at that peak amplitude. The voltage is rapidly dissipated by action of the 100,000-ohm resistor. Within 100 microseconds of the sharp peaking rise of the voltage at the output of the capacitor it again drops to zero as the voltage is discharged by the resistor. This action is disclosed by the graph at the bottom of the illustration in Fig. 24.

Later, when the square-wave voltage at the input of the capacitor suddenly drops to zero at the end of .005 second, it sends the voltage at the

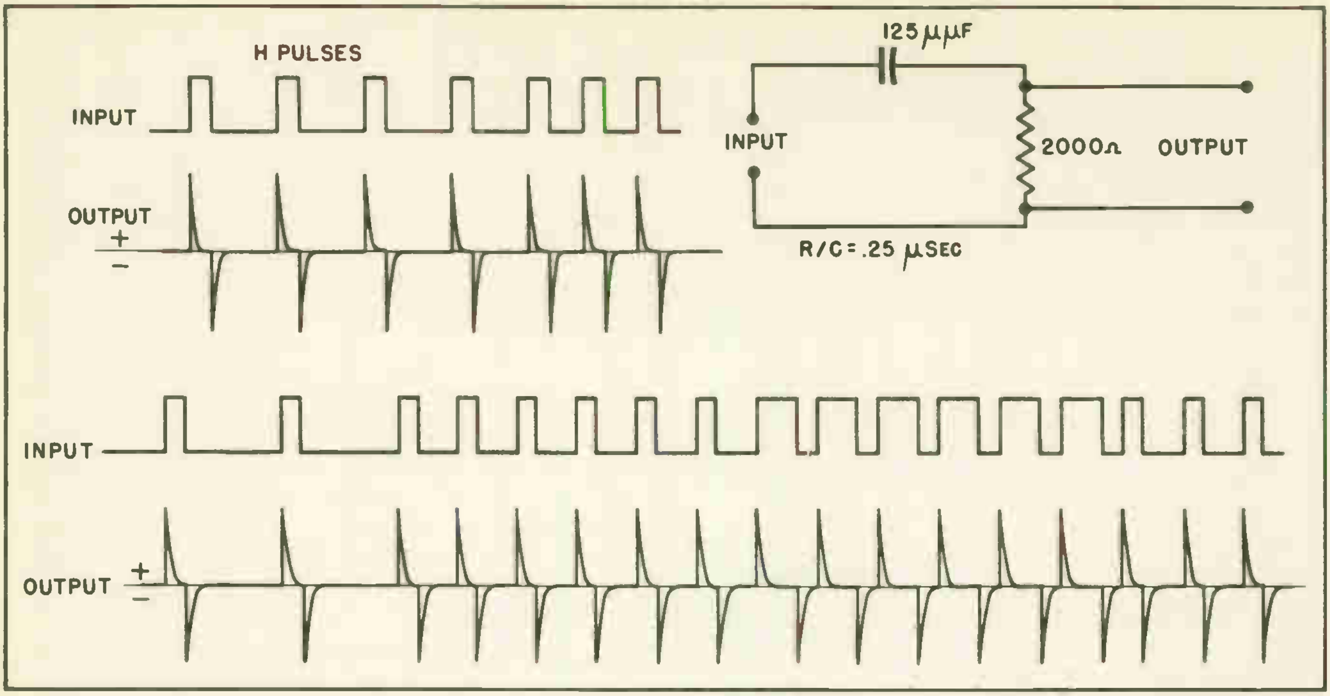

Figure 25. Waveforms at input and output of TV differentiating circuit.

output of the capacitor in the same direction. But since the original voltage at the output of the capacitor has already been dissipated this sudden new drop in the voltage causes the voltage at the output to go below the zero-line. The exact shape of the output voltage is shown by the graph in Fig. 24.

A somewhat better idea of the actual action in a differentiating circuit used in a television receiver can be obtained by studying Fig. 25.

The successive pulses from the sync separator tube are shown at the top of the drawing in Fig. 25. They have the normal square shape of most sync pulses.

That string of pulses is applied to the input of the differentiating circuit. The voltages at the output resemble those shown at the bottom of the illustration.

The additional series of pulses in the lower pair of graphs describe the action during the arrival of equalizing and vertical pulses. Note that the output voltage pips continue in a regular pattern on the upper sides of the zero line. There are variations in the pattern below the zero line, but they are unimportant.

When studying this illustration it is well to note that width of the incoming voltage pulse has little influence on the signal at the output of the differentiating circuit. A wide pulse, such as one of the vertical pulses shown in Fig. 23 and the lower part of Fig. 25, creates a voltage pip at the output exactly like one of those from a short horizontal sync pulse. The pulses on the upper side of the output zero-line will appear at regular intervals, and regularly spaced. They will come twice as frequently when the equalizing and vertical pulses are present, but the output pulses continue to be regularly spaced.

The voltage pips below the zero-line of the output signal may be displaced from their normal position because of the varying widths of the equalizing and vertical sync pulses, but that is of no importance. The lower pips have no significance, and are quickly disposed of because they are not useful.

This can all be summed up rather simply. If the series of voltage pulses shown in Fig. 23 were fed into the differentiating circuit shown in Fig. 25 the output from that circuit would be a series of voltage peaks, or "pips." A voltage would appear at each interval of H. These voltage pips spaced at intervals of H from each other are what maintain the horizontal oscillator in synchronism. These voltage pips are fed into the oscillator circuit to keep it synchronized.

This is what we have tried to show with our graph at the bottom of Fig. 25.

One of these voltage pips occurs at the leading edge of each horizontal sync pulse, but they also occur at the leading edge of each equalizing pulse and each vertical sync pulse.

It is true that additional voltage pips appear half-way between the synchronizing voltage pips when the equalizing and vertical sync pulses are present but that is not important. These voltage pips are unable to trigger the horizontal oscillator because at the time they appear the horizontal oscillator is not in condition for synchronizing action. Therefore, the pips, created by the alternate equalizing and vertical pulses, produce no action of any kind in the horizontal circuit, and can be completely ignored.

A study of the differentiating circuit in Fig. 25 shows it has a very short time constant. The capacitor has only 125 mmfds. of capacity. The leakage resistor has a resistance of only 2000 ohms. Applying the time/constant formula we multiply .000125 by .002, and come up with the rather formidable value of .000,000,25 seconds. Reducing this to microseconds we find we have less than one microsecond. We have only 0.25 microseconds, or ¼ microsecond to be exact.

Since the incoming sync pulses have a frequency of 15,750 cycles, and the total duration of the horizontal pulses is only 8% of H, or 8% of 63.5, we can begin to see the need for such a very short time constant. The voltage rises very rapidly at the front edge of the sync pulse. It rises in approximately one-quarter of a microsecond, although the total duration of the sync pulse is about 5 microseconds.

Even though the time constant of the differentiating circuit is so short, it is still sufficiently long to respond to the sharp rise in voltage at the leading edge of the sync pulse. But being short, it is not affected by the length of the pulse. It is not affected by the length of either the horizontal sync pulse nor the length of the equalizing pulse, which is only half as long. This being true, it naturally is not affected by the additional length of the vertical pulses.

All of which is very much to the good. It is not desirable that the circuit intended to separate the horizontal sync pulses should be affected by the additional length, in terms of duration, of the vertical pulse.

The whole purpose in designing a circuit of this kind is to provide a method for filtering out the horizontal pulses, and separating them from the other pulses present, but not permit any of the other pulses to pass through. The leading edge of each vertical pulse causes a voltage pulse to pass through the differentiating circuit, but the additional length of the vertical pulses does not additionally affect the differentiating circuit.

It is desirable for the sharply rising voltages at the front edge of the vertical pulses and equalizing pulses to affect the differentiating circuit. But it is not desirable to have the width — or length, or duration — affect it.

Section 14. SEPARATING THE VERTICAL SYNC PULSES

An entirely different kind of circuit is used to separate the vertical pulses. This should be a circuit which responds to length, or duration, of the sync pulse, and be insensitive to suddenly rising voltages. Because the vertical synchronizing pulse actually consists of a group of six pulses, the circuit should be capable of adding all the voltages from those pulses together, and thus create a triggering voltage to act upon the vertical sweep oscillator. This is accomplished by the integrating circuit.

Fig. 26 gives a pretty good idea of the basic essentials for an integrator circuit.

The integrator circuit shown in the diagram in Fig. 26 is not necessarily one that is actually used in commercial television receivers. But it does show the essential elements of a circuit which is used to perform integration action.

The purpose of an integrating circuit, whether intended for use in a television receiver or for some other purpose, is that it be capable of accepting a series of electrical pulses, then add their voltages together to arrive at a total combined voltage. This is done by passing the successive pulses through a relatively high value resistor to charge a relatively large capacitor.

Presence of the high resistance resistor makes the charging process relatively slow. This means that short electrical voltage pulses do not pass

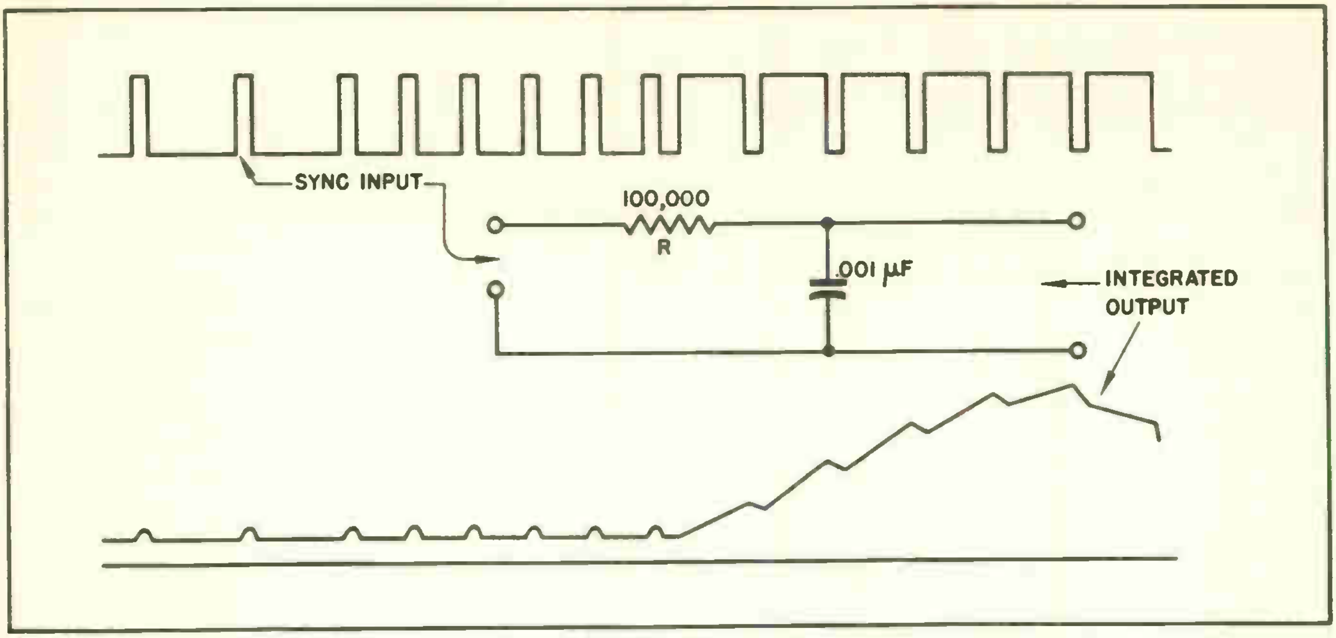

Figure 26. Basic integrator circuit

any great amount of electrical charge through the resistor.

Furthermore, the relatively large capacity of the capacitor takes longer to charge, especially when the charge must pass through a resistor. By combining the high resistance with the large capacitor we create a circuit which is little affected by any short electrical pulse which happens to strike the input to the circuit. But if the electrical pulse is long continued, or there are a succession of long pulses, electrical charges pass through the resistance to charge the capacitor.

In Fig. 26 we see a capacitor with a capacity of .001 mfd. It is charged by electrical pulses passing through a resistance of 100,000 ohms. By applying our time/constant formula we find the circuit has a time constant of 100 microseconds. This is a long time when compared with the time constant of 0.25 microseconds in the differentiating circuit for the horizontal pulses.

In Fig. 26 we see that a succession of short, but widely-spaced, horizontal sync pulses strike the integrator circuit. Each of these pulses apply a small charge to the capacitor, but the pulses are so short they actually apply very little charge.

Furthermore, they are so widely spaced that any charge which is placed on the capacitor by one pulse is able to leak off before the arrival of the following one. Thus, no two successive horizontal pulses add together to increase the total electrical voltage charge on the capacitor.

Note the arrival of the equalizing pulses. They are closer together than the horizontal pulses, being spaced only half as far apart. However, because they are short pulses they have no more effect in placing a charge on the capacitor than is true of the horizontal pulses.

After the equalizing pulses come the series of six long vertical pulses. Note what happens to the capacitor then.

Each of the long vertical pulses places a substantial voltage charge on the capacitor. And the long vertical pulses follow each other so closely that the charge from one cannot leak off before the following pulse arrives to add more voltage to the capacitor.

As the successive vertical pulses follow one another the charge on the capacitor builds higher and higher. The electrical voltage charge builds far higher on the capacitor than can possibly be done by the short horizontal pulses.

The rising voltage charge on the capacitor is coupled to the grid circuit of the vertical sweep oscillator in such a way that when the voltage on the capacitor rises to some predetermined level it triggers the vertical oscillator and starts the retrace of the vertical sweep circuit. It is thus the vertical sync pulses control the frequency of the vertical oscillator to keep it in step with the sweep circuit in the camera at the transmitter.

Note the qualification in the preceding paragraph. It is when the voltage across the capacitor in the integrating circuit reaches a definite, *predetermined* level that it triggers the vertical oscillator.

When the voltage rise hits that definite level it triggers the oscillator. The rising voltage does not trigger the vertical sweep oscillator earlier. If it did, the vertical retrace would occur too soon. Nor does it trigger the vertical oscillator a little later. If it did, the vertical retrace would be too late.

The timing must be exactly right.

The exact amount of voltage needed to trigger the vertical oscillator during one cycle must be exactly the same as that for the preceding cycle and for the following cycle, and for all the other cycles which precede and follow.

Section 15. HOW INTEGRATOR CAPACITOR IS ELECTRICALLY PREPARED FOR VERTICAL PULSES

Each of the successive vertical pulses are carefully controlled. Each adds a certain definite amount of voltage to the charge on the capacitor. This is controlled at the transmitter.

But all this being true it presents another rather interesting problem. It presents the necessity for applying the first pulse of the six in the vertical group to the integrator circuit when the existing voltage on the capacitor is some definite value.

To better understand this problem it should be kept in mind that many kinds of voltages may possibly be applied to the capacitor in the integrator circuit. The varying levels of the camera signal may reach the capacitor in the integrator circuit.

If the camera signal during the preceding line is carrying information for a dark picture area the amplitude of the camera signal is high, and thus some of the voltage may reach the integrating capacitor. This is because it is higher than during a period when the picture is light.

Thus, the picture information in the composite video signal may possibly reach the integrator capacitor if the preceding separator is not functioning properly, or there may be something else to cause the voltage on the capacitor to vary from one field to another.

From all this it can be seen that some means must be provided to make certain the voltage on the integrator capacitor at the time the six vertical sync pulses arrive is exactly the same as it was at the end of the preceding field. And it must be the same for all other succeeding fields.

This is where the equalizing pulses do their stuff. They strike the integrator capacitor immediately ahead of the six vertical sync pulses.

The successive equalizing pulses are all exactly alike. They are equally spaced. They place a small amount of voltage on the integrating capacitor, but it is very little. The equal spacing between the pulses provide for leakage from the integrator capacitor of most of the applied voltage, although some slight traces may remain.

The important fact is that these equalizing pulses always precede the vertical sync pulses. They prepare the integrator capacitor for the arrival of the vertical sync pulses.

They insure that any possible voltage charge which may be on the integrator capacitor when one group of vertical pulses arrive, is exactly the same as that on the capacitor when each of all the other vertical pulse groups arrive. In plain words, they insure that the voltage on the integrator capacitor is always at exactly the same level when each group of vertical sync pulses arrive. The voltage on the integrating capacitor is never higher nor lower when one group arrives than it is for another group.

This makes it possible to trigger the vertical sweep oscillator at exactly the same place in all its successive sweeps. It is the same for all those which precede, and all those which follow.

The reason is so each of the vertical pulses places a definite and specific amount of voltage charge on the integrator capacitor. So, if the existing voltage on the capacitor is always the same when the sync pulses begin to arrive, the

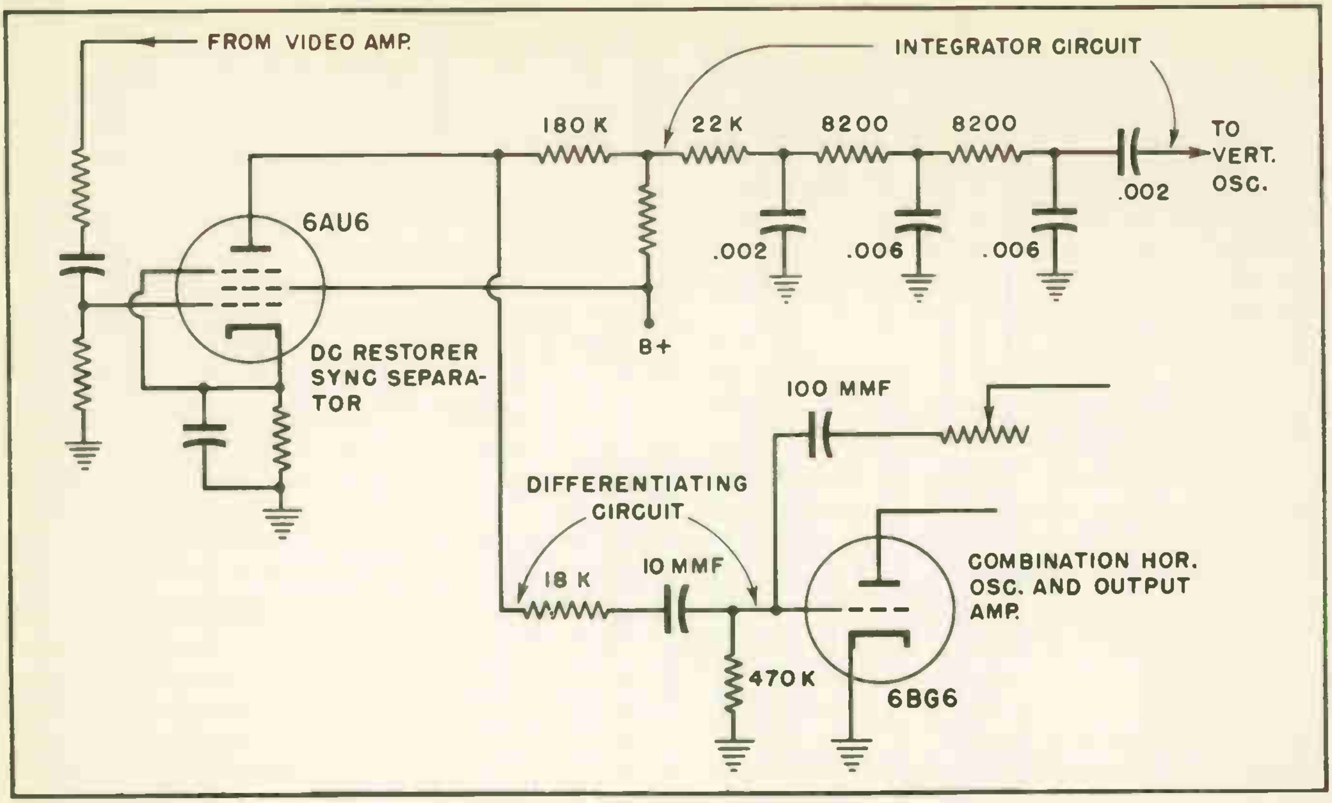

Figure 27. Simple Sync Separator Circuit

voltage from the pulses will always build up to the triggering level after the arrival of the same given number of vertical pulses.

Section 16. PRACTICAL SEPARATOR CIRCUITS

In the preceding sections of this lesson we have tried to break down the essential actions of the various parts of sync separator circuits into individual circuits so the actions could be more easily studied, and be more easily understood.

In practical circuits it is a little more difficult to separate the circuits into their individual components. In many cases the circuits are so closely interconnected it is difficult to point to one specific portion and say it performs one specific function.

Separator circuits are very simple in some receivers. They become very complex in others. Much depends on the ideas of the manufacturer and his designers. The cost at which a receiver is to be sold is always an important and controlling factor.

It must never be forgotten that television manufacturing is a highly competitive business. The difference of only a few cents in cost is often an important item. This is especially true in the case of inexpensive receivers, and most especially those built for large scale merchandisers who sell under private labels at competitive prices.

A sync separator circuit which is about as simple as any ever included in a television receiver is shown in Fig. 27. It is the sync separator circuit in a 1950 Coronado receiver built for the Gamble-Skogmo stores.

A single 6AU6 pentode acts as the D-C restorer and sync separator tube. The output of the tube is a series of pulses. These are the horizontal and vertical synchronizing pulses similar to those shown in Fig. 23. The anode of the tube is maintained at low voltage, thus effectively limiting the amplitude of the pulses, and preventing the camera signal getting through into the output of the tube.

Both the differentiating and integrating circuits are connected directly into the anode circuit without any other tube or circuit intervening. This is somewhat different from many other receivers, some of which have one or two other tubes between the sync separator and the oscillator tubes.

Instead of the integrator circuit having only one resistor it has several. This is not unusual. In fact, it is quite common for the integrator to be arranged in this manner. The arrangement of the integrator circuit is described in several other lessons.

Between the individual resistors are capacitors connected to ground. This arrangement makes it possible to filter out to ground any individual short noise pulses which happen to get into the circuit. This helps filter out the horizontal pulses and keep them from affecting the action of the vertical oscillator.

The time constants of the various elements of the circuit are such that they encourage the build up of a voltage by a series of long pulses, but effectively filter out short voltage pulses. The result is that the successive vertical pulses build up a triggering voltage on the .002 capacitor which leads to the vertical oscillator tube, but the short horizontal pulses have no effect on it.

The horizontal deflection circuit is truly unusual. Only a single tube is used as the horizontal oscillator and horizontal amplifier, and no attempt is made to feed the horizontal sync pulses into an AFC circuit before they reach the horizontal tube.

The differentiating circuit is just about as simple as it can be made. It merely consists of a single 18K resistor in series with a 10 mmfd. capacitor. This circuit has a very short time constant, but is sufficient to pass the triggering voltage pulses needed to keep the horizontal oscillator synchronized with the sweep circuits in the transmitter.

At the other extreme is the sync separating circuits devised by RCA and used in their model T-100. The same circuits were used virtually unchanged in many other models built by RCA. Because so many other manufacturers operate under patent licenses from RCA, this same circuit can be found almost unchanged in dozens of other makes of television receivers.

A diagram of the circuits used in this sync separator system is shown in Fig. 28. Even a glance at the diagram in Fig. 28 discloses the fact the circuit is much more elaborate and complicated than that in Fig. 27.

In the circuit in Fig. 28 the composite video signal is introduced to the grid of the first sync separator tube. This signal is tapped off the video amplifier wherever it is most convenient.

The first sync amplifier has a low anode voltage. This causes the tube to exclude the camera signal and pass only the pulses.

Those pulses are introduced to a second tube, which is usually called a sync amplifier. The purpose of that tube is to increase the amplitude of the pulse voltages which pass through the first tube.

After the pulses are amplified they are passed to a second sync separator tube. But before they reach the control grid of the second separator tube they must pass through a circuit to which is connected the anode of a diode limiter tube. The purpose of the limiter is to provide an additional leveling action to the amplitude of the pulse voltages, thus causing them all to have the same magnitude.

The first sync separator tube acts to separate the sync pulses from the camera signal. The second separator tube is intended to aid in the action of separating one type of sync pulse from the other. The sync pulses are tapped off the cathode circuit of the second separator tube rather than the anode, as is the more customary practice in most amplifier circuits.

Both the integrator and differentiating circuits are tied directly to the cathode of the second separator tube. The integrator circuit consists of a group of resistors and capacitors arranged in very much the same manner as those in the integrator circuit in Fig. 27. If you compare the integrator circuit in Fig. 27 with that in Fig. 28 you will find the values of the components are quite similar. This is not surprising, since both are intended to pass the same type of vertical sync pulses, and exclude the passage of the same type of horizontal sync pulses.

But a study of the circuit which handles the horizontal sync pulses discloses that it is radically different from that in the circuit shown in Fig. 27. In fact, it is rather difficult to identify any portion of the circuit in Fig. 28 as being a dif-

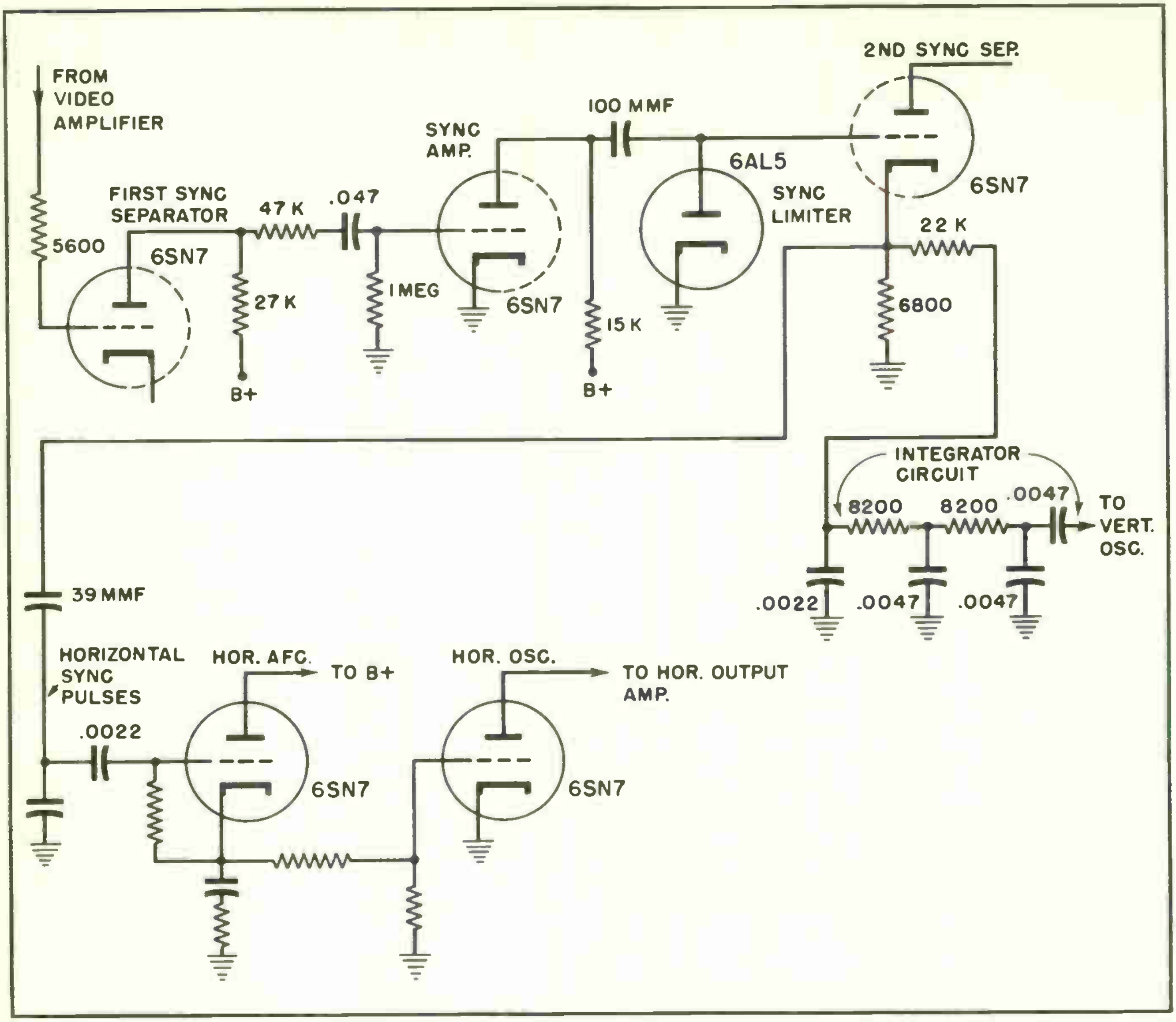

Figure 28. Sync Separator circuits used in RCA models.

ferentiating circuit. At least it is difficult to identify it as being similar to what we have previously described in connection with differentiating circuits.

The 39 mmfd. capacitor in the circuit linking the second separator tube with the grid of the horizontal AFC circuit will pass only very short voltage pulses. The capacitor itself, even without a resistor, has a very short time-constant.

However, the synchronizing pulses are not applied directly to the horizontal oscillator circuit. Instead, they are applied to the control grid of the horizontal Automatic Frequency Control circuit. It is the output voltage developed at the cathode of the horizontal AFC tube which controls the frequency of the horizontal oscillator.

We have not discussed the details of a horizontal oscillator circuit, and have scarcely mentioned the automatic frequency control circuit which is often included with the horizontal oscillator. That is taken up in detail in later lessons. There is not enough space to get into that subject at this time.

The purpose of the automatic frequency control is to control the frequency of the horizontal oscillator. Its purpose is to keep the horizontal sweep going through its cycles at exactly the correct frequency of 15,750 cycles per second.

By interposing the AFC circuit between the incoming horizontal sync pulses and the horizontal oscillator it helps prevent random noise pulses triggering the horizontal oscillator at the wrong time, and thus get it out of synchronism.

The incoming sync pulses are fed into the automatic frequency control as a part of several pulse signals which are introduced to that grid. All the pulse signals added together act to create the control voltage for the following tube— not the sync pulses alone.

The horizontal sync pulses arrive at the control grid of the automatic frequency control tube at regular intervals. The other signals, also in the form of pulses which are impressed on that control grid, arrive at regular intervals from other sources. It is necessary for all the signal pulses to arrive at the same time to create the necessary control voltage for controlling the frequency of the oscillator at the following tube.

The advantage of this type of control system is that erratic and random electrical noise pulses from automobile ignition systems, fluorescent lamps and similar sources cannot act directly upon the control grid of the horizontal oscillator tube to knock it out of synchronism. All these electrical noise pulses first strike the control grid of the control tube. Unless they arrive at exactly the same instant as the other voltage pulses from other sources they have no effect on the oscillator tube frequency.

This is a rather complex arrangement, and will be described in detail in later lessons. The circuit, and modifications of it, are found in millions of television receivers. The circuit has been greatly simplified through the process of evolution. Fewer tubes are used in many of the more modern receivers. But the basic essentials of the circuit continue to be widely used.

Section 17. MODIFIED SEPARATOR CIRCUITS

Most manufacturers prefer a somewhat more reliable horizontal synchronizing circuit than that used by Coronado in the circuit shown in Fig. 27. They are also reluctant to include so many tubes as are required by the elaborate circuit shown in Fig. 28.

The circuit in Fig. 27 maintains synchronism between the receiver horizontal sweep circuits and those in the transmitter. At least they do so when there is no outside disturbing electrical noise.

But they are susceptible to noise interference. It is not so bad in rural areas where interfering electrical noise pulses are of little concern. But in metropolitan areas the noise level is often so high it creates a jerky appearance in the picture.

On the other hand, the circuit shown in Fig. 28 contains so many tubes the construction and assembly cost is excessive, and the extra tubes frequently bring special problems of their own. The more tubes in a television receiver circuit the more chances the receiver will need attention from service technicians.

Manufacturers have pressured their engineers into designing sync separator circuits which are insensitive to outside interfering noise, yet are not so complicated as the one originally developed by RCA. The modified circuit shown in Fig. 29 is one that has been adopted by many manufacturers.

In the circuit shown in Fig. 29 the composite video signal present in the video amplifier is fed to the grid of the sync separator tube. This is usually one-half of a 6SN7, as shown in Fig. 29. But quite often it is one-half of a 12AU7, which is a miniature tube with characteristics similar to the 6SN7.

The sync separator tube separates the synchronizing pulses from the camera signal. Only the pulses are present in the anode circuit of the tube.

The sync pulses are then fed into a Sync Phase Inverter tube. This is usually one-half of a 6SN7, but may be a 12AU7.

The output of the phase inverter tube feeds a signal into the integrator circuit where the vertical synchronizing pulses are separated from the others. The vertical pulses are then fed through the integrator circuit to the vertical oscillator.

But note also, a portion of the anode signal is tapped off and fed into another circuit. To be more exact you should note that a portion of the anode pulse signals, and a portion of the pulse signals developed at the cathode of the sync phase inverter are fed to the cathode of the horizontal

AFC tube. These two groups of pulses are 180° out of phase with each other.

The net effect of these two groups of pulses is to place a strong positive pulse on the control grid of the AFC tube at the same instant a strong negative pulse is placed on the cathode. The combination of these two pulses on those two elements of the AFC tube is such to make the grid of the AFC tube momentarily positive with respect to the cathode, and thus in condition to conduct.

However, the tube cannot conduct unless a positive pulse is simultaneously placed on the anode. The anode is normally at zero voltage, but regular positive pulses are fed back from the horizontal transformer.

These combinations of voltages help to stabilize the action of the horizontal oscillator, and isolate it from electrical noise pulses which do not arrive at regular intervals. Irregular electrical noise pulses do not affect the oscillator circuit, nor its frequency.

To provide additional stabilization a voltage pulse is also fed back from the horizontal oscillator. These pulses are fed to the control grid of the AFC tube to reinforce the voltage pulse from the sync phase inverter.

The advantage of this circuit over the others studied previously is that it does not require so many tubes, nor so many complicated combinations of resistors and capacitors. The fewer tubes present in a receiver the less trouble they are likely to give the owner. The same holds true for resistors and capacitors.

Section 18. OTHER VARIATIONS IN SYNC SEPARATOR CIRCUITS

We have tried to explain the action of several types of sync separator circuits used in modern television receivers. It is impossible to describe all the variations from these basic circuits.

There are more than 100 television manufacturers in this country. Many of these manufacturers have built well over 500 models. From this it can be seen that many thousands of different models of television receivers have been built and sold. A detailed explanation of all the variations which have appeared in all those various models would prove boring, and would serve no purpose.

Once the basic purpose for the sync separator circuits has been fully grasped, and the reason certain things have been done are understood, it becomes possible to study the circuit diagram of any receiver and understand it.

The sync separator circuits in all receivers serve the same basic functions. They serve to separate the vertical pulses from the others, and pass them on into the vertical oscillator circuit so the vertical oscillator of the receiver is synchronized with that at the camera. They also serve to isolate the horizontal sync pulses from the other electrical voltages in the composite video signal, and feed them into the horizontal control circuit in such a way that the horizontal sweep oscillator is synchronized with that at the camera.

The exact manner in which these basic purposes are accomplished varies from one receiver to another. But the basic functions must be served. Otherwise the separator circuits serve no purpose at all.

It has become almost universal custom to feed the horizontal pulses into some type of automatic frequency control circuit which acts to control the frequency of the horizontal oscillator. They are fed into the AFC control tube rather than being fed directly into the oscillator tube. Such isolation of the horizontal oscillator acts to stabilize the frequency of the horizontal sweep, and make it insensitive to random electrical noise pulses.

There are several kinds of AFC circuits in common use in television receivers. Some employ the basic principle of a phase detector, such as the one shown in Fig. 29. Others work on the principle of a tank circuit which regularly places a positive voltage on the AFC tube sufficient to make it conduct. Others feed back voltage pulses from the horizontal oscillator or from the horizontal output transformer.

It is impossible to more than touch on this subject in this lesson. It is a big subject, and is handled in detail in several lessons which follow later in the course.

Section 19. SERVICING SYNC CIRCUITS

Trouble in sync circuits shows up in the pat-

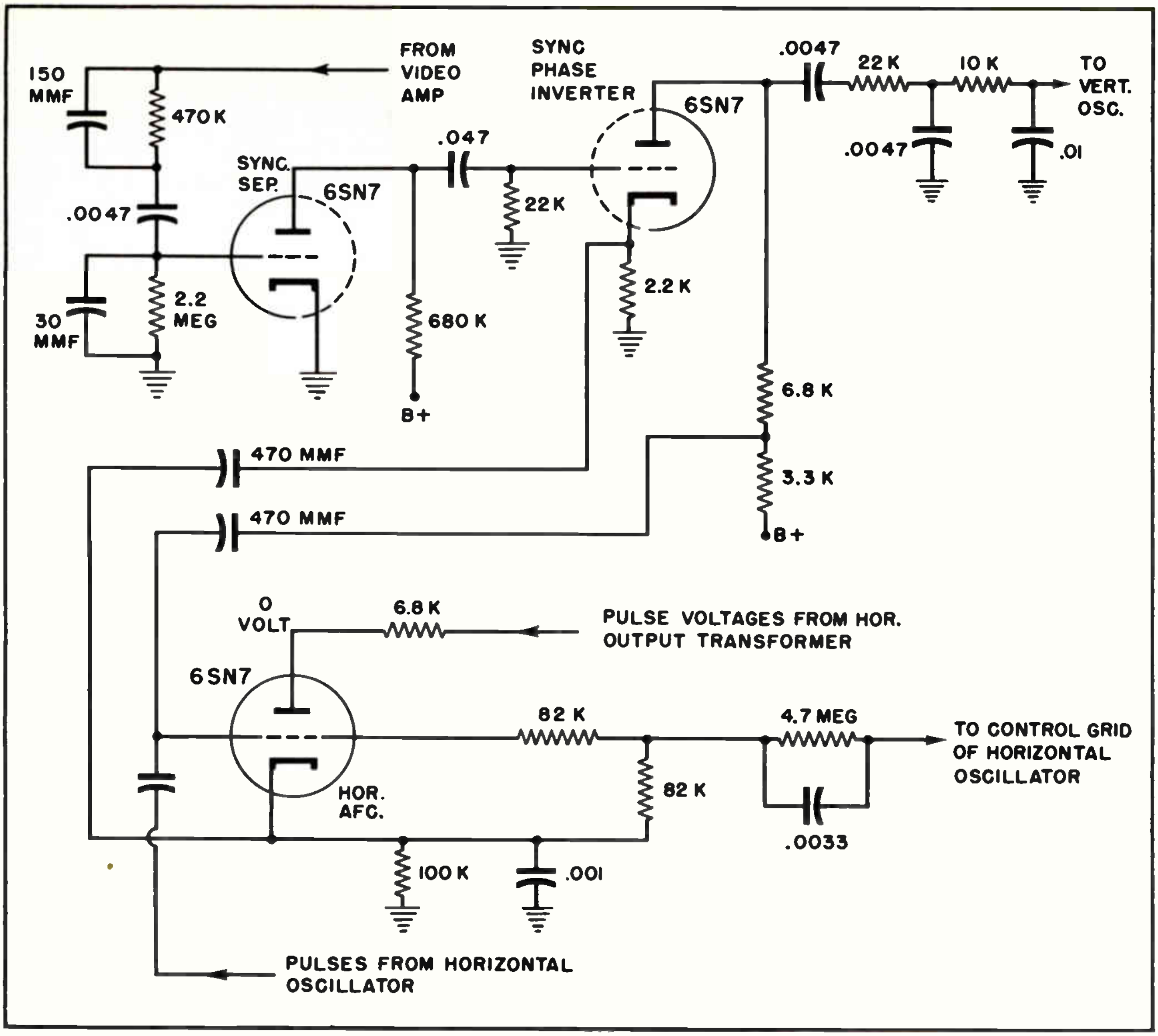

Figure 29. Modified Sync Separator Circuit

tern on the screen as being a condition in which it is impossible to properly synchronize the deflection circuits.

If the trouble is present in the circuit which separates the synchronizing pulses from the video signal there will be no synchronizing pulses on either the vertical or the horizontal circuits. In that case it will be impossible to maintain synchronism in either the vertical or horizontal directions.

There is always the possibility the sync pulses are temporarily missing from the signal itself. This is not a frequent condition, but it has been known to happen.

Sometimes mis-adjustment of the I-F or R-F circuits results in the sync pulses being lost.

All of which means the pattern on the screen must be studied—if possible—to see if the sync pulses can be seen on the screen. If they can be seen on the pattern on the screen it is clearly evident they are present at the electrical position where they are normally tapped off by the separator circuit.

The next thing is to make a check around the sync separator tube itself. To be exact, the first step in a case of this kind is to remove the sync separator tube and install another known to be good.

If the trouble resulted from a defective tube, the act of replacing the tube should clear up the trouble without further search. Probably in nine cases out of ten replacing the tube will clear up the trouble.

Occasionally it will not. Then comes more serious trouble-shooting procedures. The next step is to see just where the signal is disappearing, and what is causing it to disappear.

Since the signal in which we are interested is a series of electrical voltages it now becomes necessary to employ some type of instrument which enables us to follow these pulses. In most cases this means using an oscilloscope.

When serious trouble develops in the sync separating circuits — trouble which cannot be corrected by replacing a tube—the only practical method of tracing down the trouble to its source is to use an oscilloscope. A 'scope is the only instrument which permits you to follow sync pulses through the circuits where they should be, and locate the place where they disappear.

Fig. 30 gives a pretty good idea of how a scope is used to follow the sync pulses through the separation circuits.

The scope is set at the horizontal frequency of 15,750 cycles per second, or at a sweep frequency of 7875 cycles per second. If the 'scope is set to sweep at 15,750 cycles per second there should be one pulse pip on the screen of the 'scope. If it is set to sweep at 7875 cycles per second there will be two pulse pips on the screen of the 'scope.

Most service technicians prefer to set the 'scope at 7875 cycles so they can watch the action through two complete horizontal cycles. Some even set their sweep to a lower frequency. Much depends on the type of 'scope being used, and the size of the screen. It is difficult to follow the action of the pulse pips when an effort is made to examine too many cycles on the screen of a small 'scope.

Most technicians prefer to insert an isolating network in the "hot" lead from the 'scope which is used to probe into the sync circuits. Presence of such an isolating network prevents any loading of the TV circuits which might possibly distort the wave-shapes, or introduce unwanted capacity into them. The isolating network is nothing more than a resistor and capacitor in series in the "hot" lead as shown in Fig. 30. The values of the resistor and capacitor are not especially critical, and they are not needed at all when using some types of 'scopes.

Usually the first probing test is made at the output of the first sync separator tube. This is indicated as position *A* in Fig. 30. When the probe is in place to pick up a signal from the output circuit of the first sync separator the horizontal frequency of the 'scope is adjusted until the sweep of the 'scope locks in with that of the receiver.

If no pulse pip can be seen on the screen of the tube it is a good sign it is not getting through the first sync separator tube. This may mean the tube is bad, or it may mean the line from the video amplifier circuit is open or short-circuited. Or, it may mean there is a defect in the tube circuits.

The next step would be to take a V-O-M or VTVM and check the circuit between the video amplifier and the input to the first sync separator. It also means checking the voltages in and around the tube itself. Sometimes leaky capacitors, or other defective components, introduce unwanted or incorrect voltages on the tube elements.

If the pulse appears at the output of the sync separator tube the next step is to check for it around the sync amplifier tube, if such a tube is used in the circuit. Remember, many TV receivers do not use a sync amplifier tube.

That tube would be checked by touching the "hot" probe of the 'scope to the output circuit of the sync amplifier tube as shown at position *B* in Fig. 30.

If the pulse pips do not show up on the screen of the 'scope it is then necessary to check all the circuits around the tube. This may mean changing the tube, and may mean a check by using a V-O-M or VTVM. Much depends on the exact type of circuit involved, and what is suspected by the appearance of the pattern on the oscilloscope.

If the pulse pips appear in good condition at

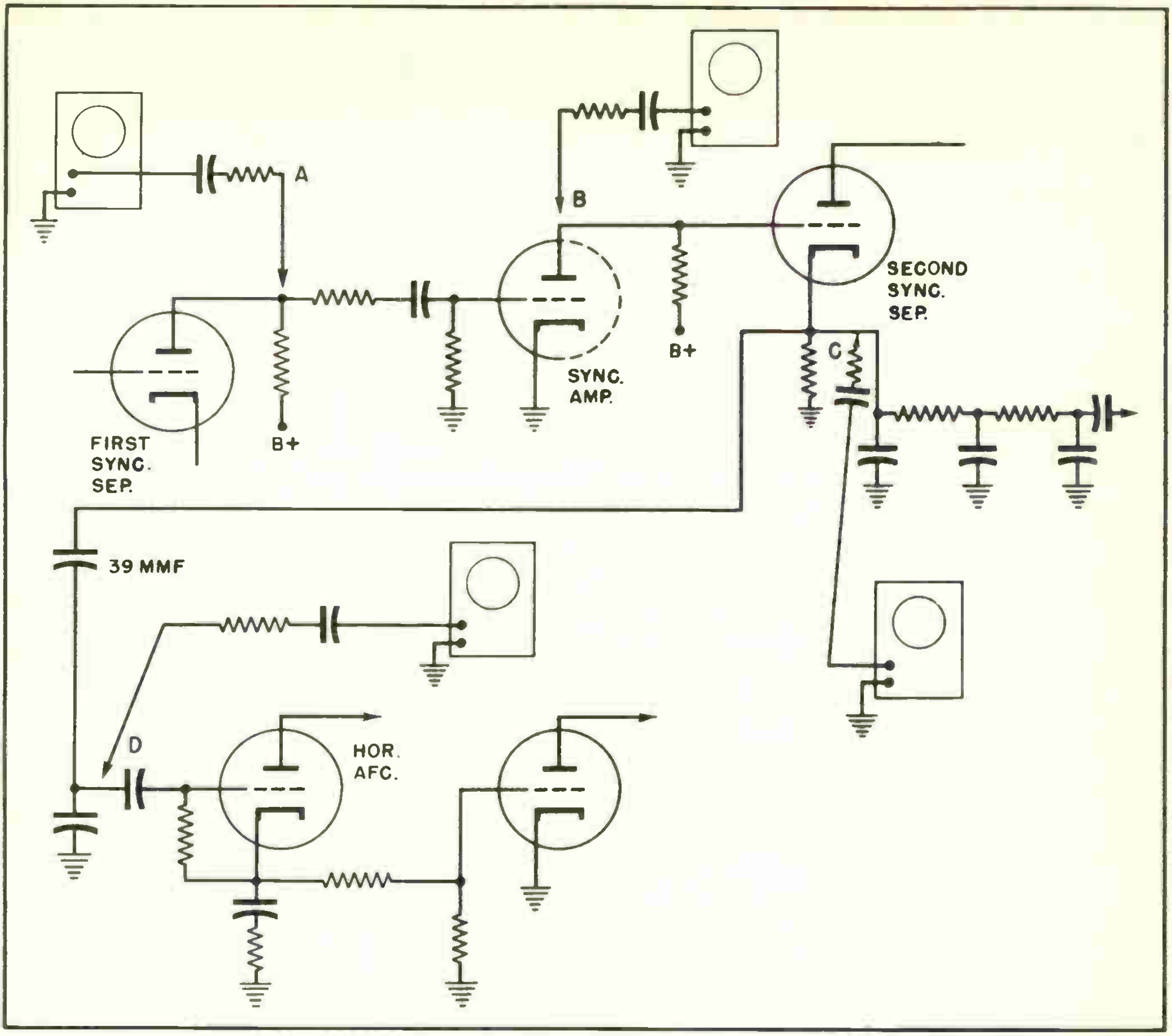

Figure 30. Using Oscilloscope to trace sync pulses.

the output of the sync amplifier tube the next check is made at the output of the second sync separator tube. That is indicated in Fig. 30 as position *C*.

If the pulses are not found at that location it is necessary to check the circuits and voltages around the second separator tube.

If the pips show up in good shape at the output of that tube the next check should be made at position *D* in Fig. 30.

Using the oscilloscope in this manner enables you to follow the sync pulses through the various circuits until they disappear. When they fail to come through a circuit it is a clear indication there is something wrong in the circuit. Usually the defect can be discovered by checking the voltages, resistances and capacitors in and around the circuit. This latter form of trouble-shooting is no different from checking a tube circuit in a radio.

In this connection it is well to interject a bit of advice we have given in other lessons — the importance of having a technical manual or data sheet available which contains all the technical information concerning the receiver being checked.

The technical manual gives the voltages at the various tube socket lugs, and other critical locations. In many cases it shows the shape of the 'scope pattern which should appear at various important locations throughout the circuit.

Trying to service a television receiver without having a manual for checking purposes is like trying to take an automobile trip through unfamiliar territory without the aid of a road map. In many cases it is even worse. One can always ask directions of a native if one gets lost while traveling. But all too often there is no one to ask when working on an unfamiliar TV chassis.

Without an oscilloscope to check the voltage patterns in sync separator circuits it is almost impossible to locate the exact cause of trouble. The 'scope points directly to the location of the trouble, and often indicates the exact component which has become defective. Without the 'scope a service technician is almost blind when confronted with trouble in those circuits.

If it is a coupling capacitor which is open, such as the 39mmfd. capacitor between the cathode of the second separator tube in Fig. 30 and the grid of the AFC tube, the 'scope points directly at the capacitor as being the culprit. If the sync pulse is present on the upper side of the capacitor but absent on the lower side it is clearly evident the capacitor has become open.

An open capacitor, as you have been told a number of times, is one which has a pigtail disconnected from one of the metallic plates. Sometimes the pigtail is pulled away from the plate, and no longer makes contact with it. In that case there is no longer any capacity in the capacitor other than the small amount of distributed "stray" capacity which is always present.

Sometimes a resistor or capacitor in the integrator circuit becomes open. The 'scope provides an ideal method for detecting such defect. It points to the exact spot where the pulse voltage disappears. No other instrument can do an equally adequate job.

There are some defects around certain types of AFC and horizontal oscillator circuits which can be detected in no way except through the use of an oscilloscope. This is particularly true of the tuned circuits often placed between the output of the horizontal oscillator and the feed-back voltage into the AFC circuit. That circuit is very critical to adjust, and the waveform of the generated voltage is very critical in the proper operation of the receiver. This circuit will be taken up in a later lesson, and detailed instructions given on how to adjust it.

NOTES FOR REFERENCE

Sync separator circuits are used to separate the synchronizing pulses from the composite video signal.

A variation of the sync separator circuits results in separation of the horizontal pulses from the vertical pulses.

The source of the signal for the sync separator circuits is usually the video amplifier circuit, but it can be tapped off immediately following the detector.

The sync separator circuit is designed so sync pulses can pass through but the camera signal is blocked from passing.

If the sync separator circuits do not operate properly it is difficult or impossible to synchronize receiver deflection circuits with those at the transmitter.

If vertical synchronizing pulses do not pass through the separator circuits properly the picture tends to roll upward or downward. It is almost impossible to keep the picture in one position.

When horizontal sync pulses do not pass through the circuit properly the picture tears, and often makes no sense.

After the synchronizing pulses have been separated from the camera signal they must be passed through special filtering circuits to separate one type from the other.

Vertical sync pulses are separated from other electrical pulses by passing them through a special filter circuit called an *integrating circuit.*

Horizontal pulses are separated by passing them through a *differentiating circuit.*

The integrating circuit has a long time constant, and is not affected by short horizontal sync pulses.

The differentiating circuit has a short constant, and the long pulses used to synchronize the vertical oscillator have no effect on it. They are blocked from passing.

Only the horizontal sync pulses pass through the differentiating circuit.

Triodes are most commonly used as separator tubes. Using such tubes makes it possible to combine the separating action with some other function.

Often the action of separating sync pulses from the video signal is combined with the D-C restorer action or with AGC action. Sometimes all three functions are performed by the same tube.

Diodes can be used as sync separator tubes, and are so used in some receivers.

A resistor and capacitor can be combined in a circuit to measure time.

Whenever a capacitor is charged — or discharged — through a resistor, the charging or discharging action requires a definite, unchanging time.

The length of time required to charge a capacitor through a resistor — or discharge it — is called the time constant of the circuit.

Capacitors do not charge at an even — or linear — rate from the beginning of the charging action to the time the action is fully completed.

During the first half of the action in which a capacitor is charged through a resistor, the rise in voltage follows a linear curve. After that the rate of charge becomes progressively slower.

The action of discharging a capacitor follows the same curve as the charging action — except it is reversed.

When using resistors and capacitors in a time/constant circuit only the first 63% of the rise in voltage is taken into account. The latter part of the voltage rise is never used because it is too erratic for accuracy.

A resistance/capacity circuit used to measure time is commonly referred to as an R/C circuit.

The larger the capacitor in an R/C circuit the longer is the time constant.

The greater the resistance of the resistor in an R/C circuit the longer the time constant.

Reducing the size of the capacity, or resistance of the resistor, in an R/C circuit reduces the time constant.

The time constant of any R/C circuit is calculated on the basis of how many seconds it takes a capacitor to charge to 63% of its peak voltage.

If a discharging action is employed for measuring time the time constant is calculated on the basis of the number of seconds required for the capacitor to become 63% discharged.

The time required for an R/C circuit to charge or discharge is calculated by the formula:

$$T \text{ (seconds)} = R \text{ (in megohms)} \times C \text{ (in microfarads)}.$$

The capacitor in an integrating circuit must be prepared for the arrival of vertical sync pulses. Otherwise, the voltage added by the vertical sync pulses might not always begin at the same level, and thus the vertical oscillator would not always be triggered at the same point in its sweep cycle.

Equalizing pulses are a group of short pulses, each of which is half as long as the horizontal pulses but arrive twice as frequently for a short interval just ahead of the vertical sync pulses.

Because vertical sync pulses are always preceded by a group of equalizing pulses, all of which are always exactly alike, after each field, the voltage on the integrating capacitor is always the same at the instant the first vertical sync pulse arrives.

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DEFLECTION OSCILLATORS

Contents: Kinds of Oscillators used in TV Sweep Circuits — The Multivibrator — Oscillator Action of Multivibrator — Shaping the Voltage Waveform — Cathode-Coupled Multivibrators — Horizontal Oscillator Using Cathode-Coupled Multivibrator — Component Values in Multivibrator for Horizontal Oscillator — Multivibrator in Vertical Circuits — Reversed Multivibrator for Vertical Circuit — Single-Cycle Multivibrator — Vacuum Tube Discharge Circuit — The Blocking Oscillator — Controlling the Blocking Oscillator with Variable Grid Voltage — Blocking Oscillator and Discharge Tube — Using Hartley Type Coil Oscillator — Notes for Reference.

Section 1. INTRODUCTION

Almost from the beginning of this course we have mentioned, from time to time, the subject of horizontal oscillators. We have also mentioned vertical oscillators quite often.

Both horizontal oscillators and vertical oscillators are deflection oscillators. They are also called sweep oscillators.

In an earlier lesson we touched on some of the basic fundamentals of a circuit designed to generate saw-tooth voltage waveforms We did not go very deeply into the technical details of such oscillators at that time, but the lesson did serve to introduce you to the subject.

The purpose of the horizontal oscillator is to generate a repetitive voltage waveform which can be used to move the electron beam from side to side inside the picture tube. As the name suggests, the horizontal sweep oscillator generates the signal which causes the electron beam to move in a horizontal direction.

Voltage signals generated by the horizontal oscillator must meet certain rigid standards if

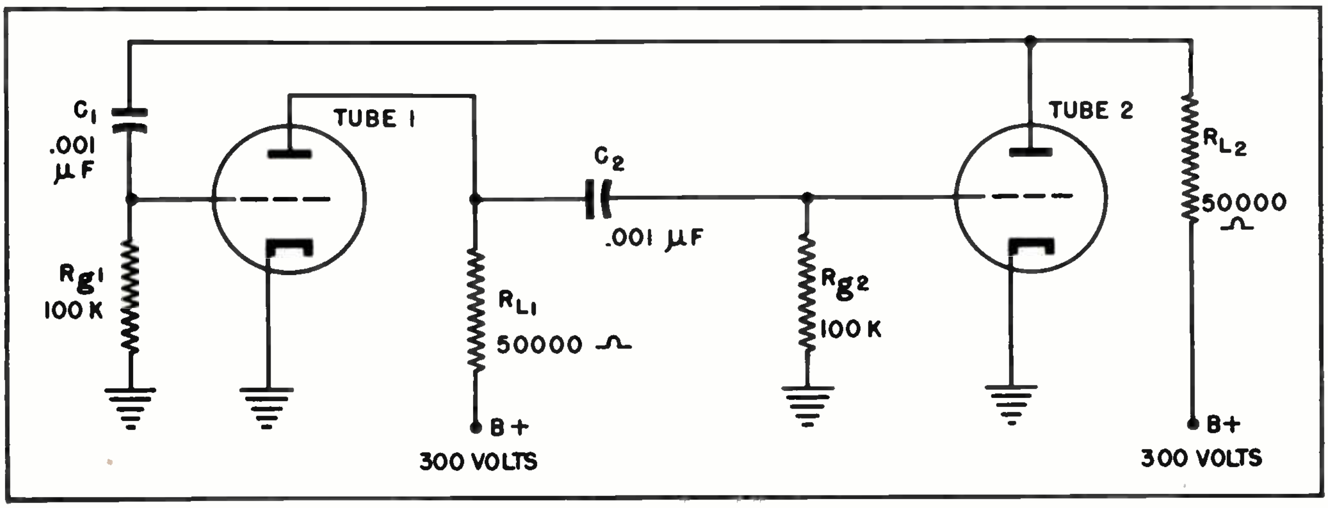

Figure 1. Multivibrator

they are to do the job intended. First and foremost, the generated signal should have a frequency closely approximating 15,750 cycles per second. The "free-running frequency" should be slightly less than 15,750 cycles, but not much less.

Another standard the signal must observe is that the shape of the voltage signal should closely approximate a saw-tooth waveform. This means the voltage of the signal should rise gradually, but linearly. It should then drop to zero rapidly and sharply.

Equally important with the two requirements just mentioned, the horizontal oscillator must be designed so its frequency can be readily synchronized with some other signal.

Standards which must be met by the vertical oscillator are not greatly different from those for the horizontal oscillator. The output signal voltage of the vertical oscillator must also have a saw-tooth waveform, and the oscillator circuit must be designed so that it can be synchronized by an external signal.

One difference between the vertical oscillator and the horizontal oscillator is that the vertical oscillator operates at a much lower frequency. It must have an output frequency approximating 60 cycles per second.

Another difference is in the way they are synchronized. In older receivers both sweep circuits were synchronized in the same way. In modern receivers they are usually synchronized differently.

Several types of oscillator circuits have been introduced to the television world from time to time to perform these functions. It is our intention in this lesson to explain those circuits, and point out the essential details of each so you can understand them.

Before going further it is well to point out that fully half of all the troubles which occur in a television receiver are traceable to defects in the deflections circuits, of which the oscillators are an important part. Of the two oscillators, it is the horizontal oscillator which gives, by far, the most trouble.

Because these deflection oscillators are the source of so much service trouble it is well that you learn as much about them as possible.

Section 2. KINDS OF OSCILLATORS USED IN TV SWEEP CIRCUITS

Several types of oscillators have been used at various times during the history of television. In the very early days a gaseous discharge tube was frequently used for this purpose. Such a circuit, employing a gaseous thyratron, was explained in our lesson on saw-tooth oscillators.

With passage of time the use of gaseous discharge tubes in the deflection oscillator circuits gradually disappeared. They are rarely, if ever, found in modern receivers.

Other types of saw-tooth oscillators were tried, and gradually disappeared from use.

At this time the industry has settled down to the use of two general types of saw-tooth generators. These are the multivibrator and the blocking oscillator. Even these two circuits have undergone considerable modification and improvement since they were first used in TV receivers. A circuit diagram of a multivibrator is shown in Fig. 1.

There is some variation in the deflection circuits from one brand or model to another in which the blocking oscillator is used as the deflection oscillator. Some receivers work the blocking oscillator into a discharge tube before the signal is passed on into the horizontal output amplifier tube. Others drive the output amplifier directly from the oscillator. This latter method is the one most widely used in modern receivers.

The manner in which the blocking oscillator is used in the horizontal circuit has undergone an almost complete cycle of changes. Originally the blocking oscillator worked directly into the output amplifier. Then, in order to secure somewhat better operating conditions, the discharge tube was introduced into the circuit following the oscillator.

When the discharge tube is used in the deflection system the blocking oscillator works into it, then the signal is fed into the output amplifier.

Still later, many manufacturers dropped the discharge tube from their horizontal circuits, and again worked the oscillator tube directly into the horizontal amplifier. The trend is such that most manufacturers have virtually discontinued use of the discharge tube, but many receivers are still in use which employ a discharge tube.

RCA has been the leader in using the blocking oscillator, and modifications of it. This type of saw-tooth oscillator will most frequently be found in RCA receivers, and in those built by manufacturers operating under RCA patent licenses.

The multivibrator is used more generally by those manufacturers who avoid operating under RCA patent licensing.

However, this is a very general rule, and must be applied quite loosely. A number of manufacturers use both a multivibrator and a blocking oscillator in their sweep circuits. One type of oscillator is used in the horizontal circuit while the other is used in the vertical circuits.

An interesting aspect of this variation is that some manufacturers use a blocking oscillator in the horizontal circuit and a multivibrator in the vertical circuit, while others use a multivibrator in the horizontal and a blocking oscillator in the vertical. This lack of uniformity may sound a little confusing at first, but it really isn't. Each type of circuit accomplishes the same function, yet the circuits are different enough so there is little chance of mistaking one for the other.

Section 3. THE MULTIVIBRATOR

The multivibrator is an old electronic circuit which has been used for many years for a variety of purposes. It is not a circuit developed primarily for television, yet it possesses characteristics which make it readily adaptable for television needs.

Basically, a multivibrator is nothing but a two-stage amplifier which has been so designed that part of the output of the second stage is fed back into the input of the first stage. That may sound a bit complicated, but a study of the details of the circuit shown in Fig. 1 should help to make the action clear.

Perhaps the action of the circuit can be understood a little better if the circuit is arranged as shown in Fig. 2. The one in Fig. 2 is exactly the same as the one in Fig. 1 except the output of the second tube is *not* fed back into the first tube. But the diagram in Fig. 2, together with the voltage waveforms, makes the action of the two tubes more easily understood.

To begin with, suppose a small positive signal reaches the control grid of the first tube, as shown in Fig. 2. That small positive voltage will be amplified by the action of the tube, and will appear in the anode circuit as an amplified signal.

However, the signal in the anode circuit of the

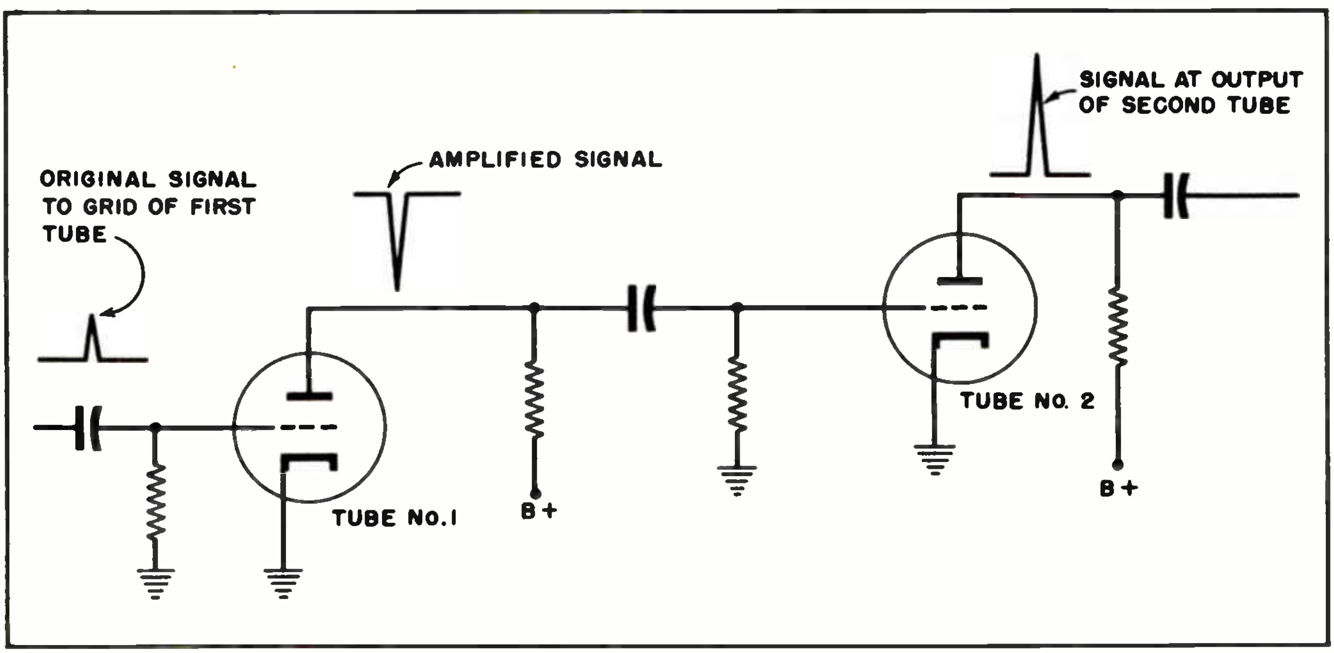

Figure 2. Single polarities in two-stage amplifier.

first tube is inverted. It has an opposite polarity to that it had when injected to the grid of the tube.

From the anode of the first tube the signal is fed to the grid of the second. The action of the second tube amplifies the signal still more, making it much stronger than it was at the *input* of either of the two tubes.

But the action of the second tube does something more. It again inverts the polarity of the signal voltage. It now has the same polarity as when first introduced to the grid of the first tube. That is, it has positive polarity.

Fig. 2 does not show what happens to the signal voltage after it has been developed in the anode circuit of the second tube. It can be passed along to a third tube — and very often it is. Or something else can be done with it.

In a multivibrator a *portion* of the signal which appears at the output of the second tube is fed back into the input of the first tube. This is shown in the diagram in Fig. 3.

Now let us take a long look at the action which takes place in the combined circuit.

Note, first, that the polarity of the signal being fed back from the second tube into the grid of the first tube is exactly the same as that of the original signal. In short, the two voltages now add together. Instead of the grid of the first tube having a *weak* positive voltage on it, it now has a *very strong* positive voltage on it.

The result of the presence of that strong positive voltage on the grid of the first tube is to cause an immediate rise in the anode current. In fact, the anode current rises to the point of saturation. As you will recall from your earlier lessons, when a tube reaches the point of saturation it is passing all the current it is capable of passing, and the presence of additional positive voltage on the control grid cannot cause the current to rise any higher.

So — that is exactly what happens in this case. The anode current in the first tube rises so high that additional positive grid voltage cannot cause it to rise any more.

Section 4. OSCILLATOR ACTION OF MULTIVIBRATOR

In diagrams Figs. 3 and 4 we are acting on the assumption the original voltage on the grid of the first tube is coming from some external source. That is not necessarily true.

Suppose we have a circuit like that in Fig. 4. A comparison will show you it is essentially the same as that in Fig. 1.

We know from our previous studies that in any vacuum tube circuit electrical changes are con-

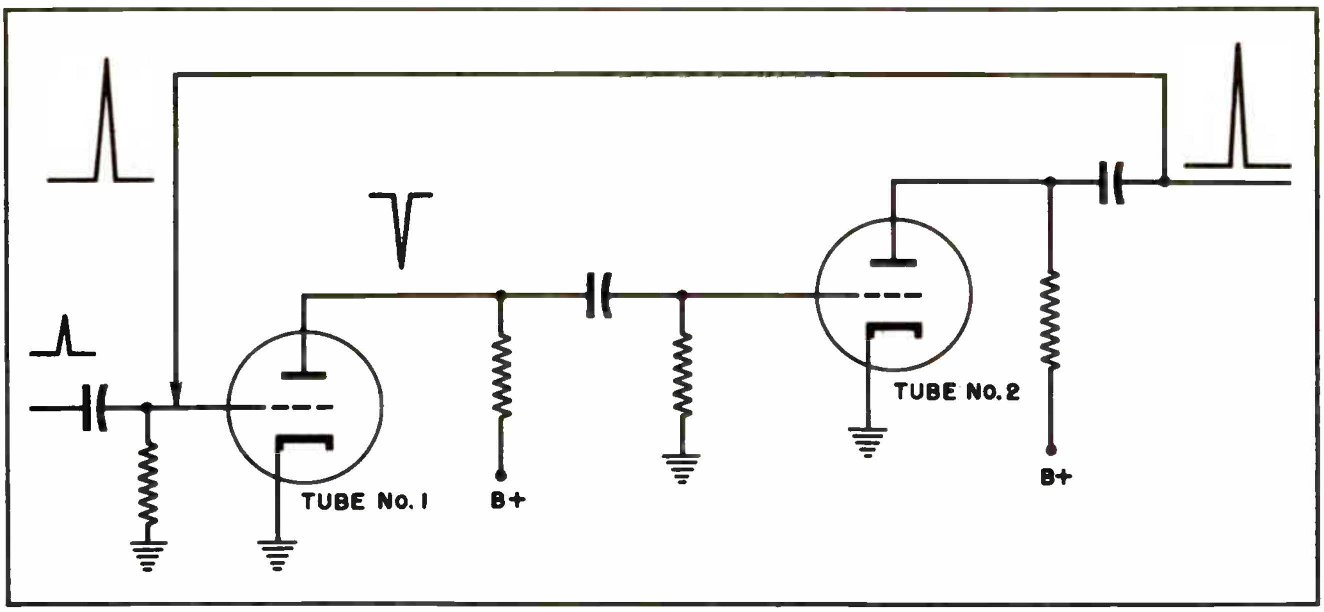

Figure 3. Polarity and magnitude of fed-back signal.

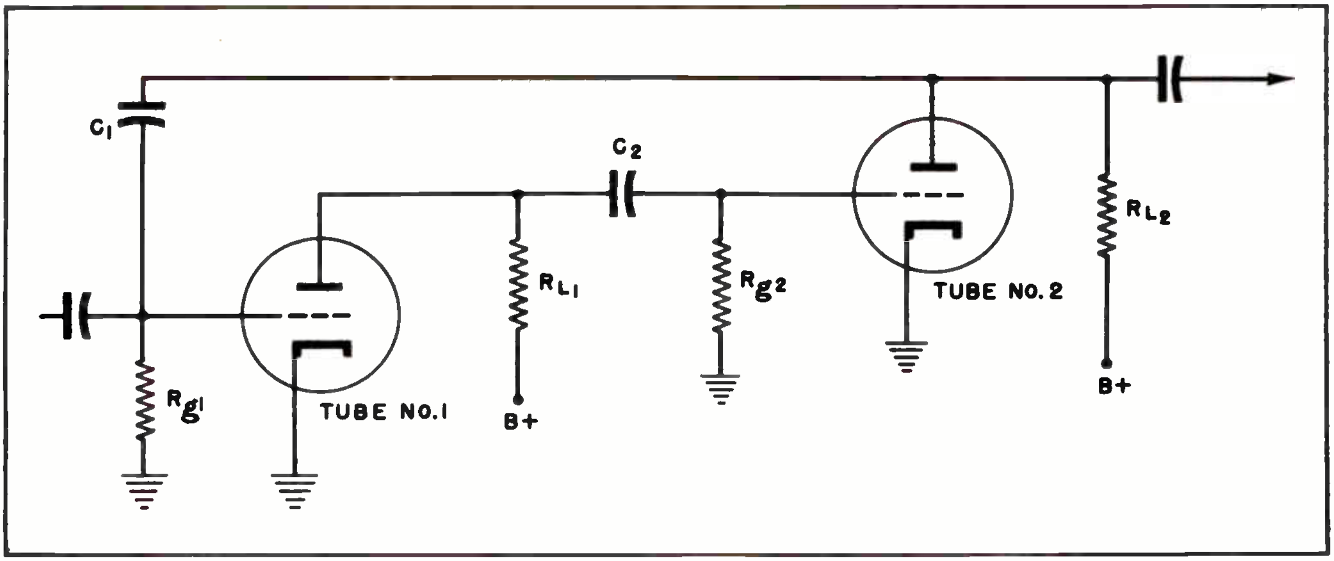

Figure 4. Multivibrator Circuit

stantly occurring. The anode current varies by small amounts. Voltage changes constantly occur at the grid.

Most of these voltage and current changes are so very small they are normally ignored. Nevertheless, they are the cause of much of the noise we hear in the background of our radios and other electrical audio circuits. The point is, such minor variations are always occurring, so when considering the action of an oscillator, we need not concern ourselves by worrying over the need for an initiating signal source.

So, in a circuit like that shown in Fig. 4, we have a set of conditions which are just waiting for a minor voltage variation to occur somewhere in the circuit. It makes no difference where the variation occurs, the variation will affect all parts of the circuit, and *affect them instantly.*

For purpose of explanation we are going to assume a voltage variation occurs which causes the control grid of the No. 1 tube to become slightly more positive. The change in the voltage on that grid may be extremely small. In most cases it is. It may be less than 1 microvolt.

However, the very instant that control grid becomes slightly more positive, no matter how very slight that additional positive voltage may happen to be, it affects the anode current of the tube. It causes the anode current to increase slightly.

The anode current may increase by only an extremely small amount, but the fact remains that it does change; it does increase.

The instant that current increases, no matter how slightly, the voltage drop across RL-1 changes. The change in the voltage drop across RL-1 is such that a negative voltage pulse is applied to C2.

When the small negative voltage pulse strikes coupling capacitor C2 it instantly makes the control grid of tube No. 2 more negative. Remember, this entire action is virtually instantaneous.

As the grid of tube No. 2 is made more negative it causes the anode current of tube No. 2 to decrease slightly. When that occurs there is a change in the voltage drop across RL-2 in the anode circuit of tube No. 2.

The change in that voltage is such that a *positive* voltage is applied to coupling capacitor C1. That positive voltage pulse is then fed back to the control grid of tube No. 1.

Now note this — — a minor voltage change on the control grid of tube No. 1 started all this. That voltage change made the control grid of tube No. 1 slightly more positive.

Now we have a new voltage being fed back to the grid of tube No. 1 from the output of tube No. 2. This fed-back voltage has the same polarity as that of the original minor voltage change. But the fed-back voltage is many times stronger than the original minor voltage change on that grid. It is far more effective in influencing the anode current of the first tube.

Furthermore, the entire action is almost instantaneous. The original voltage on the grid of the first tube scarcely begins to change before it is reinforced by the fed-back voltage from the output of the second tube.

This increased positive voltage causes the anode current of the first tube to increase still further. That increased anode current, in turn, places an increasingly higher negative voltage on the control grid of the second tube, thus reducing still further the current through the second tube.

All of which causes the control grid of the first tube to go still further positive.

This action continues until the grid of the first tube is driven so far positive the anode current reaches saturation, and the control grid of the *second* tube is cut off completely.

This entire action is very fast. The minor positive voltage pulse scarcely strikes the control grid of the first tube until the fed-back positive voltage forces the tube to saturation. When the action is observed on the screen of an oscilloscope it can be seen that the rise of the voltage on the grid of the first tube is sharp and steep and sudden. Some idea of the suddenness of the sharp rise in the positive voltage on the control grid of the first tube is indicated by the graph in Fig. 5.

Section 5. SHAPING THE VOLTAGE WAVEFORMS

The graph in Fig. 5 shows the sudden changes which occur in the voltage on the grid of the No. 1 tube as various actions take place in the multivibrator circuit. The first action occurs when the grid voltage suddenly goes positive. The voltage on the grid attains its maximum positive value when the first tube reaches saturation and the second tube reaches cut-off.

The next thing to consider is how long the grid retains its positive charge, and how long tube No. 1 continues to keep its anode current flowing at a maximum rate. This depends on several things.

Primarily, it depends on how long the second tube remains at cut-off so no anode current flows from it. That, in turn, depends on the time/constant of the resistance-capacity network in the grid circuit of the second tube. That network consists of C2 and Rg2 shown in Figs. 1 and 4.

To explain this a little further — when tube No. 1 conducts to saturation it places a highly negative voltage on C2. This negative voltage is also placed on the control grid of tube No. 2. That negative voltage remains until it can leak off through Rg2, and thus permit the grid of tube No. 2 to become more positive, and thus approach the condition necessary for conduction.

So long as tube No. 2 remains at cut-off, and no anode current flows from that tube, the voltage on the grid of the first tube remains station-

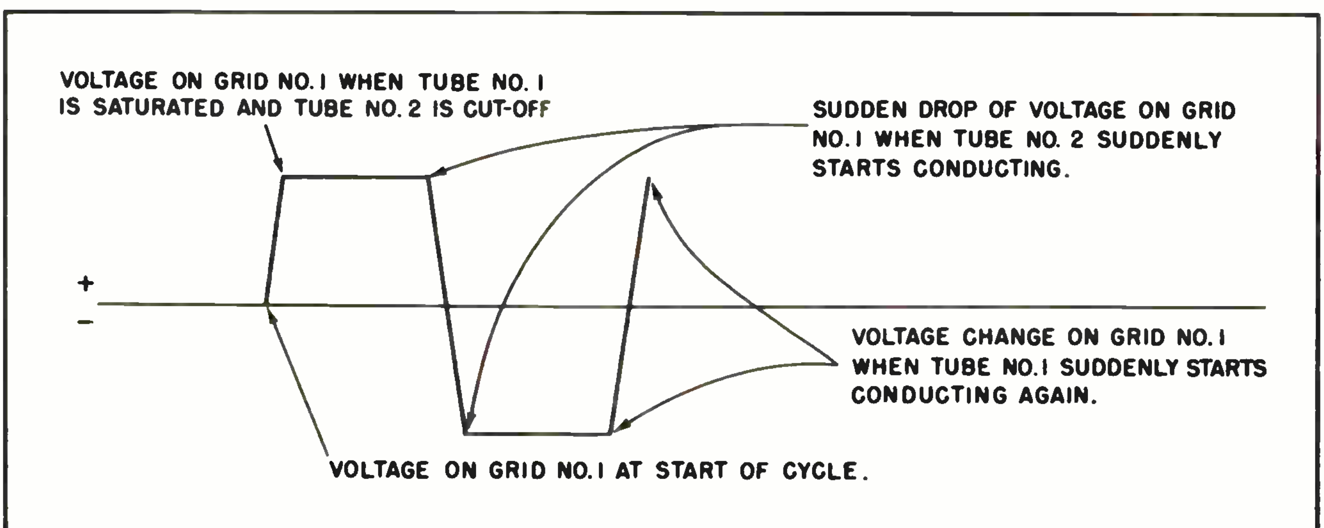

Figure 5. Changes in voltage on grid of Tube No. 1 during one complete cycle.

ary. That is represented by the level horizontal line at the peak of the graph in Fig. 5.

But after the passage of a certain period of time the high negative voltage on the grid of the *second* tube leaks off, and that tube approaches the condition needed for conduction. When the negative voltage on the grid of the second tube leaks off to the cut-off point that tube begins conducting. When that occurs other things happen very suddenly.

The instant tube No. 2 begins conducting a negative voltage pulse feeds back through C1 from the anode of tube No. 2 to the control grid of tube No. 1. That action tends to reduce the current through tube No. 1.

As current through tube No. 1 decreases it feeds a positive voltage pulse back through capacitor C2 into the grid of tube No. 2. This has the effect of making the grid of tube No. 2 more positive.

Thus we have a condition in which voltages are being fed from the output of each tube to the grid of the other. One is going negative, the other positive. Both actions occur simultaneously.

Now we have a condition in which the grid of tube No. 1 is becoming more negative while that of tube No. 2 is becoming more positive. Remember, both these actions set up reactions which feed back additional voltages from the anodes of each tube to the grid of the other to accelerate the action.

The net result of all this is that the grid of tube No. 2 is suddenly made so positive the tube is driven to saturation, and the grid of No. 1 is driven so negative the tube is cut-off. This is indicated on the graph in Fig. 5 by the sudden drop in voltage from the peak level, through the zero level, to maximum negative voltage. The action is further indicated by the explanatory notes.

Now we have a condition in which the first tube is at cut-off while tube No. 2 is conducting at full saturation. The voltage on the grid of the first tube continues to be highly negative until the condition reverses. This is indicated on the graph in Fig. 5 by the horizontal level line at the bottom.

The voltage graph shown in Fig. 5 is one that would be drawn on the screen of an oscilloscope when the capacitor C1 has a high capacity, and the resistance of Rg1 is quite high. In this case most of the timing action would be controlled by the capacitor and resistor in the grid circuit of the second tube.

The shape of the voltage graph will change if, and when, the values of the resistance and capacity in the two grid circuits are changed.

The values of the two capacitors can be made the same, and the two resistors can have the same resistance. In that case the shape of the voltage waveform at both tubes will be much the same. Furthermore, the waveform will closely approximate a square-wave voltage, such as shown in Fig. 5.

The shape of the voltage wave at the output of the second tube can be caused to assume any of a variety of forms by using different values of resistance and capacity in the grid circuits of the two tubes. The time/constant of the R/C circuit in the grid of one tube may be quite different from that in the grid of the other. This is the general practice when the multivibrator is used to generate saw-tooth waveform voltages.

For example, the time/constant of one grid circuit may be made quite short while that of the other is quite long. An example of the time of voltage waveform which can be generated when one of the time/constants is made slightly longer than the other is shown in Fig. 6. Note that the duration of the positive voltage on the control grid of tube No. 1 is much shorter than the duration of the negative voltage on it.

By making other changes it is possible to make one of the voltage changes occur quite rapidly, just as we have been indicating, but cause the

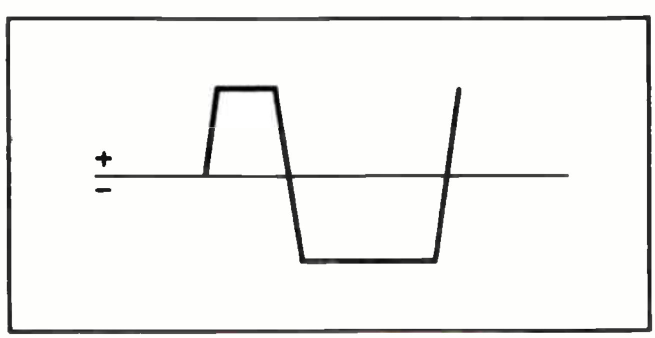

Figure 6. Shape of waveform can be changed by using different time/constants.

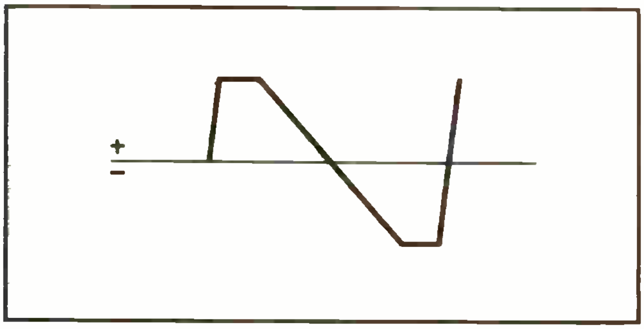

Figure 7. Using different values of resistance and capacity in time/constant circuits create different waveforms.

change in the other voltage to occur over a much longer period of time. That is indicated in Fig. 7.

In Fig. 7 it can be seen that the period during which the voltage on the grid of tube No. 1 is sufficiently positive to cause a condition of saturation is much shorter than in Figs. 5 or 6. Furthermore, the transition from peak positive voltage to peak negative voltage requires considerably more time.

In short, the change from peak positive voltage to peak negative voltage is a long slanting curve, rather than being sharp and abrupt as in Figs. 5 and 6.

This control over the shape of the voltage waveform can be carried to much greater lengths. The period during which the voltage remains at peak positive or peak negative can be shortened so it is almost zero. This means the tube is barely driven to peak saturation before it starts acquiring a negative voltage to drive it in the other direction.

The same is true at the other end of the cycle.

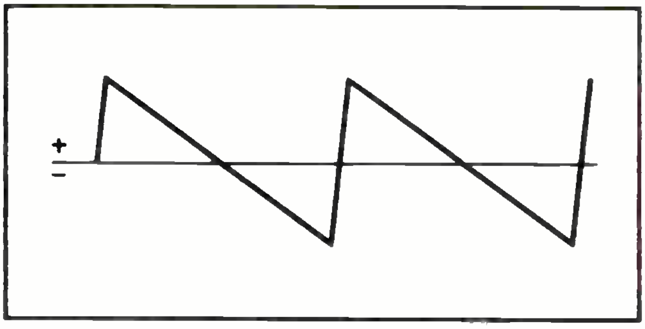

Figure 8. By controlling values of resistance and capacity the multivibrator generates a saw-tooth waveform.

The grid is no sooner driven to its extreme negative voltage condition before it again starts becoming more positive. This action is shown in Fig. 8.

It is well worth noting that in Fig. 8 the waveform of the voltage assumes a true saw-tooth waveform. True, the shape of the saw-tooth voltage is reversed from that needed to apply it to a sweep amplifier, but that is a minor detail. All that is needed is to reverse the components in the two grid circuits. That is a simple matter. Either that, or pass the signal through another amplifier to reverse the waveform.

Section 6. CATHODE-COUPLED MULTIVIBRATOR

The multivibrator described in the preceding sections is the old reliable oscillator circuit which has been used by electronic men for years. It has been used for a wide variety of purposes.

In addition to the ability of a multivibrator circuit to generate a wide variety of waveform voltage signals — signals which have been used for many different purposes in industrial electronics, radar work and counting circuits, as well as for television — an important feature of the circuit is the fact the circuit can be readily synchronized with the action of another circuit. All that is necessary is to feed a voltage pulse from some external source to initiate a voltage change in one direction or the other.

It is this feature which makes the multivibrator so attractive to television designers. It is imperative that the sweep circuits in a television receiver be capable of synchronization.

The multivibrator circuit we have described has been used in many television receivers. In the early days of receiver construction it was used almost universally.

However, a modification of the basic multivibrator circuit is used even more widely. It is called a *cathode-coupled multivibrator* to distinguish it from the original basic circuit. The arrangement of the circuit is shown in the diagram in Fig. 9.

The action of the circuit in Fig. 9 is even more conducive to the generation of saw-tooth waveforms than the true multivibrator. Furthermore, the circuit is simpler, and requires even fewer components.

The action of this circuit is very interesting. During the initial portion of a cycle its action is quite similar to that of any other multivibrator. A small positive voltage on the grid of tube No. 1, for example, causes that tube to begin conduction. That causes an increase in the anode current from that tube.

When the anode current through tube No. 1 increases it automatically makes the anode circuit somewhat less positive. .This is due to the additional voltage drop across anode load resistor R_L1. This has the effect of making coupling capacitor C1 slightly more negative, and that small negative voltage pulse is placed directly on the control grid of tube No. 2. This action is no way different from that which occurs in any other multivibrator.

However, there is a dropping resistor which is common to both cathodes. When the current begins flowing through tube No. 1 it also increases through the common cathode resistor. This makes both cathodes somewhat more positive than before, and has the effect of placing an additional negative voltage on the control grids of both tubes.

The negative voltage developed across the cathode resistor has less immediate effect on the grid of tube No. 1 than on tube No. 2. This is because there is already a slight positive voltage on the control grid of tube No. 1, and the further fact that the voltage coupled through the C1 capacitor acts to make tube No. 2 less conductive than tube No. 1.

All these actions and forces are cumulative. The grid of tube No. 1 becomes progressively more positive until the tube is driven to saturation. The grid of tube No. 2 is driven progressively more negative until the current through it is cut off.

The control grid of tube No. 2 continues to be negative until the voltage can leak off capacitor C1 through resistor Rg2. When the charge on C1 has leaked off sufficiently so the second tube can begin conduction some anode current begins to flow.

When curent begins flowing through tube No.

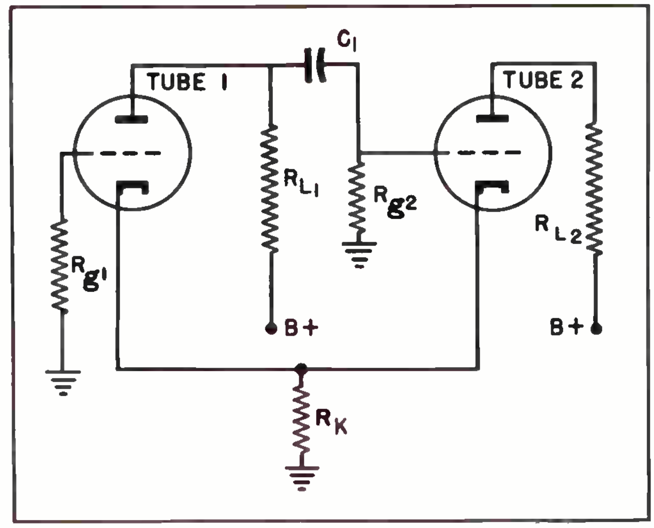

Figure 9. Cathode-Coupled Multivibrator.

2 it must also flow through the common cathode resistor Rk. This creates additional voltage drop across that resistor which is instantly reflected back onto the grid of the first tube. The result is that tube No. 2 begins conducting and tube No. 1 ceases conducting.

The values of resistance and capacity in the circuit can be selected so that the output voltage generated at the anode of the second tube assumes a saw-tooth waveform.

Section 7. HORIZONTAL OSCILLATOR USING CATHODE-COUPLED MULTIVIBRATOR

It would be well to examine a practical circuit of this type actually being used in a television receiver. In Fig. 10 we have one that is used to generate the horizontal sweep voltages in a Montgomery Ward TV receiver sold under the Air King brand as model 17C2.

The phase-detector circuits and other sources of the synchronizing pulses are not shown in Fig. 10. But the automatic frequency control circuit is shown. It is somewhat different from any we have previously mentioned, but it will be described in detail a little later. Basically, the AFC circuit is merely a tuned circuit in the anode circuit of the first half of the multivibrator. The tuned circuit is tuned to a frequency of 15,750 cycles per second.

Located, as it is, in the anode circuit of the first multivibrator tube it causes the positive voltage

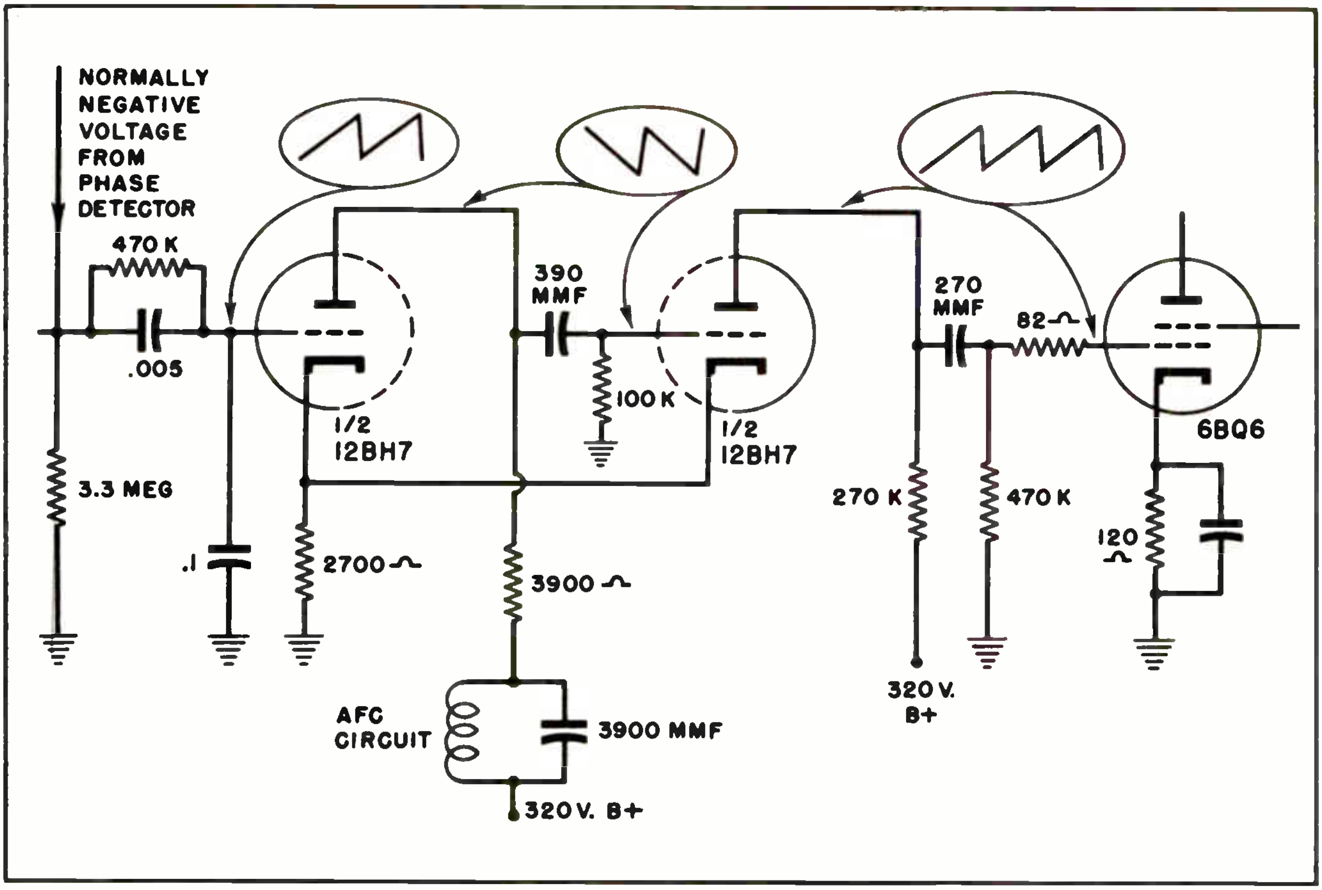

Figure 10. Cathode-Coupled Horizontal Multivibrator.

on the first tube to become alternately positive and then zero. Since the frequency of the tuned circuit coincides with the frequency of the synchronizing pulses it acts to make the anode positive, and thus conductive, at the same time the synchronizing pulse comes along. But it keeps the anode voltage low at other times. This prevents random electrical noise pulses having any effect on the multivibrator.

The control grid of the first tube is normally maintained at a negative voltage. This is a negative voltage with reference to ground, or B−, and not necessarily negative with respect to the cathode. As it so happens, this also means the control grid is maintained negative with respect to both B− and the cathode.

This negative bias voltage is developed in the phase detector circuit, and is completely independent of the negative voltage which may be developed across the cathode resistor in the cathode circuit. It is developed in the phase detector circuit as a result of the sync pulses from the composite video signal, and other pulses fed back from the horizontal output transformer.

The resistance/capacitance circuit in the grid circuit of the first tube has a relatively long time/constant. The R/C circuit permits the negative voltage to slowly leak off the control grid of the first tube, thus permitting the control grid to become progressively more positive.

As the control grid becomes progressively more positive it permits progressively more current to flow in the anode circuit of the tube.

The increasing current in the anode circuit of the first tube sends an increasingly negative voltage pulse through the 390 mmfd. coupling capacitor to the control grid of the second tube. This has the effect of progressively reducing the current in the anode of the second tube.

When the first tube anode current finally climbs to saturation it can go no higher. At that instant there is no additional voltage change being passed through the 390 mmfd. coupling capacitor. The anode current in the first tube no longer increases; that in the second tube no longer decreases.

Suddenly, the anode current for the first tube starts decreasing. The current in the second starts increasing. As the current in the second tube begins increasing it makes the cathode of the first tube extremely positive, thus placing a heavy negative voltage on the control grid of the first tube. The whole action has the effect of driving the first tube suddenly to cut-off, and the second tube suddenly to saturation.

Due to the differing time constants in the two circuits the rise and fall of anode currents in the two tubes is not at the same rate. The current increases slowly in the anode circuit of the first tube, but falls rapidly to zero. It increases rapidly in the anode circuit of the second tube, but decreases slowly.

The rise and fall of current in the anode circuit of the second tube is such as to produce a varying saw-tooth waveform voltage drop across the 270K load resistor in the anode circuit of that tube. The saw-tooth voltage developed across that resistor is applied through the 270 mmfd. coupling capacitor to the control grid of the 6BQ6 output amplifier tube.

The output of the 6BQ6 is fed directly into the horizontal output transformer, where it is converted into current of the correct amplitude to drive the deflection coils in the deflection yoke positioned around the neck of the picture tube.

There are some slight deviations from the exact waveform voltages we have shown in Fig. 10. These result from the necessity for using a modified saw-tooth waveform current in the deflection yoke to overcome the inductive effects of the coil on the deflection current.

Section 8. COMPONENT VALUES IN MULTIVIBRATOR FOR HORIZONTAL OSCILLATOR

The values of the components used in the R/C circuits in the grid circuits of a multivibrator are rather critical. The values have a closely determining effect on the frequency and the waveform of the generated voltages.

This does not mean the capacitors used in a multivibrator in the horizontal oscillator of one receiver are always *exactly* the same as those used in similar circuits in another receiver. But they are *similar.*

Fig. 11 shows the schematic diagram of a multivibrator used in the horizontal circuits of a Truetone TV receiver. This particular circuit is used in model 2D1194A, but it is closely similar to circuits used in other models built by the same company. It is also similar to circuits used by other companies.

A study of the circuit shows the values of resistance and capacitance are on the same general order. Where there are discrepancies in the value of a given capacitor, the slight difference is usually balanced by a change in the value of the corresponding resistor. The final result is much the same in all receivers.

When trouble of any kind develops in one of these circuits, and the defect requires that a resistor or capacitor be replaced, the replacement must have a closely similar value. Otherwise, there is danger the frequency of the circuit will be disturbed, and perhaps the circuit will not synchronize properly.

Section 9. MULTIVIBRATOR IN VERTICAL CIRCUITS

The multivibrator circuits we have been describing are essentially modifications of relaxation oscillators. Most types of multivibrators are classed as forms of relaxation oscillators.

Multivibrators are by no means confined to the horizontal circuits of TV receivers. They are probably used in just as many vertical circuits, although those used in vertical circuits are not necessarily identical with the types used in horizontal circuits.

A multivibrator used in the vertical deflection system of a Zenith TV receiver is shown in Fig. 12. It is the vertical circuit used in their model H2229R, but the same or similar circuits are used in other Zenith receivers.

A single tube is used as the oscillator and vertical output amplifier. It is a 6BL7 twin-triode, which is designed to operate as a power amplifier.

One section of the tube is usually designated as

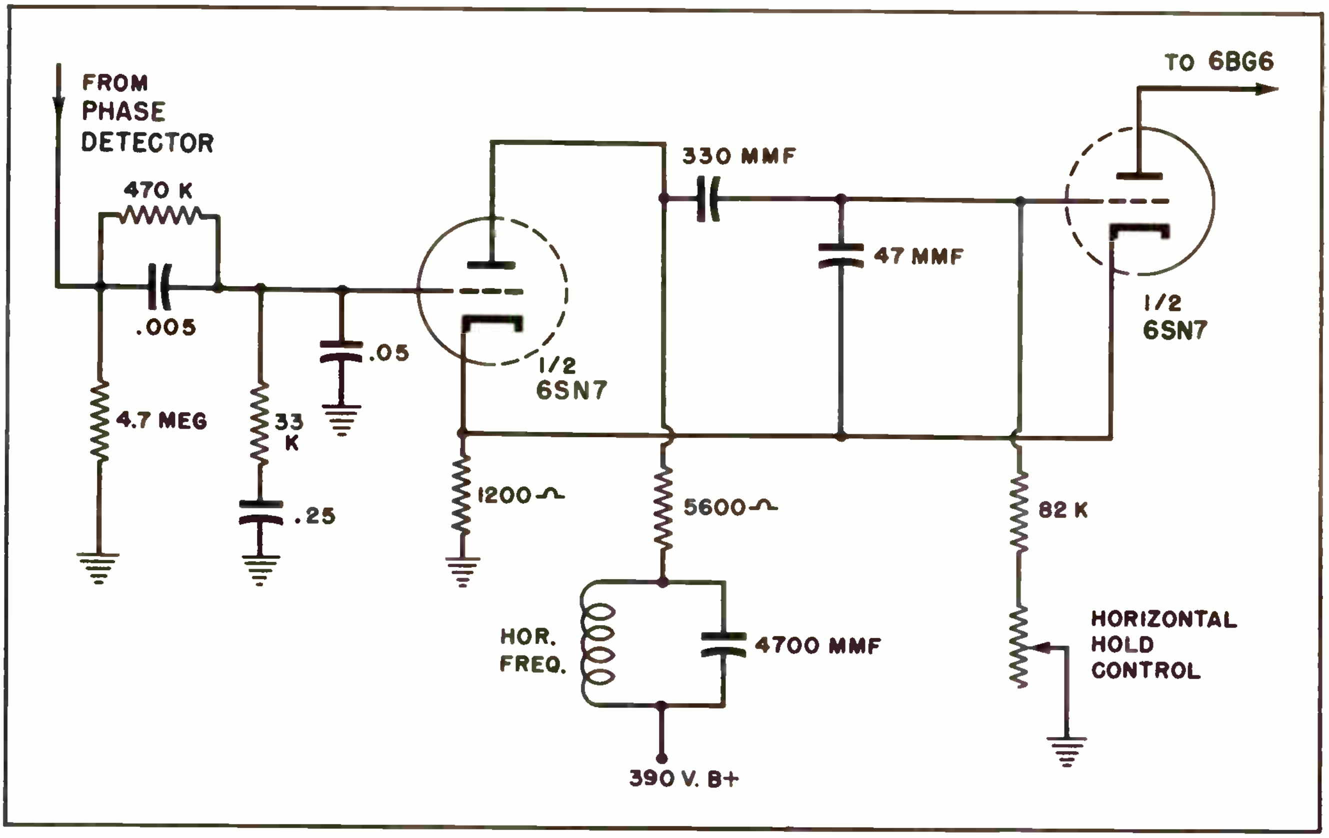

Figure 11. Modified Horizontal Multivibrator.

the vertical *oscillator* and the other as the vertical *amplifier*. This is the manner in which we have marked the two sections of the tube in Fig. 12.

Actually, however, both sections of the tube are part of the multivibrator oscillation action, with the second section serving as the power amplifier.

A study of the circuit discloses that a signal from the so-called oscillator section of the tube is fed into the control grid of the second section. In turn, a signal from the anode circuit of the second section is fed back into the grid circuit of the first section. This is virtually the same action described in connection with Figs. 1 and 4.

One distinguishing feature of this circuit is the manner in which the synchronizing pulses are fed to the first section of the tube. Instead of those pulses being fed into the grid circuit of the multivibrator, they are fed into the cathode circuit.

There is an R/C network in the grid circuit of the tube, the network being connected between the grid and ground, or B—. That is a part of the timing circuit of the multivibrator. It consists of a 330K resistor in parallel with a .0012 mfd. capacitor.

Another R/C circuit is in the grid circuit of the second section of the tube, the one marked *vertical amplifier*. It consists of a 3.3 megohm resistor and .1 mfd. capacitor. This second timing circuit has a much longer time/constant than the first one.

The action of the two R/C circuits generates the saw-tooth waveform needed for the vertical sweep.

The multivibrator in Fig. 12 will operate as a free-running oscillator whether any synchronizing pulses are coming in or not. The frequency will be slightly lower than 60 cycles per second.

The synchronizing pulses strike the cathode of the first section of the tube. Their polarity is such that they place a sudden negative voltage on that cathode, thus momentarily overcoming the normal positive voltage which is usually present there.

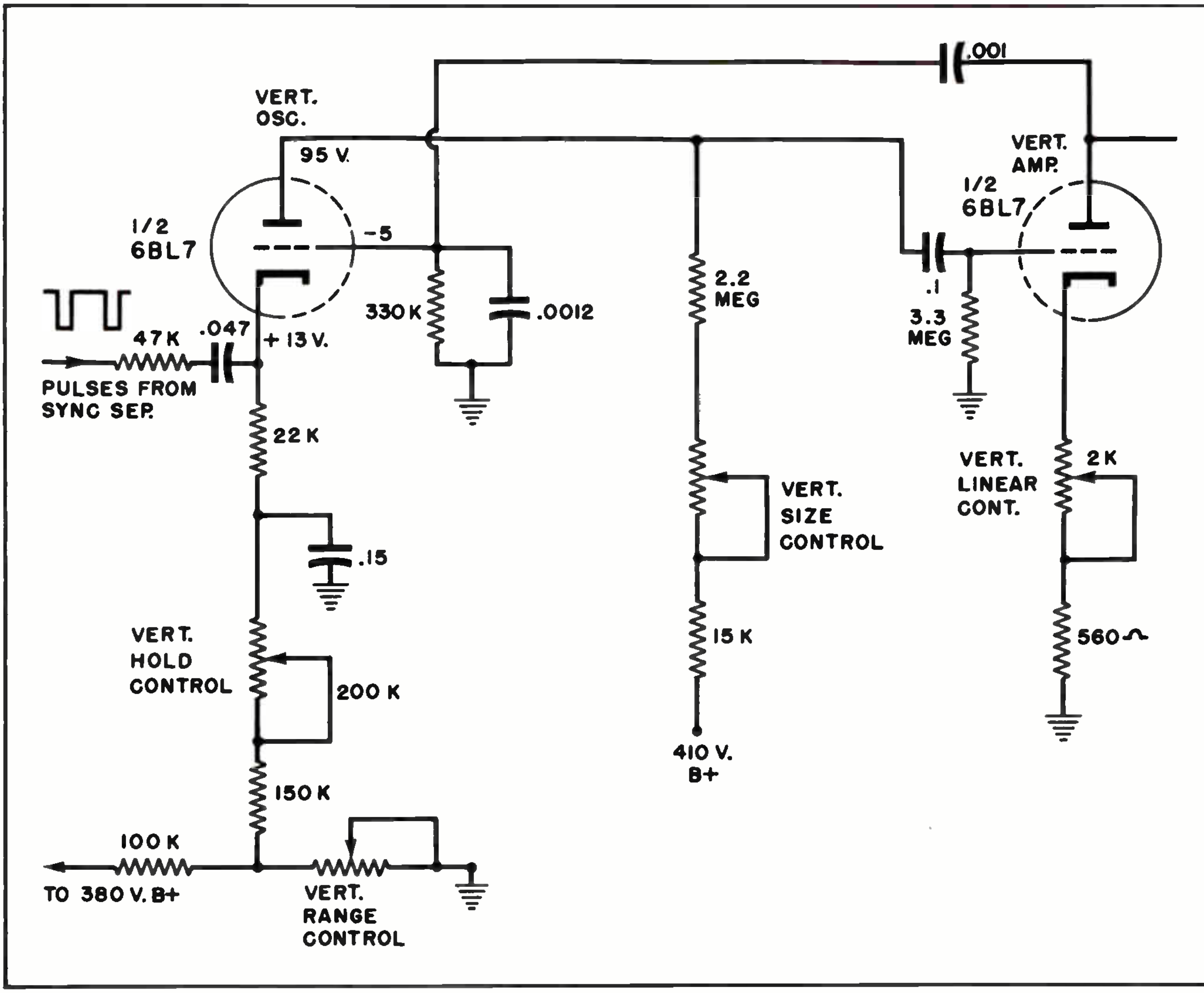

Figure 12. Relaxation oscillator in vertical circuit.

The negative sync pulse makes the cathode negative, and thus in condition to conduct. In fact, the pulse actually makes the cathode more negative than the grid, so some electrons are attracted to the grid. At the same instant a strong positive voltage pulse is fed back from the anode circuit of the second section of the tube. This places an even heavier positive voltage on the grid of the first section.

The grid attracts electrons, and thus charges the .0012 mfd. capacitor in the grid circuit. When the positive pulse from the output section of the tube has vanished, and the cathode has again assumed its normal positive voltage, the first section of the tube is no longer conducting.

But during the short time interval during which it was conducting it was able to charge the .1 mfd. capacitor in the grid circuit of the second half of the tube. That charge leaks off slowly, permitting the current in the second tube anode circuit to rise slowly.

By these interconnected actions between the two tubes the combined circuit generates the saw-tooth waveform needed to sweep the electron beam up and down in a vertical direction. It moves the beam downward slowly as the current through the output tube increases; it moves upward when the current is suddenly cut off.

Section 10. REVERSED MULTIVIBRATOR FOR VERTICAL CIRCUIT

In the circuits described previously the synchronizing pulses are fed into the first tube, while the output of the circuit is taken from the second tube to perform its useful functions. This is the more conventional method, but under certain conditions the circuit is modified to operate in a somewhat different manner.

The circuit in Fig. 13 is one used in a number of relatively inexpensive receivers. The circuit is reliable, and it is rather strange it is not used more widely than it is.

The synchronizing pulses are fed into the grid circuit of the second tube, and the output of the second tube is fed directly into the primary winding of the vertical output transformer. The so-called "first tube" does little more than provide the retrace voltage necessary to momentarily drive the second tube to cut-off.

The second tube is a beam power tube. In the diagram shown in Fig. 13 it is shown to be a 25L6. This particular tube is the one most often used. This is because the 25L6 adapts itself to operation in AC-DC television circuits, and this particular multivibrator seems to be used most frequently in AC-DC receivers.

This does not mean that some other type of tube cannot be used instead of the 25L6. Most any other tube having similar characteristics can be used instead. Nor do we mean to imply that this circuit is usable only in AC-DC receivers. That would be wrong. It can be used in almost any kind of receiver; but the fact remains that it is found most often in AC-DC receivers.

The so-called "first tube" is shown to be a 6SR7 in the circuit in Fig. 13. The 6SR7 is often used in this circuit, but a 6SQ7, or any of several types of triodes, can be so used. The 6SR7 has a pair of small diode anodes which can be used for other purposes in a TV circuit, and for that reason is chosen more frequently than single purpose triode tubes.

In action, when the 6SR7 conducts it charges the .25 mfd. capacitor in its anode circuit with a

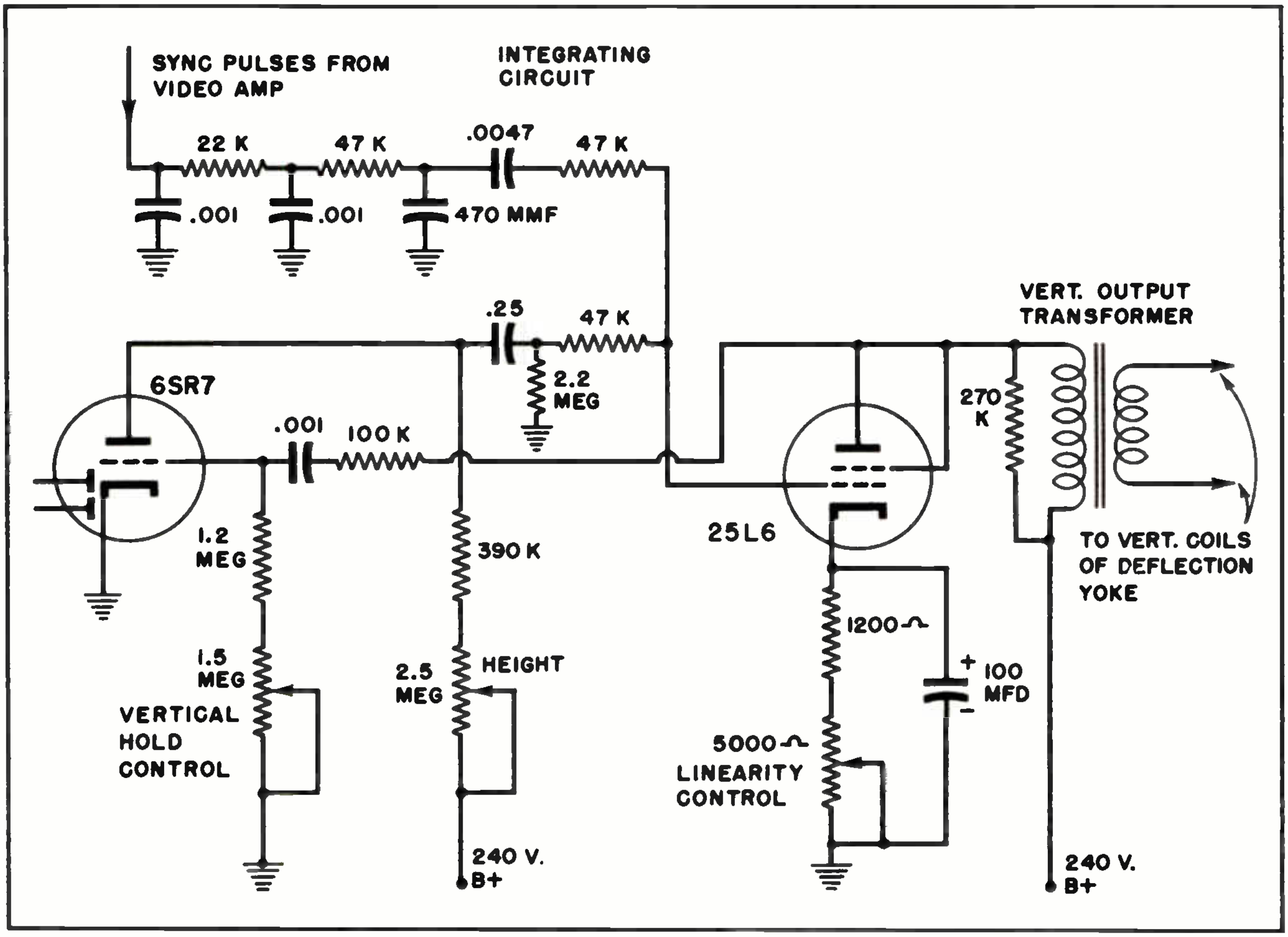

Figure 13. Reversed multivibrator for vertical circuit.

negative voltage. That .25 mfd. capacitor couples the anode of the 6SR7 to the control grid of the 25L6.

When the .25 mfd. capacitor is charged negatively it places a heavy negative voltage on the control grid of the 25L6, causing that tube to be cut-off. That represents the retrace period of the vertical cycle.

Almost as quickly as the 25L6 is cut-off the .25 mfd. capacitor begins discharging. It begins discharging through the 390K resistor and 2.5 megohm rheostat in the anode of the 6SR7. As the negative voltage on the .25 mfd. capacitor is slowly dissipated the control grid of the 25L6 gradually becomes less negative. The result is that the anode current from the 25L6 will gradually rise to start a new trace sweep current flowing into the primary of the vertical output transformer.

As the current continues to rise in the anode circuit of the 25L6 it causes a negative voltage to be fed-back through the 100K resistor and .001 mfd. capacitor to the control grid of the 6SR7. This fed-back voltage maintains the 6SR7 at cut-off during this period.

As the anode current from the 25L6 reaches its peak, it ceases to rise, thus ending the progressively rising negative voltage being fed-back through the R/C circuit to the grid of the 6SR7. As the anode current in the 25L6 ceases to rise, the 6SR7 begins to conduct. When that happens a negative voltage is fed-back through the .25 mfd. capacitor to the grid of the 25L6. That causes the current through the 25L6 to drop.

All this action occurs very rapidly at this instant. The grid of the 25L6 becomes increasingly negative, the grid of the 6SR7 more positive. The result is that the anode current of the 6SR7 rises sharply and suddenly, and the current in the 25L6 is cut off.

This is the retrace period.

As soon as the current through the 6SR7 rises to its peak, which is quite rapidly, the cycle again starts. The grid voltage on the 25L6 again permits the current through that tube to begin its relatively slow rise, and a new cycle is under way.

This action occurs over and over—cycle after cycle.

The circuit is synchronized by feeding the synchronizing pulses to the control grid of the 25L6. The voltage polarity of the synchronizing pulses must be negative.

Application of a sudden negative pulse to the control grid of the 25L6 is sufficient to halt the rising anode current of the 25L6, even though it has not yet reached its peak. Halting the rise in the anode current, even momentarily, sends a positive pulse feeding back into the control grid of the 6SR7, starting the sudden rise in the anode current of that tube—and thus initiating the retrace action of the circuit.

This circuit is sometimes called a *reversed multivibrator*, but this is merely a name which serves to distinguish it from other circuits which are more conventional. The basic action of the circuit is not much different from that of other multivibrator circuits. It distinguishes itself only by the fact the sync pulses are fed into, and the output tapped off, the same tube. But there is nothing new nor different in the action of the circuit itself.

Section 11. SINGLE-CYCLE MULTIVIBRATOR

Before we leave the subject of multivibrators it is well that we touch on another variation of this interesting and useful circuit. It is a variation which is called by the technical name of *single-cycle multivibrator*, but it is better known to radio and electronics men as the *flip-flop circuit*.

The flip-flop circuit is not used very much in television receiver circuits but is used in pulse generators, and for other purposes around TV transmitters. It is widely used in radar work. It is also used in counting circuits, and other circuits in industrial electronic devices.

There is only one difference between the flip-flop circuit in Fig. 14 and the cathode-coupled multivibrator in Fig. 9. That difference is in the manner in which the control grid of the second tube is connected. Otherwise the two circuits are identical.

In the cathode-coupled multivibrator, described in Fig. 9, the control grids of both tubes are returned to ground. This returns them both to the same potential.

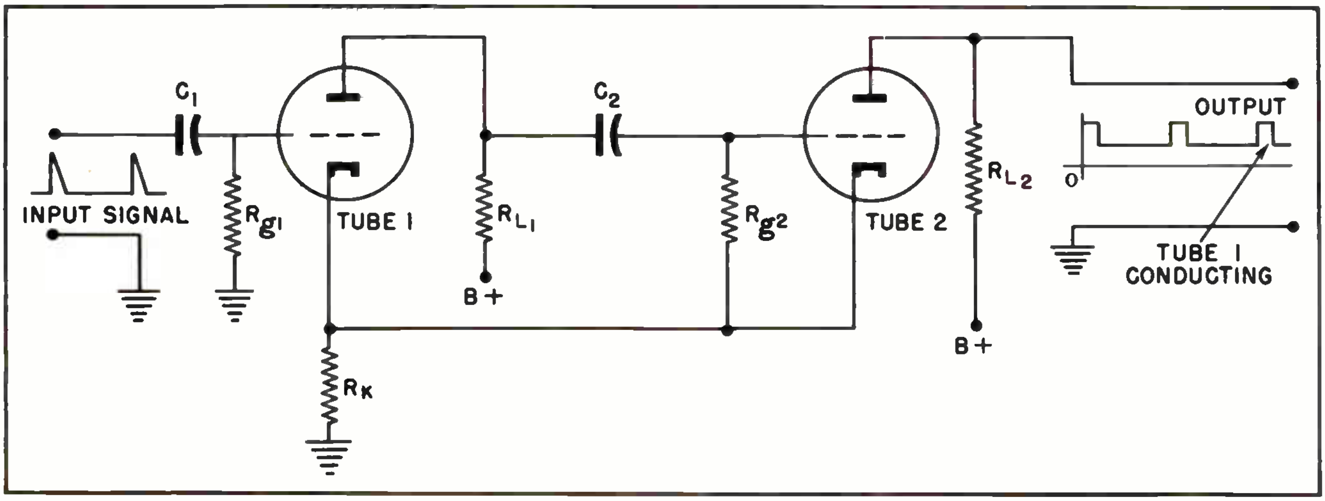

Figure 14. "Flip-Flop" Circuit. Technically known as single-cycle multivibrator.

In the case of the flip-flop circuit the control grid of the second tube is connected directly to its own cathode, and not to the ground potential. The grid of the first tube remains connected to ground.

In action, an input signal of some kind is placed on the control grid of the first tube. This may be a sine-wave voltage, a saw-tooth voltage, or any other that is needed to accomplish some specific purpose. In certain types of industrial electronic circuits it is a signal from a phototube.

Each positive pulse on the control grid of the first tube causes that tube to conduct. When it conducts, the first tube sends a negative voltage pulse to the control grid of the second tube, just as is always true in any kind of multivibrator. That negative pulse on the control grid of the second tube is sufficient to cut-off the second tube.

At the end of the first half of the cycle the first tube reaches its peak anode current, the second tube is cut off. All this is just the same as happens in any other multivibrator.

After an interval, determined by the R/C time constants of the circuit, the anode current of the first tube drops, and the second tube begins conducting. Shortly thereafter, the first tube ceases to conduct while the second tube goes to peak conduction.

The second tube does not remain at peak conduction, or at saturation. The current quickly drops to normal conduction—then continues to conduct.

The second tube does not drop to cut-off, as is customary in other types of multivibrators. So long as current flows through the second tube it also flows through the cathode resistor common to both tubes. This continues to maintain a negative voltage on the control grid of the first tube, preventing it from conducting until another pulse voltage of some kind comes along from the external circuit.

The difference between this circuit and the others we have described is that this one goes through one cycle, then stops. It cannot begin another cycle until some kind of initiating voltage is placed on the control grid of the first tube to overcome the negative voltage placed there by the action of the common cathode resistor.

The circuit is often used for the generation of pulse voltages. By selecting the proper values of resistance and capacitance for the various parts of the circuit almost any type of pulse can be created. The circuit can also be used to convert ordinary sine-wave voltages into pulse voltages.

The circuit is also used in counting circuits. It will be found in many kinds of electronic circuits used in industrial electronics work.

Section 12. VACUUM TUBE DISCHARGE CIRCUIT

A circuit that was used quite widely in early model TV receivers for the generation of saw-tooth waveforms is the relaxation oscillator known as a discharge tube. Gaseous type tubes have virtually disappeared from the television field insofar as their use as saw-tooth oscillators are concerned; but the vacuum type discharge tube continues to be used in some receivers.

The essential elements of a discharge tube saw-tooth oscillator circuit is that a capacitor shall charge up through a resistor, then discharge by action of tube conduction.

The circuit in Fig. 15 gives a good idea of how a vacuum tube can be used for this purpose. The capacitor in the anode circuit of the tube charges through the resistor so it acquires an electrical charge having the polarity shown by the polarity marks. This action occurs during a time when the tube is not conducting.

To bring about the charging action of the tube it is necessary to bias the vacuum tube so the negative voltage on the grid is beyond cut-off, thus preventing the tube from conducting.

The charge on the capacitor will rise in a linear manner so long as the total charge on the capacitor is never permitted to approach close to full charge. This can be controlled by carefully selecting the values of the capacitor and resistor, especially in view of the B+ voltage with which the circuit is connected.

Periodically, a pulse voltage is fed to the control grid of the tube. This pulse voltage is positive, and permits the tube to conduct. The anode current rises quite rapidly under the influence of the strong positive voltage pulse, and acts to discharge the capacitor quite rapidly.

After the passage of the short voltage pulse the tube ceases conduction. The capacitor can then charge again through the resistor, and another cycle is begun.

This circuit is not a true oscillator. It requires a signal source other than that of its own making. Because of that the circuit is nearly always used with some form of pulse oscillator. In television work, especially in television receiver circuits, the vacuum discharge tube is most often used with a blocking oscillator. In the earlier days of television the discharge tube operated on the sync pulses; but that was not satisfactory. The tube would not oscillate when no signal was coming in.

The blocking oscillator and discharge tube were widely used during one period in the early days of television. They were used in one of RCA's most widely copied receiver circuits, and thus could be found in receivers built by a large group of manufacturers who followed RCA's lead.

In recent years there has been a trend away from use of the vacuum discharge tube, and it is not found in the circuits of many modern receivers. There is nothing wrong with the circuit. In fact, it is one of the best horizontal oscillator circuits ever developed. But it does have the drawback of requiring at least one extra tube, and the modern trend is away from using so many tubes in receiver circuits.

Section 13. THE BLOCKING OSCILLATOR

The blocking oscillator has been widely used in television receivers. It has been used in both horizontal and vertical circuits. In some receiv-

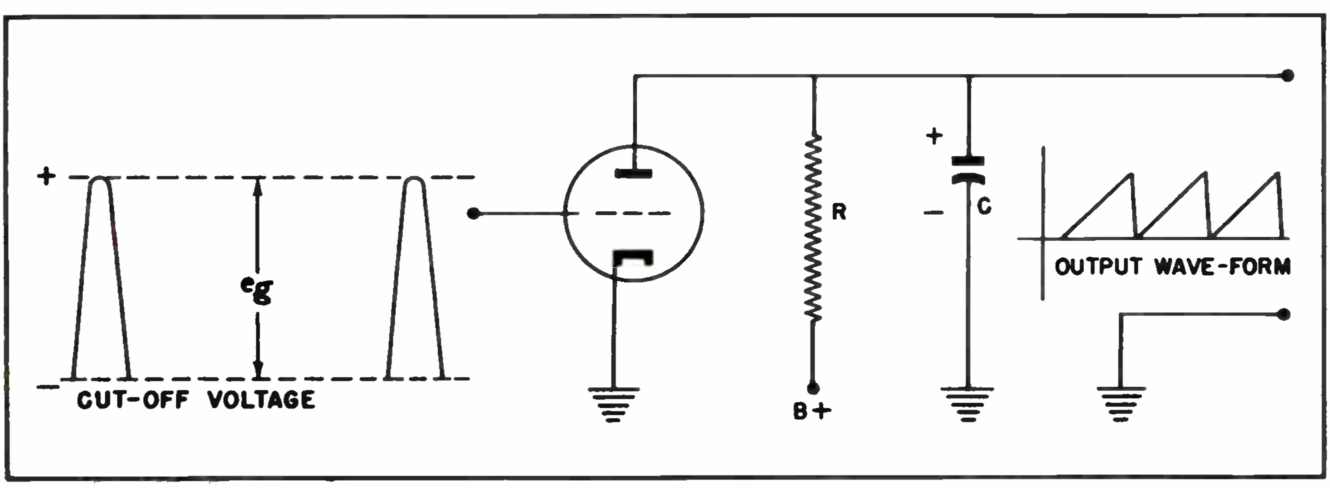

Figure 15. Vacuum discharge tube operating as saw-tooth generator.

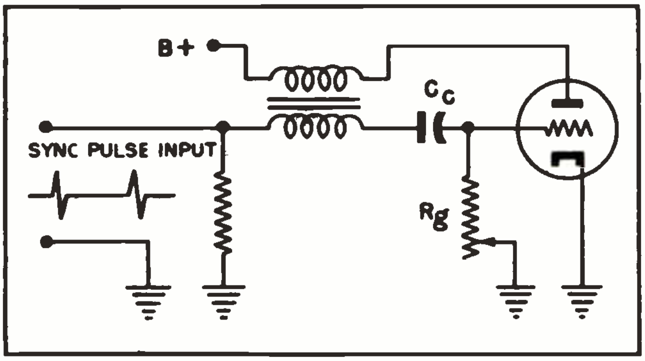

Figure 16. Blocking Oscillator.

ers it is used in both sets of circuits.

The blocking oscillator can be used by itself or with a vacuum discharge tube. When it was first used in television receivers it was used without the discharge tube. Later, when magnetic deflection picture tubes began making their appearance in television receivers, it became regular practice to use the vacuum discharge tube in combination with the blocking oscillator.

Still later, the trend changed again. The practice of using the discharge tube with the blocking oscillator was gradually discontinued by many manufacturers. At the present time relatively few manufacturers use the discharge tube with the blocking oscillator.

The principal features of a blocking oscillator are shown in Fig. 16. A study of the circuit discloses no apparent difference between a blocking oscillator and an ordinary Armstrong oscillator.

As a matter of fact there is no great difference between a blocking oscillator and an Armstrong oscillator except that the R/C combination in the grid circuit of the blocking oscillator has a time-constant much longer than the normal cycle of the oscillator. This action is such that during the initial portion of the oscillator cycle the grid is driven quite positive, thus drawing electrons from inside the tube to the grid. This leaves the grid quite negative.

So far, there is little difference between this action and that of an ordinary Armstrong oscillator. The difference is that there is considerably more resistance in the grid-return resistor than is common in an Armstrong oscillator. The capacity of the capacitor is also rather large for the frequency involved.

The action of the blocking oscillator, then, is this: the circuit goes through the initial portion of the cycle in the normal manner, very much as would occur in an Armstrong oscillator. But, after the grid has been driven negative, it continues to remain negative for considerable time, thus preventing the beginning of the next cycle.

The circuit cannot begin the second cycle until the negative voltage has leaked off the control grid of the tube through the R/C network.

Some idea of the voltage on the control grid of the blocking oscillator can be obtained by studying Fig. 17. That is a graph of the voltage changes on the grid.

The graph shows the voltage on the graph suddenly rises very sharply in the positive direction. That is when the anode current begins to rise, causing a sudden positive voltage pulse to be fed back onto the grid through transformer action. (The phasing of the windings on the transformer must be such that increasing current in the anode circuit induces a positive voltage for application to the control grid of the tube.)

What happens is that any increase in the anode current causes a reaction to make the control grid more positive. The cumulative effect is such that the control grid is driven so positive as to drive the tube to saturation.

During the period in which the control grid is driven positive it attracts electrons from the space charge inside the vacuum tube. Those electrons become trapped on the grid, thus tending to make the grid negative.

The instant the tube reaches saturation, and

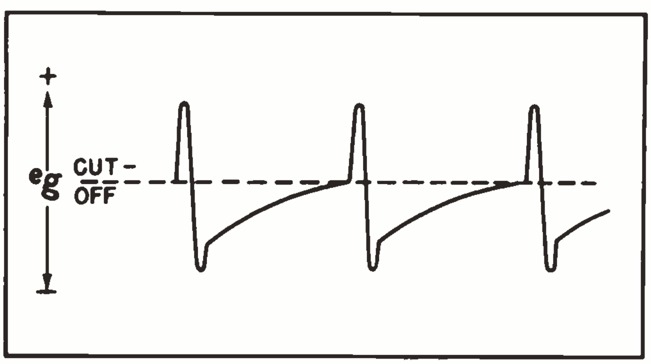

Figure 17. Voltage waveform on grid of blocking oscillator.

the anode current is no longer increasing, the transformer ceases to feed back a positive voltage for application to the control grid. When that happens the negative charge on the control grid, resulting from the trapped electrons, acts to reduce the anode current. This quickly changes the tube from saturation to cut-off.

This is the normal action of any similar oscillator circuit set up as an Armstrong oscillator.

But it is the next action which is different. A normal Armstrong oscillator would use such values of capacity and resistance as permit the tube to continue going through its oscillating cycles. But a blocking oscillator is different.

When the grid of a blocking oscillator is driven so negative as to force the tube into cut-off the control grid continues to retain a high negative voltage until it can leak off through the grid-return resistor.

As the negative charge leaks off the control grid circuit, through the return resistor, the voltage on the grid will rise slowly in a positive direction. The grid will not yet be positive but the voltage will become increasingly less negative, meaning that it rises in a positive direction.

This action is clearly indicated in the graph of the grid voltage in Fig. 17.

The first peak voltage in the positive direction above the grid cut-off line represents the high positive voltage placed on the grid because of the transformer action which drives the grid positive. The sharp dip below the cut-off line represents the strong negative voltage placed on the grid as the anode current drops from saturation to cut-off, thus inducing a sharp negative voltage through the transformer to be applied to the grid.

As soon as that sharp negative voltage is ended the grid voltage begins to rise sharply in a positive direction. Then it encounters the high negative voltage placed on the grid by the trapped electrons. That high negative voltage keeps the tube cut off, and prevents conduction.

The graph shows the voltage rising slowly as the negative voltage leaks off the grid through the resistor.

Finally, as the grid voltage rises toward cut-off, and the grid permits a little anode current to begin flowing, the cycle repeats. The instant any anode current begins flowing a positive voltage is again fed back through the transformer to the grid, and the grid is suddenly made highly positive again.

And so the action goes, cycle after cycle.

Although Fig. 16 shows the primary of the oscillator transformer in the anode circuit, it works equally well in the cathode circuit. It is often placed in the cathode circuit.

The blocking oscillator can be readily synchronized by placing a positive voltage pulse on the grid just as the grid voltage is approaching conduction. When the grid voltage rises to the point where the tube is almost ready to conduct, it takes very little additional voltage in the form of a pulse, to start the cycle. This is shown in Fig. 18.

The first three pulses in Fig. 18 show the normal free-running frequency of the oscillator. The final cycle is started a little sooner by applying a synchronizing pulse just before the tube would normally begin to conduct.

By applying a positive synchronizing pulse to the control grid, just before the tube is ready to begin conduction at the beginning of each cycle,

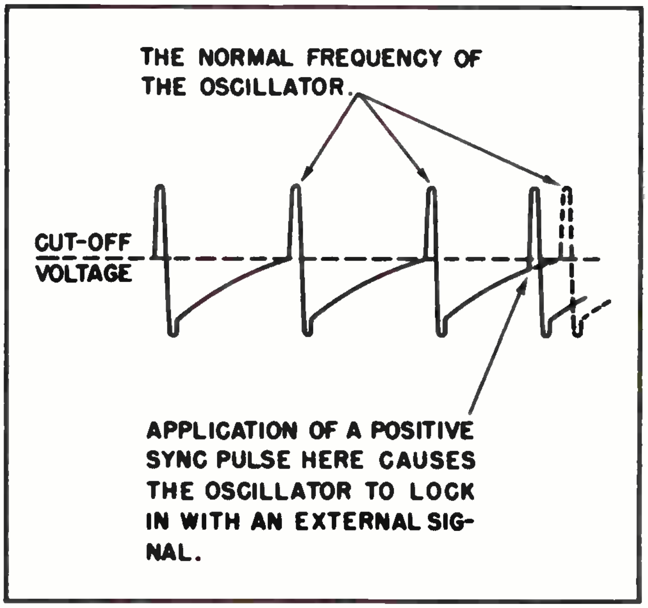

Figure 18. Blocking oscillator can be synchronized by applying positive sync pulse immediately before conduction would normally begin.

makes it possible to synchronize the oscillator with any source of pulse voltages. The oscillator has some definite "free-running frequency," the frequency being determined by the values of the resistors and capacitors in the circuit, also by the inductance of the transformer.

It is the practice in television work to have that free-running frequency a little lower than the frequency of the circuit into which it works. Then, when the sync pulses are introduced to the blocking oscillator, it is readily synchronized with the other circuit.

Section 14. CONTROLLING THE BLOCKING OSCILLATOR WITH VARIABLE GRID VOLTAGE

Instead of controlling the frequency of the blocking oscillator by applying the sync pulses directly to the control grid a newer method is to control the frequency by regulating the negative voltage on the control grid. This is done indirectly, as shown in Fig. 19.

The blocking oscillator is set up to operate as a free-running, blocking oscillator. No effort is made to control the frequency by applying the sync pulses directly. The negative bias voltage is controlled indirectly by controlling the voltage on the cathode.

The cathode of the oscillator obtains its current through a resistor which is also in the cathode circuit of the control tube. When the cathode of the oscillator tube is slightly more positive it causes the control grid to become slightly more negative with respect to it, thus reducing the free-running frequency of the oscillator. On the other hand, if the oscillator cathode is made slightly less positive it is the same as making the control grid slightly more positive, thus increas-

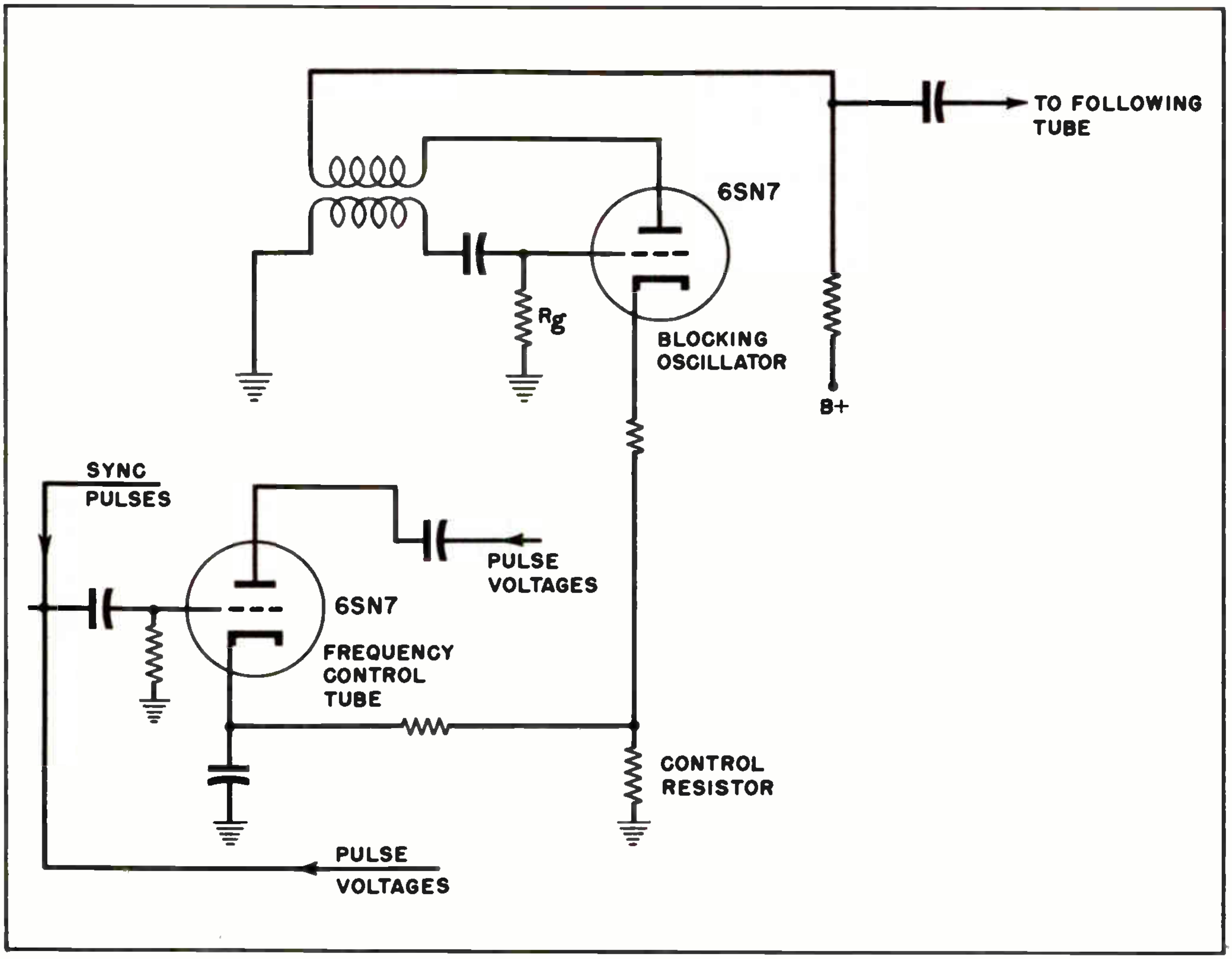

Figure 19. Controlling oscillator frequency with control tube.

ing the free-running frequency of the oscillator.

The amount of positive voltage on the cathode of the oscillator at any given moment depends on the amount the control tube is conducting. The control tube conducts in a series of pulses. This occurs as various groups of pulses are placed on the grid of the control tube.

The pulses arrive *almost* together, but not quite. If they arrive *exactly* together, the length of time the tube conducts is shortened. If they arrive a little too far apart the tube conducts too long. (The details of this action will be covered more fully in a latter lesson.)

This means the adjustment of the tube circuits is quite critical. They must be so adjusted that the amount of current through the control tube is just right to maintain the voltage on the cathode of the oscillator tube exactly right. Any tendency for the oscillator frequency to vary in either direction changes the amount of current through the control tube, and thus the voltage on the two cathodes.

The net result is to maintain the frequency of the oscillator in exact step with the incoming sync pulses, but it is so controlled indirectly rather than directly.

By arranging the control in this manner there is little danger that random noise pulses will affect the frequency of the sweep voltage, or affect the oscillator. This circuit was designed by RCA and is used in many of their receivers. It is also found in other brands built under RCA license.

This method of control, or modification of it, is used quite widely when the blocking oscillator is used in the horizontal sweep circuits. This subject will be explained in more detail in following lessons, but it is well to become acquainted with the underlying basic principles at this time.

Very often the oscillator, and its control circuit, use the two halves of a 6SN7 twin-triode tube. In fact, one of the principal advantages of controlling the oscillator tube in this manner is that the entire oscillator and controlling action can be handled in a single tube. This helps reduce the number of tubes in a receiver, and simplify construction.

Section 15. BLOCKING OSCILLATOR AND DISCHARGE TUBE

It was mentioned earlier in this lesson that the blocking oscillator and discharge tube was a combination used in many TV receivers at one stage of TV receiver development. RCA introduced the circuit, and many of the other manufacturers followed their lead. The result is that millions of receivers still in use employ that combination of circuits.

The blocking oscillator and discharge tube combination is not often found in the more modern receiver. This is not because there is anything wrong with the circuit. It is merely that newer methods using simplified circuits have become more popular.

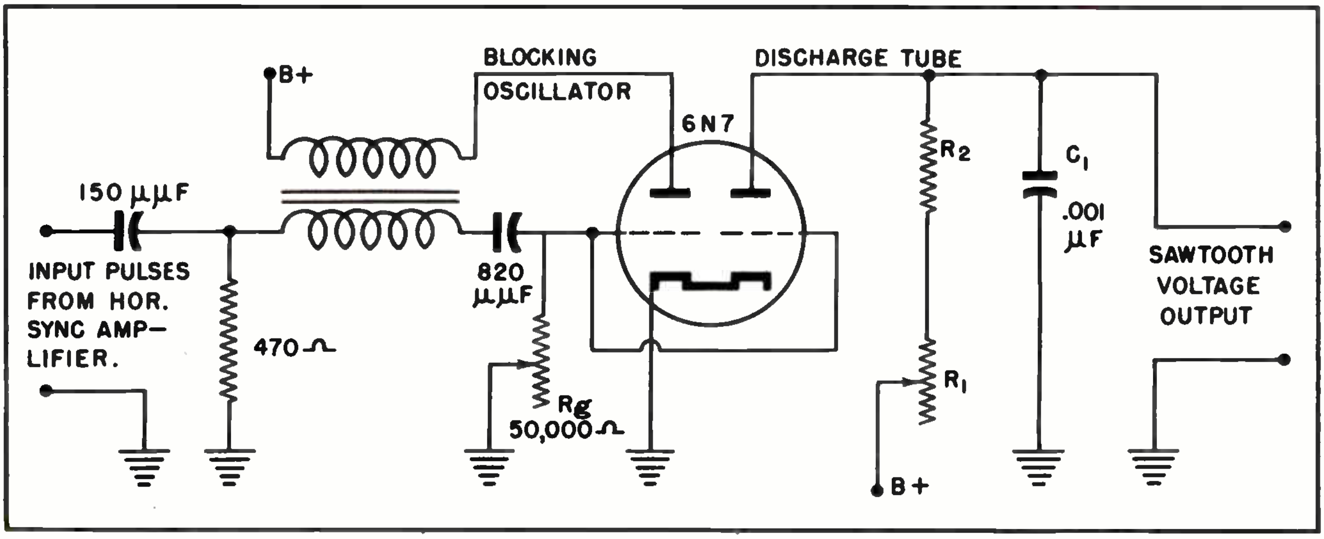

Figure 20. Vacuum discharge tube controlled by blocking oscillator.

The blocking oscillator works very much as the one described in connection with Fig. 16. The oscillator is synchronized directly by sync pulses applied to the control grid. The oscillator frequency could also be controlled by use of a control tube, such as the one in Fig. 19.

The peak positive pulses from the blocking oscillator are applied to the discharge tube as shown in Fig. 15. A study of Fig. 20 shows that the two control grids are tied together, thus causing the positive peak pulses to appear on the grid of the second tube at the same time they appear on the grid of the first. The shape of the voltage is the same as that in Fig. 17, but only the strong positive pulses have any effect on the conduction of the second tube. Thus, only those positive pulses have any effect on the resistor/capacitor combination which shapes the saw-tooth waveform in the anode circuit of the discharge section of the tube.

The circuit shown in Fig. 21, together with modification of that circuit, is one that is probably used more often in modern receivers than any other. The blocking oscillator feeds directly into the discharge capacitor, across which is developed the necessary saw-tooth waveform.

Section 16. USING HARTLEY TYPE COIL IN OSCILLATOR

One disadvantage of using a transformer like those shown in Figs. 16, 19, 20 and 21 is the necessity for making so many connections to them. These types of transformers have been used in many receivers, and are still in use. But there is a tendency to use a newer, and different type of oscillator coil in the horizontal oscillator. The double-winding type of transformer continues to be used in the vertical oscillator circuits.

A coil, somewhat like that in Fig. 22, is found in millions of television receivers. It has three connections to the coil. Actually the transformer consists of only one winding, but that winding is tapped.

The transformer is not usually tapped at the center. The practice is to use more turns in the coil in the lower part of the winding — that is, the grid portion — than in the anode portion.

In action the transformer performs much like any other auto-transformer. Variations in the current in the upper part of the winding affects both portions, but it induces a much greater voltage in the lower part, the part which is connected to the grid. Thus, variations in the anode current cause large voltage changes to be placed on the control grid of the tube.

Action of the fed-back voltage usually maintains the control grid very negative with respect to ground, or the cathode. This prevents the tube conducting except when the positive pulses are fed back from the transformer.

The tube conducts in a series of pulses. These series of pulses serve to charge the .001 mfd. dis-

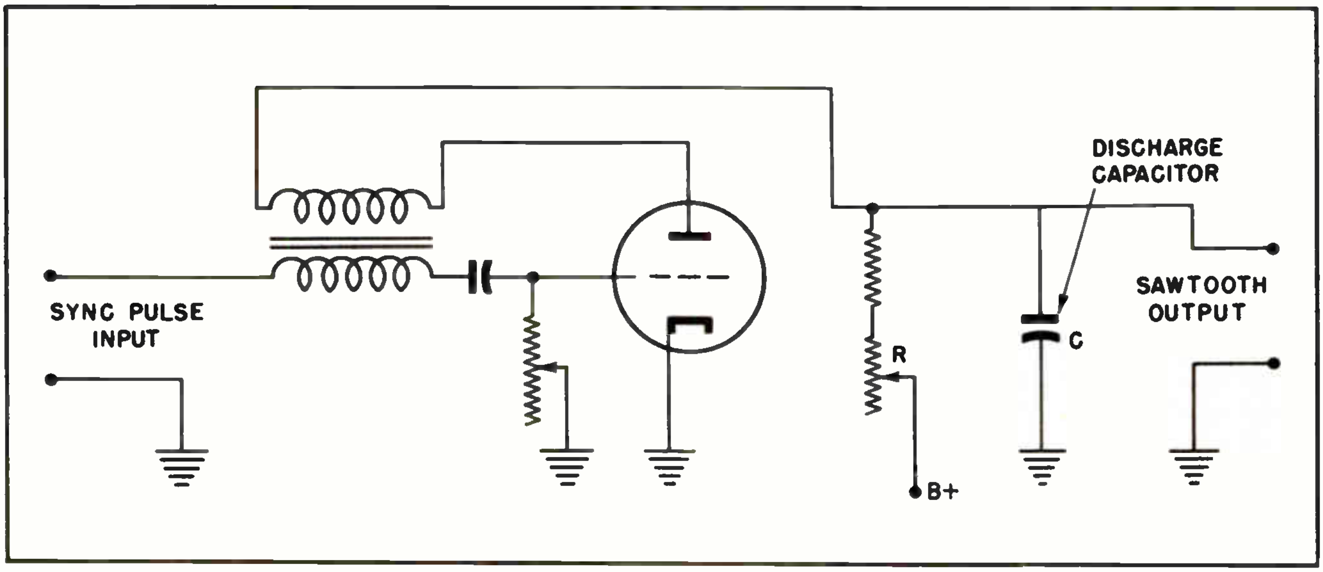

Figure 21. Blocking oscillator circuit without discharge tube.

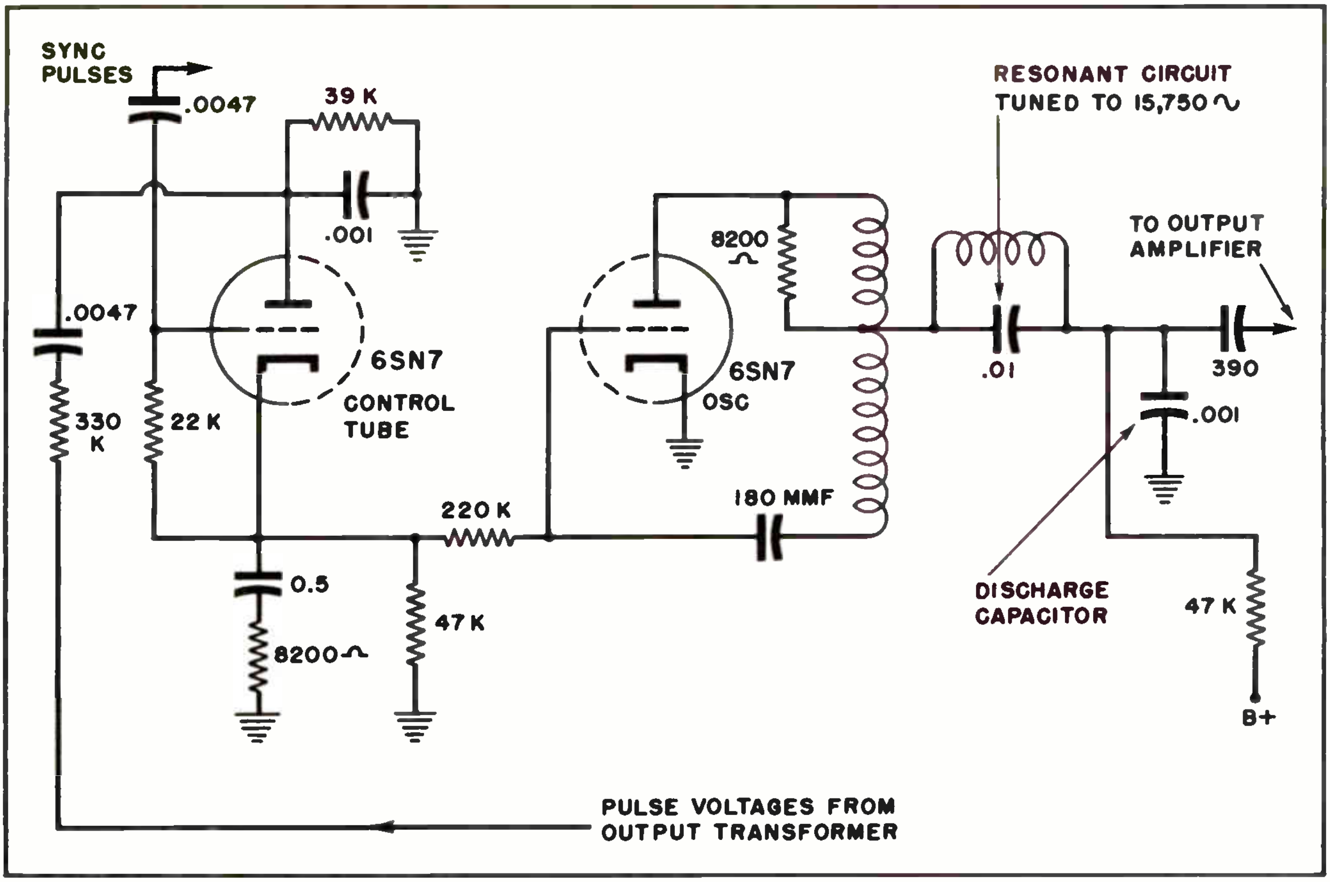

Figure 22. Hartley type coil used in blocking oscillator.

charge capacitor at the end of each cycle. The saw-tooth voltage is developed across the discharge capacitor.

The resonant circuit consisting of the coil and the .01 mfd. capacitor are not essential to the operation of the circuit. Nevertheless, those components are usually included to provide a stabilizing action to the circuit. Being tuned to a frequency of 15,750 cycles per second — the horizontal sweep frequency — it helps maintain the circuit frequency, and help prevent interference by random noise pulses.

The stabilizing circuit can usually be short-circuited without interfering with the action of the oscillator, provided the circuit is otherwise operating correctly. During servicing jobs the stabilizing circuit is often short-circuited so the horizontal oscillator can be adjusted.

NOTES FOR REFERENCE

Oscillator circuits are needed to generate the voltages which cause the electron beam to sweep across the screen of the picture tube.

The oscillator which generates voltages needed to sweep the electron beam horizontally across the screen is called the horizontal oscillator.

The oscillator which generates vertical sweep voltages is called the vertical oscillator.

Oscillators which generate sweep voltages in a television receiver must be designed so they can be synchronized with other circuits.

Sweep oscillators must also be designed so the signals they generate move the beam rapidly in one direction, but slowly in the other. This means they must generate saw-tooth waveforms.

A multivibrator is essentially a two-stage amplifier, so connected that the output of the second stage feeds back into the first stage.

A multivibrator can generate a square-wave voltage waveform or a saw-tooth waveform.

Multivibrators are used in many television receivers to generate the necessary saw-tooth waveforms.

The multivibrator may be used as either a horizontal oscillator or a vertical oscillator.

Some receivers use a multivibrator in both the vertical and horizontal circuits.

The multivibrator is an old electronic circuit which was used in electronic devices long before television became popular.

The blocking oscillator is another circuit which is often used to generate saw-tooth waveforms needed in television sweep circuits.

The blocking oscillator may be used in either the horizontal or the vertical sweep circuits.

Some receivers use a multivibrator in the horizontal sweep circuits but a blocking oscillator in the vertical circuits.

Other receivers use a blocking oscillator in the horizontal oscillator circuits, but a multivibrator in the vertical circuits.

The action of a blocking oscillator is similar to that of an Armstrong oscillator except that the time/constant of the grid R/C circuit is longer than in conventional oscillators.

In a blocking oscillator the circuit goes through one complete cycle of oscillation, then stops until the negative bias voltage can leak off the grid circuit of the tube.

A discharge tube is often used to shape the voltage applied to the discharge capacitor.

In many other receivers the discharge tube is omitted. This is the increasing tendency in modern receivers, but many receivers still in use have a discharge tube.

The saw-tooth shape of the waveform at the output of a multivibrator is accomplished by making the time/constant of one grid circuit short and the other long.

The cathode-coupled multivibrator is used in more TV receivers than the more conventional multivibrator circuit.

In a cathode-coupled multivibrator the signal from the second tube is fed back to the first tube by means of the voltage drop across a resistor which is common to both cathode circuits.

A modification of the cathode-coupled multivibrator is the flip-flop circuit. The flip-flop circuit has no importance in TV receiver work, but is used in many other electronic circuits, including TV transmitter circuits.

A modification of the blocking oscillator uses a single-winding transformer. This type of blocking oscillator is now the most widely used of all, especially in horizontal circuits.

Blocking transformers used in vertical circuits usually have an iron core, but those used in horizontal circuits frequently do not.

The blocking oscillator can be readily synchronized by applying sync pulses to the grid of the oscillator tube.

The blocking oscillator frequently is often controlled by a separate control tube when used in the horizontal sweep circuits of a TV receiver.

The control tube controls the frequency of the horizontal oscillator by controlling the negative bias on the oscillator grid.

When a control tube is used with a blocking oscillator the sync pulses are applied to the control tube instead of the oscillator tube. The sync pulses are mixed with other voltage pulses from other parts of the horizontal circuit so a combination of them all is what controls the control tube.

The "free-running" frequency of a sweep oscillator is always slightly lower than the sweep frequency to which it is synchronized.

NOTES

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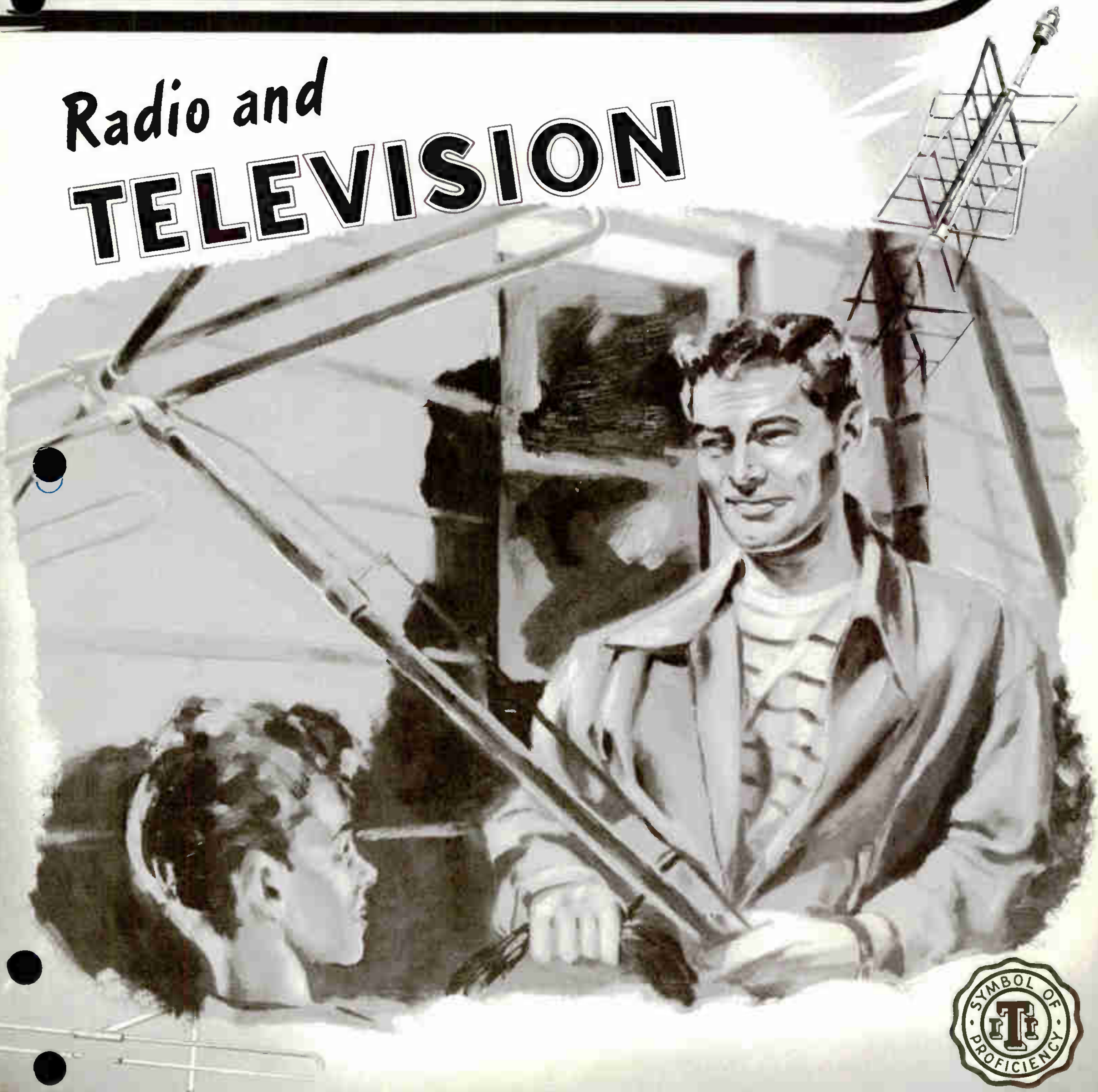

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TECHNICAL TRAINING SERVICE

RADIO TELEVISION

VERTICAL DEFLECTION SYSTEMS

Contents:

Section 1. INTRODUCTION

In previous lessons we have gone into the make-up of the composite video signal which supplies the synchronizing pulses for the sweep circuits. We have tried to explain the actions caused by the several parts of the signal.

In one lesson we examined the methods which are commonly used in receivers to separate the sync pulses from the composite signal. Also the manner in which the vertical sync pulses are separated from the horizontal pulses.

In another lesson we explained how sweep voltage signals are generated. Those are the voltages which provide the drive to move the electron beam from position to position inside the picture tube.

We have shown how synchronizing pulses from the composite video signal are able to "trigger" the sweep oscillators so the voltages generated by them are kept in step with other sweep voltages at the camera.

It is now time for us to look a little more closely into the details of the circuits which actually move and control the electron beam inside the picture tube. One group of those circuits, which constitute the *vertical deflection system,* provide the force needed to move the electron vertically inside the picture tube.

The other group of circuits, called the *horizontal deflection system,* provides the force necessary to move the beam horizontally.

The vertical deflection system includes the in-

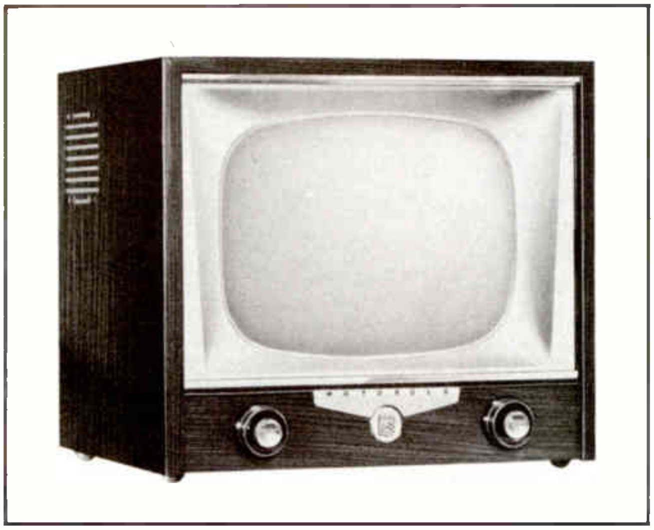

Figure 1. Vertical deflection circuits cause the electron beam to move vertically on the screen of a receiver.

tegrator circuit, the vertical oscillator, the vertical output amplifier, and the vertical deflection coils inside the deflection yoke. It is that group of circuits we will now study as a complete operating system.

You have already studied the integrator circuit, and it shouldn't be necessary to inquire too deeply into the details of that circuit in this lesson. Nevertheless, it is a part, an important part, of the vertical deflection system.

You have also studied saw-tooth oscillators, which generate the deflection signal voltage, so there is little need to delve into the oscillator circuits very deeply at this time. Yet, the vertical deflection oscillator is an important part of the vertical deflection system, and must be considered as a working part of the complete system.

In your earlier lessons you have studied power amplifiers. These were first explained when you were studying basic vacuum tube action, but were covered more deeply when you took up the study of audio amplifiers. Audio amplifiers are power amplifiers, since they act to convert electrical waveform voltages into electrical power.

The power amplifier, used at the output of the vertical deflection system in which electromagnetic deflection is employed, is very similar in most respects to the power amplifiers used in audio amplifiers. This means the vertical amplifier is similar to output amplifiers in radio receivers.

If, by any chance, you find your understanding of power amplifiers a little hazy, or you feel you have forgotten some of the things you learned earlier in the course, it would be wise to go back and review the basic principles and theory of vacuum tube amplifiers. It would also be wise to review the lessons on the audio section of radio receivers, especially as those lessons touch on power amplifier circuits.

A good understanding of those basic principles of electronics will make it much easier for you to understand power amplifiers used in the vertical deflection system. Especially those power amplifiers used in electromagnetic deflection systems. It is important to understand power amplifiers, and electromagnetic deflection systems, since that type of deflection is now being used in more than 95% of all the television receivers.

Section 2. TYPES OF VERTICAL DEFLECTION

Picture tubes are divided into two general groups or classes, insofar as the method used to deflect the electron beam is concerned. The first group uses electrostatic deflection, the other uses magnetic deflection.

The first group causes the electron beam to be deflected by varying the electrostatic voltage present on a set of deflection plates. These plates are located inside the tube, just as are those in cathode ray tubes used in oscilloscopes. These picture tubes are called electrostatic deflection picture tubes.

The drawing in Fig. 2 gives a good idea of the arrangement of the deflection plates inside an electrostatic picture tube. One set of plates deflects the beam in a horizontal plane. These are

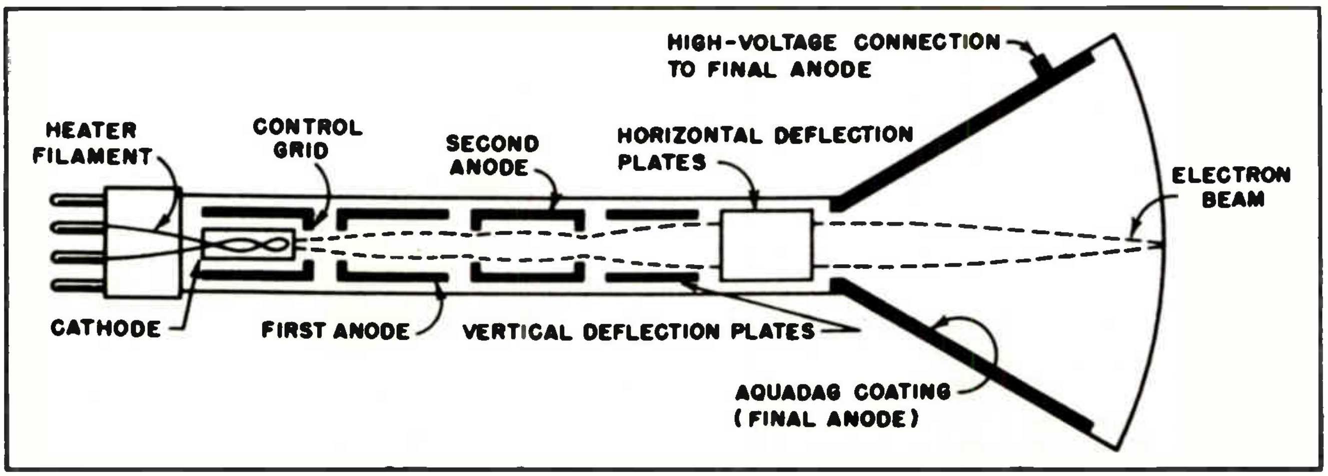

Figure 2. The electron beam in an electrostatic tube is deflected by a set of deflecting plates.

the set of plates shown as being closest to the flare of the tube. The other set of plates deflect the beam vertically.

Originally, all cathode ray tubes used electrostatic deflection. Virtually all cathode ray tubes used in oscilloscopes still use electrostatic deflection.

When television was in its developmental stage, and even after it became commercially available, all receivers used picture tubes with electrostatic deflection. As a matter of fact, at that time the the only type of deflection used by any cathode-ray tube was by means of electrostatic plates and voltages.

So long as the screen area of the tube was small, electrostatic deflection enjoyed some definite advantages. All operating elements concerning the tube were inside. No external focusing arrangement, and no external wire-wound yoke, was needed. Once the circuits were wired all that was then needed was to insert the tube and everything was ready for operation.

As the general public became acquainted with television the demand for larger screen area became insistent. This meant manufacturers had to provide receivers with larger picture tubes.

As picture tubes exceeded the 7-inch and 10-inch sizes, it became necessary to devise new and different types of deflection. Technically, it is possible to build an electrostatic tube with a screen area as large as anyone could desire. But practical limitations are more restrictive.

When electrostatic deflection is used the final anode voltage must be quite high. The deflecting voltage must be on the order of hundreds of volts if it is to be effective. When voltages that high are placed on the deflection plates it is necesssary to use radically higher voltages on the final anode to keep the electrons moving toward the fluorescent screen and not be attracted to the deflecting plates. This is one of the big reasons for the high voltages on the final anodes of electrostatic picture tubes.

The final anode voltage is not excessive so long as the size of the screen does not exceed 7 inches to 10 inches. But when the screen is larger the final anode voltages must be quite high.

Another undesirable feature of electrostatic tubes is their length. Even a 7-inch or 10-inch tube is as long as, or longer than, many 19-inch and 21-inch magnetic deflection tubes. Attempts to build electrostatic picture tubes larger than 10 inches makes them so long it is difficult to build a cabinet large enough to hold them.

The result was that when the demand grew for the production of larger picture tubes the manufacturers turned to electromagnetic deflection. Virtually all modern television receivers use electromagnetic deflection. The exceptions are a few small portable receivers. By their very nature portable receivers use small tubes, thus electrostatic picture tubes can be used in them if the manufacturer so decides.

Section 3. DEFLECTION YOKE

Electromagnetic deflection is accomplished by varying an electric current through a coil of wire which surrounds the neck of the picture tube. Varying the current through the wire sets up a varying magnetic field. Since the movement of an electron beam is strongly influenced by the presence of a magnetic field it is readily possible to deflect the electron beam inside a picture tube by controlling the strength of the magnetic field through which the beam is caused to pass.

Fig. 3 provides a good idea of the arrangement of the deflection coils around the neck of a picture tube. The deflection coils create a varying magnetic field as the current through the coils is caused to vary from instant to instant. The lines of force in that magnetic field pass through the neck of the tube.

The drawing in Fig. 3 does not give a very clear idea of the exact appearance of the coils in a deflection yoke, but it does indicate quite clearly the physical position of the yoke around the neck of the tube. The actual physical arrangement of the vertical and horizontal deflection coils in the yoke is shown somewhat better in Fig. 4.

When the deflection yoke is properly positioned around the neck of the picture tube the vertical coils are on each side of the yoke, and opposite each other. The horizontal deflection coils are so positioned that one is above the neck and the other is below.

Since the vertical windings of the deflection yoke are located on each side of the picture tube

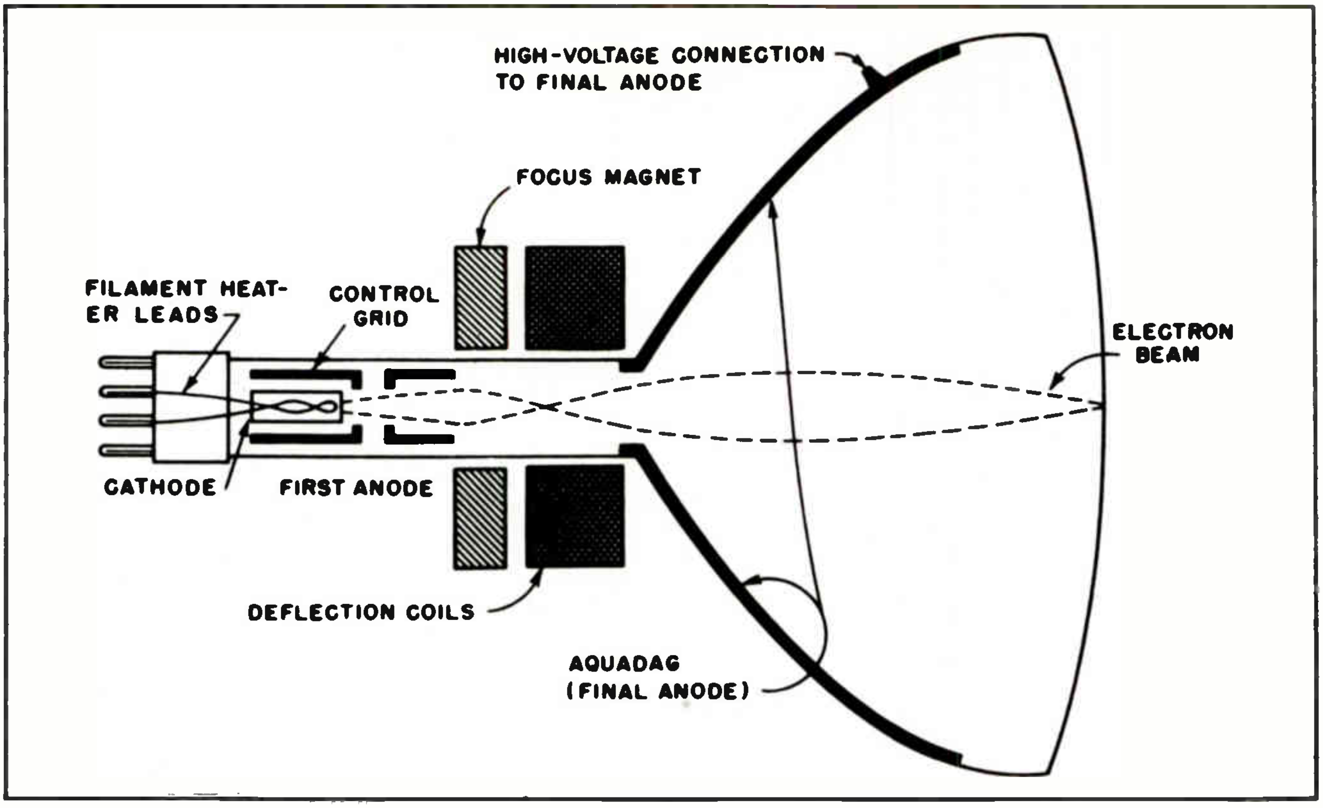

Figure 3. Electromagnetic coils set up a varying magnetic field around neck of tube.

neck the magnetic lines of force between the two windings lie in a horizontal plane. This means the magnetic lines of force between those two windings pass through the neck from one side to the other.

The electrons in the beam must pass through these magnetic lines of force on their way from the electron gun in the end of the neck to the screen at the front of the tube. The free electrons in the beam are acted upon by the magnetic lines

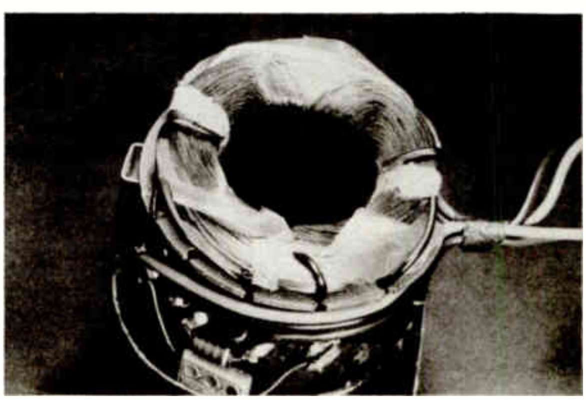

Figure 4. Deflection Yoke

of force in exactly the same manner they would be acted upon if they were moving through a metallic conductor.

When electrons pass through a magnetic field they are affected by the magnetic lines of force. They are deflected at right angles to the lines of force.

In this case, since the magnetic lines of force lie in a horizontal plane, the electrons in the beam are deflected upward or downward.

They are deflected at right angles to the lines of force when they are deflected upward. An upward movement of the electrons in the beam represents a movement at right angles to the lines of force, and at right angles to their direction of travel. They are also deflected at right angles when deflected downward, since that also represents a deflection at right angles to the lines of force, and to the direction of movement.

Whether they are deflected upward or downward depends upon the instantaneous polarity of the magnetic field through which they pass. If the north magnetic field happens to be at one side at a given instant the beam is deflected upwards. If the north magnetic field happens to be on the opposite side at that given instant the beam is deflected downward.

As you well know, the polarity of the magnetic field at any given instant depends on the manner in which the coil windings are wound, and the direction of the current through the conductors of the coil. The polarity is reversed by reversing the direction of the current flow. From a practical point of view this is accomplished by reversing the electrical connections to the windings.

Section 4. ELECTROSTATIC DEFLECTION SYSTEM

Electrostatic deflection is largely a thing of the past in television receivers, except in the case of a limited number of portable receivers, and a limited number of ancient, small-tube receivers manufactured during the days immediately following the second world war. Nevertheless, it is only right and proper that we devote a little time to these circuits because there is always the possibility you may run into one of them.

The deflection circuits used with electrostatic deflection tubes are relatively simple and straightforward. In most ways they are simpler than those used with magnetic deflection tubes.

The principal details of the deflection circuits used with an electrostatic picture tube are shown in Fig. 5. The saw-tooth waveform sweep voltage is generated in a multivibrator. That circuit is shown in the lower part of the diagram in Fig. 5.

A 6SN7 is shown as the oscillator tube. The output of the 6SN7 saw-tooth oscillator is resistance-coupled into another 6SN7 which acts as a voltage amplifier. This is an ordinary resistance-coupled amplifier, and is little different from the many other resistance-coupled amplifiers discussed so many times in earlier lessons.

The second 6SN7 tube, the voltage amplifier tube, can be thought of as being used in push-pull. The two sections of that tube, however, do not work into a transformer, as is customary in most push-pull amplifiers. Nor do the two sections operate as power amplifiers.

They are simply two voltage amplifiers whose outputs are 180° out of phase with each other. When the voltage at the anode of one tube is becoming progressively more positive, at any given instant, the anode of the other tube is becoming progressively more negative. The rise in positive voltage at the output of one tube is exactly equalized and balanced by the rise in negative voltage at the output of the other tube.

The reverse is also true. As the output of one tube tends to become more negative, the other tends to become more positive.

The outputs of these two sections of the 6SN7 vertical amplifier tube are fed to a pair of deflection plates inside the neck of the picture tube. One plate is at the bottom of the neck, the other at the top.

As one of the plates tends to become more positive the other tends to become more negative. This creates an electric field between them.

When the electron stream passes through that electric field the beam is influenced by the field. If the upper electrostatic plate is positive and the lower one negative the beam is deflected upward. When the voltage polarities on the two plates are reversed the beam is deflected downward.

This action has been discussed in considerable detail in earlier lessons, but we are repeating it at this time to refresh your memory. If you have forgotten the details it would be well to go back and review the lessons where this subject was explained.

The coupling between the anodes of the two sections of the 6SN7 output tube is not made directly to the deflection plates inside the picture tube. Instead, the voltage is coupled through a pair of .05 mfd. capacitors. These are clearly shown in the diagram in Fig. 5.

A centering control for the vertical plates is also provided. This makes it possible to position the raster directly on the center of the picture tube screen by merely adjusting the DC voltage on one of the vertical plates.

Because no currents are involved in the deflection circuits to electrostatic deflection plates it is not necessary to make any allowances for time-delay due to inductive action. The voltages to the deflection plates can be, and should be, pure saw-tooth waveform voltages.

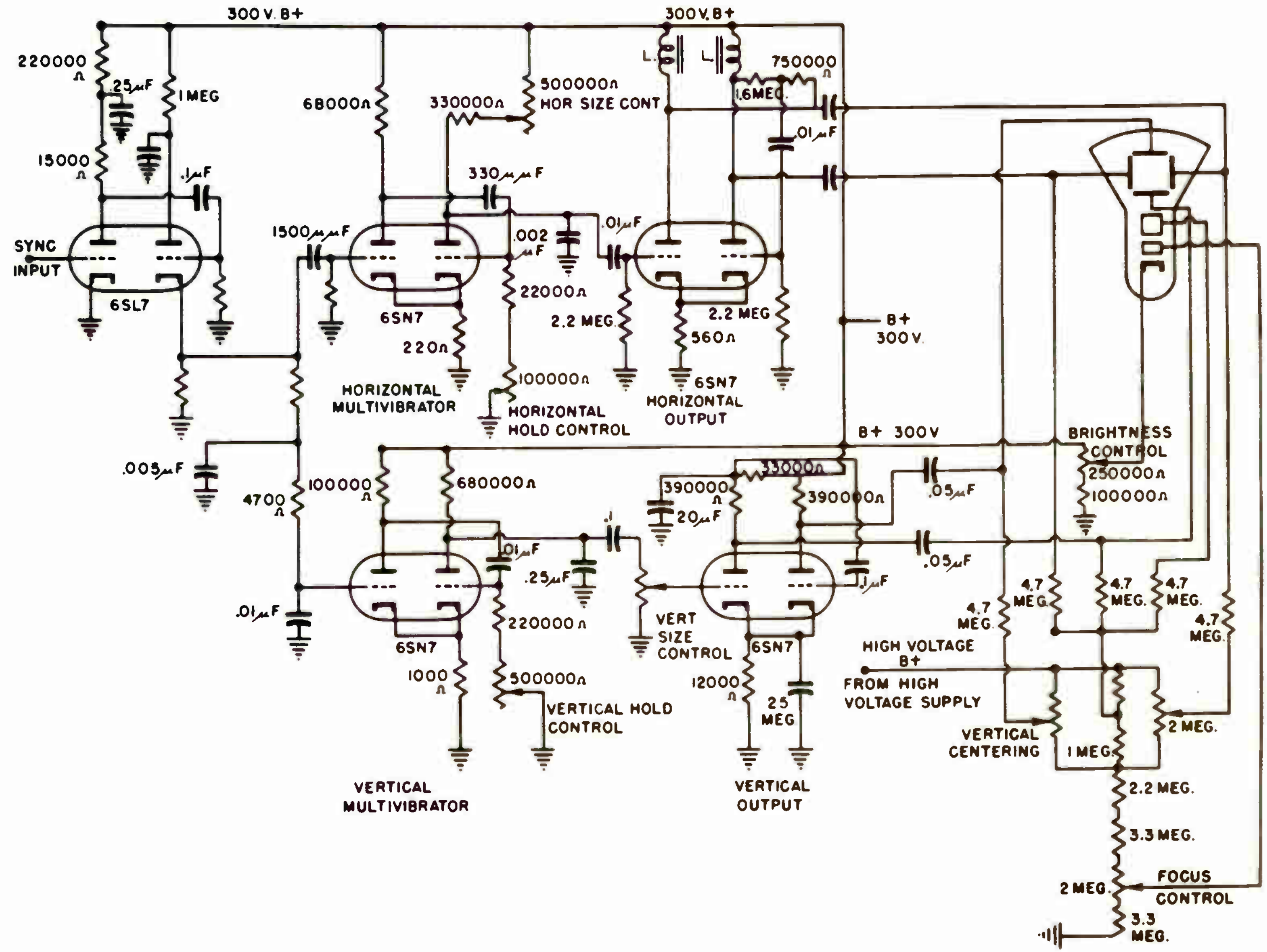

Figure 5. Deflection circuits used with electrostatic picture tube.

Section 5. MAGNETIC DEFLECTION IN VERTICAL CIRCUIT

In many ways the circuits required for electromagnetic deflection are more complicated than those used for electrostatic deflection.

Electric currents are necessary to create the magnetic fields which actually deflect the electron beam inside the picture tube. It is necessary to provide some modifications of the circuits when they are intended to handle relatively high-frequency A-C *currents* rather than A-C voltages. This is necessary to prevent inductance in the circuit distorting the movement of the beam.

A circuit similar to that used in the vertical deflection system of many modern TV receivers is shown in Fig. 6. The circuit shown in Fig. 6 is used in Sparton model 11T210, but it is also used with little or no variation in other models built by the same company.

In fact, the vertical deflection systems used in receivers built by other companies differ very little from this particular circuit.

The oscillator in this circuit is a blocking oscillator which has an iron-core transformer. The transformer is so wound that there is 107 ohms of resistance in the primary winding which is in the cathode circuit of the oscillator tube. The secondary winding, in the grid circuit of the tube, has many additional turns. It has a resistance of 540 ohms.

Current through the tube must pass through the primary of the blocking transformer on its

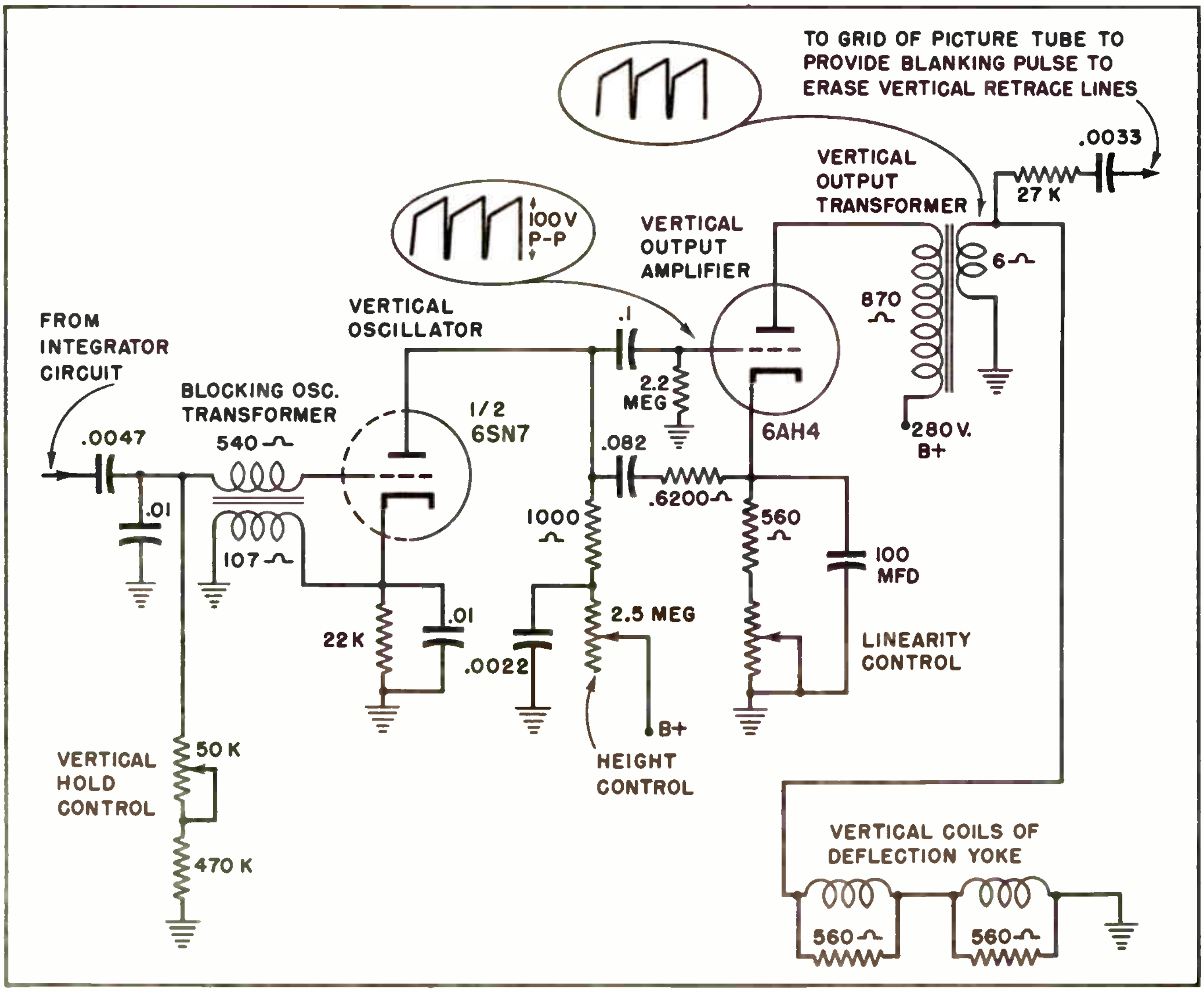

Figure 6. Vertical deflection circuit using magnetic deflection.

way to the cathode. This provides the necessary tickling action—through the transformer—to drive the grid positive. Due to the step-up of the voltage through the transformer the grid is driven highly positive during the interval when the current is flowing.

The free-running frequency of the oscillator is controlled by the variable resistor in the grid-return circuit. A potentiometer is connected as a rheostat so the grid resistance can be adjusted to a frequency just under the 60-cycle sweep frequency. By adjusting the free-running frequency so it is slightly lower than the 60-cycle sweep frequency it is easy to synchronize the oscillator with the sync pulses coming from the transmitter.

The output of the oscillator is fed into the coupling circuit between it and the grid of the output amplifier. The resistors and capacitors in that circuit are chosen so they will shape the waveform of the signal voltage applied to the grid of the amplifier to the correct dimensions. Since this is an electromagnetic deflection system, and since currents are involved in the circuit, the waveform of the signal must be a *modified* saw-tooth rather than a true saw-tooth. This will be explained a little more fully later in the lesson.

The object is to control the current through the output amplifier tube in such manner as to induce a voltage through the output transformer so the current in the output circuit of the transformer will rise in a linear manner. Since the current in the output circuit of the transformer flows through an inductive circuit it is necessary to provide a special shape to the voltage in order to force the current in the deflection coils to rise as a linear saw-tooth rather than as a sine-wave, or as some other shape. This action requires some special explanation, and will be taken up later in the lesson.

The vertical output transformer in the anode

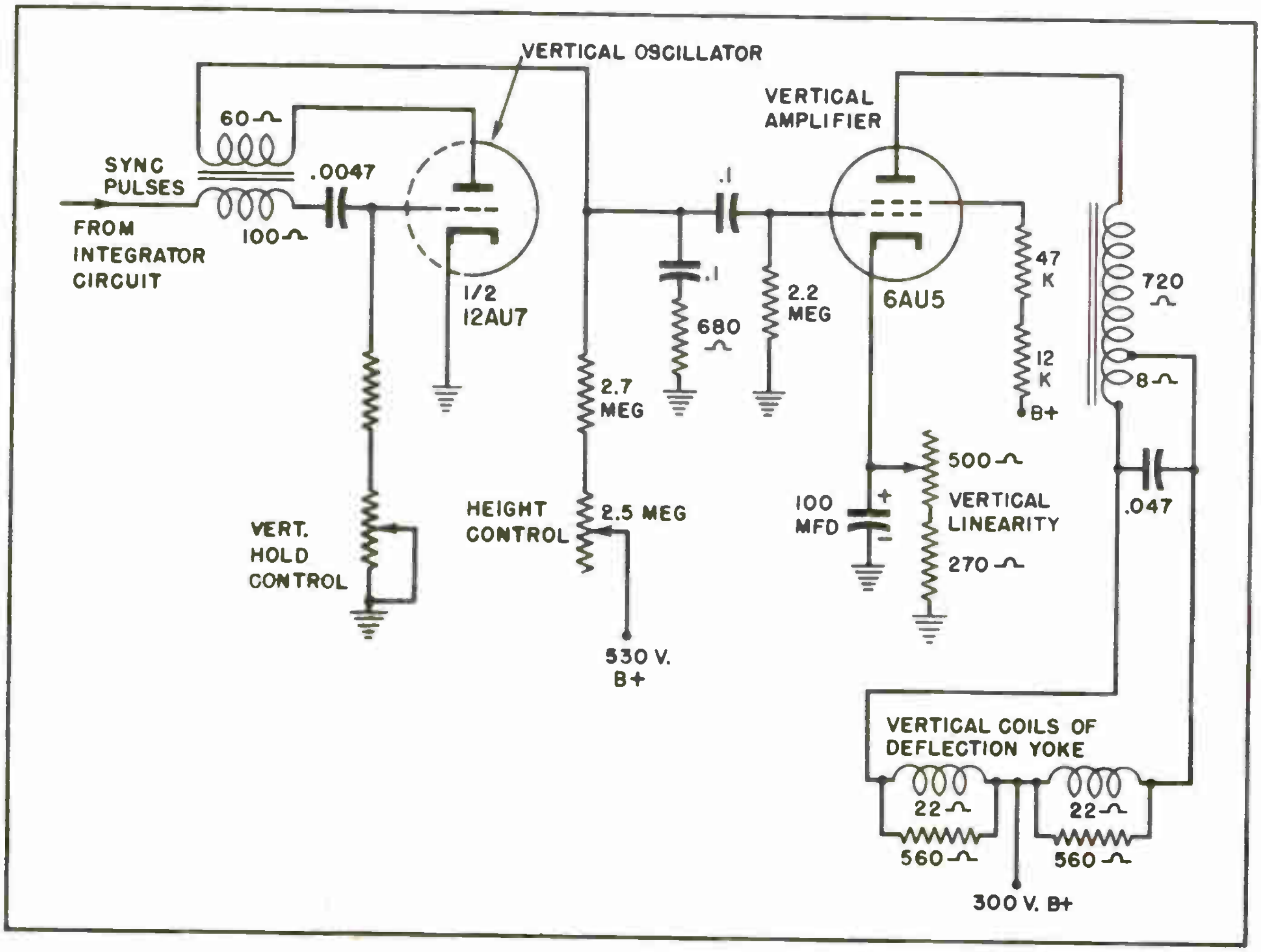

Figure 7. Auto-transformer in output amplifier circuit.

circuit of the output amplifier is similar in many respects to an audio output transformer. Its purpose is to convert the power in the anode circuit of the tube from a high-voltage/low-current relationship to a low-voltage/high-current ratio. It is the current in the output of the transformer which flows through the vertical coils in the deflection yoke to create the necessary magnetic field to deflect the electron beam.

Section 6. VERTICAL RETRACE BLANKING PULSE

One interesting feature of the circuit in Fig. 6 is the provision for feeding a voltage pulse from the output of the transformer to the control grid of the picture tube. That voltage pulse coincides with the retrace action, and acts to drive the control grid of the picture tube so negative it is not possible for the vertical retrace lines to be visible.

That special blanking circuit consists of a 27K resistor in series with a .0033 mfd. capacitor. The time/constant of the blanking circuit is long enough to blank the picture tube during the normal retrace action, but not long enough for the blanking pulse to interfere with the picture content. If the time/constant of the circuit were made too long there would always be the danger some of the horizontal lines of the picture would be blanked near the top of the raster.

A service technician is rarely, or never, called upon to design a blanking circuit of this nature. Therefore, there is no real reason why it is necessary for you to concern yourself over these component values.

However, there are many TV receivers in use which do not have such a special blanking circuit. Occasionally a technician is asked by the owner of such a receiver to make the necessary changes to end the annoyance of vertical retrace lines. It is always nice to know how such a problem can be solved.

It must be kept in mind that a circuit exactly like the one shown in Fig. 6 cannot always be used to blank out the retrace lines in every TV receiver. It is first necessary to study the receiver circuits to figure out exactly what is the best approach to use.

The Sparton receiver shown in Fig. 6 injects the video signal into the cathode of the picture tube. This means that a strong negative signal on the control grid during the retrace action will blank the retrace lines. Therefore the sharp pulse voltage from the output of the vertical transformer has a negative polarity. That occurs at the instant the saw-tooth waveform reaches its peak value and suddenly drops to zero. That sudden pulse voltage is negative.

In some types of receivers the pulse voltage must have a positive peak, and must be applied to the cathode of the picture tube. That is true when the video signal is applied to the control grid of the picture tube.

There are other variations. Sometimes the blanking pulse voltage is tapped off the output from the oscillator rather than from the output tube. In other cases it is tapped off the input to the output amplifier. Much depends on the nature of the other circuits which are involved.

Section 7. AUTO-TRANSFORMER IN VERTICAL OUTPUT CIRCUIT

The circuit of the Sparton TV receiver in Fig. 6 shows a conventional transformer in the anode circuit of the output amplifier. It has a separate winding for the primary and the secondary.

Such transformers are widely used in television receivers. A number of manufacturers use such transformers exclusively.

The primary windings are wound with much finer wire than the secondary. There are also many more turns on the primary than the secondary. The output transformer in Fig. 6 has a resistance of 870 ohms on the primary and a resistance of 6 ohms on the secondary. At first glance this might seem that the primary had approximately 100 times as many turns as the secondary; but this would not be true. The current is much higher in the secondary, thus requiring larger wire with less resistance.

Actually, the turns ratio is approximately 10:1. This means the voltage changes developed in the anode circuit of the output tube are stepped down to one-tenth that magnitude, while the current changes are stepped up. The magnitude of the current in the secondary is ten times as great as that in the primary. This is the reason the resistance in the primary is so much greater than that in the secondary. The wire is smaller in the primary, and there are many more turns of it.

But not all vertical output transformers have separate windings for the primary and secondary. In fact there is a trend among many manufacturers to use auto-transformers instead. Fig. 7 shows the diagram of a vertical circuit in which an auto-transformer is used for the output transformer.

The circuit in Fig. 7 is one used in Stewart-Warner model 24C-9360A, but receivers built by other manufacturers use auto-transformers in almost exactly the same way.

Section 8. REPLACEMENT TRANSFORMERS

An important bit of information to a service technician is what to do when called upon to service one of these transformers which is defective and must be replaced. The most obvious answer, of course, is to obtain an identical replacement transformer and install it in place of the defective component.

But the solution is not always so easy. Because of the large number of models which have been built by the many different manufacturers it is not always possible for a service technician to stock all the replacement parts needed to repair all the receivers which come into his shop. Often it is necessary to use some substitute part when a component in a receiver is found defective.

Several manufacturers of component parts, such as Merit Coil and Transformer Company, and Chicago Transformer Company, and Stancor Transformer Company, and others, make what they call "universal replacement transformers." These transformers are designed so they can be used as replacement for a large number of different model receivers.

Your first reaction might be to inquire how it is possible to build a universal transformer which will work in a variety of different model receivers. The answer is not as difficult as you might think.

It is much like replacing tires on an automobile. Each automobile comes from the factory with a given set of tires built by a given tire manufacturer. But when it is necessary to replace those tires it is not necessary for the owner to use exactly the same brand as those used originally. So long as he buys a set having the correct size they will work as well as the original.

Much the same is true in the case of these transformers. In this connection it is well to remember that the television manufacturer rarely manufactures his own coils and transformers. He buys most of them from manufacturers who specialize in making those items. The truth is that the original transformer may have been built by the same manufacturer who builds the universal replacement, and very often the electrical and physical characteristics of the original transformer and the replacement are identical.

Even knowing this to be true you may still be uncertain as to the best course when confronted with a problem in which you have a receiver with a defective component and be unable to obtain an exact replacement. This is a situation which occurs over and over. It occurs almost daily in the busy repair shop. The replacement might not always be a transformer, but situations of this kind arise constantly.

You may know that a universal replacement transformer can be used to replace the one that is defective. But you may not know which universal transformer to use as a replacement, or know where to obtain that information.

It is in just such a situation as this that technical manuals prepared by one of the publishers of technical information prove invaluable. These are the manuals prepared by such organizations as John F. Rider and Company in New York, and Howard W. Sams and Company in Indianapolis. These are not the only companies which publish this technical information, but they are the largest.

Such manuals are often even more valuable than the original manuals prepared by the manufacturer. This is because the manuals prepared by the commercial publishers provide a list of alternate replacement parts which can be used as substitutes for original components in almost every receiver.

Most manufacturers list only the original replacement parts which they, alone, are able to supply. Often this source of supply is not open to ordinary service technicians; the manufacturer making the parts available only to their franchised service organizations.

But commercial publishers like Sams and Rider and Supreme and Telaides, list from two to six alternate parts which can be used to replace virtually every part used in every television receiver on the market. This includes speakers, resistors, electrolytics and other items, as well as transformers. It is partly for this reason that we recommend that little or no servicing be attempted on any television receiver unless one of the service manuals is available.

Section 9. SUBSTITUTING A DOUBLE WINDING TRANSFORMER FOR AN AUTO-TRANSFORMER

Despite the fact receivers which use auto-transformers in the vertical output section are quite common, it is not always possible or convenient to obtain an exact replacement. Sometimes it is not even possible to obtain a universal replacement auto-transformer.

In a case of this kind it might be thought that there is little which could be done to make a repair. But an experienced and resourceful technician can often solve just such a problem, and make another satisfied customer, not to mention the additional money he can make as a result of the repair job.

Back in some of the earliest lessons of this course we explained that separate primary and secondary windings of a transformer could be connected together to make an auto-transformer. It is possible to make use of that information at this time.

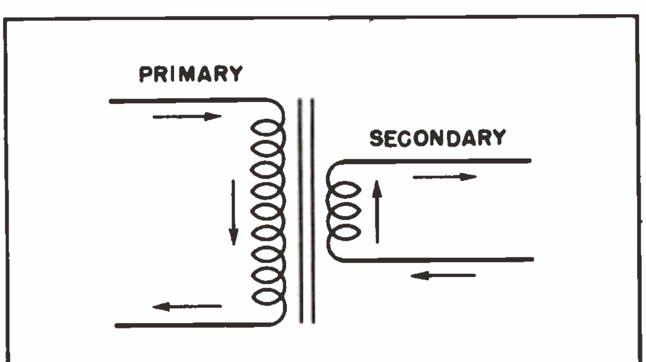

Figure 8. Current relationship in two-winding transformer.

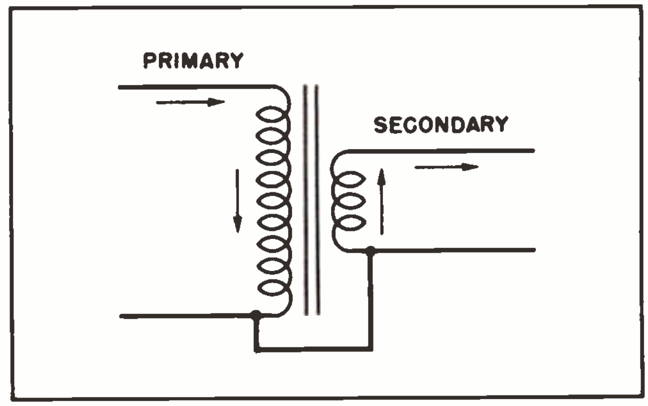

Figure 9. Two-winding transformer reconnected to operate as auto-transformer.

The diagram in Fig. 8 shows the two windings of a transformer. Arrows alongside the windings, and the leads to the windings, show the instantaneous direction of the currents in the transformer at any given instant of time.

When the current is moving in one direction in the primary winding of the transformer, at any given instant, it is moving in the opposite direction in the secondary. This is in conformance with the action which takes place in any transformer. In any transformer the current in the secondary is always moving in the opposite direction from that in the primary.

It is a well-known electrical principle that the two windings of a two-coil transformer can be connected together to make an auto-transformer. This principle has long been used in electrical work, one of the best examples being that of reconnecting a power distribution transformer in an electric power system to act as a voltage booster. In electrical power distribution systems a *voltage booster transformer* is usually nothing more than an auto-transformer.

We show in the diagram in Fig. 9 how the transformer in Fig. 8 can have its two windings re-connected so the transformer acts like an auto-transformer. Note that the current flows in the same manner in Fig. 9 as it does in Fig. 8. The only difference between the two diagrams is that one end of the primary winding is electrically connected to one end of the secondary winding.

A comparison of the electrical action in a regular auto-transformer with that in a two-winding transformer connected like an auto-transformer can be seen by studying Fig. 10.

The auto-transformer can be used as a step-up transformer or as a step-down transformer.

The auto-transformer at *A* in Fig. 10 can be connected so the primary is between terminals 1 and 2, while the secondary is between terminals 1 and 3. In that case the transformer would operate as a step-up transformer because there are more turns in the secondary winding than in the primary.

On the other hand, if the primary connections were between terminals 1 and 3, while the secondary connections were between terminals 1 and 2, the transformer would act like a step-down transformer. This results from the fact there are then fewer turns on the secondary winding than the primary winding.

Still other combinations can be arranged. The primary might be between terminals 1 and 2, while the secondary is connected between 2 and 3. Whether or not this would be a step-up or a step-down transformer would depend on the number of turns between the several connections to the transformer.

Now let us take a look at the diagram at *B* in Fig. 10. This is the same two-winding transformer shown in Figs. 8 and 9. The windings are connected exactly like they were in Fig. 9, but the diagram of those connections is arranged a little differently. The electrical connections are the same in one case as the other, but the appearance of the diagram is different.

The principal point we are trying to make is that the electrical action of the transformer at *B*

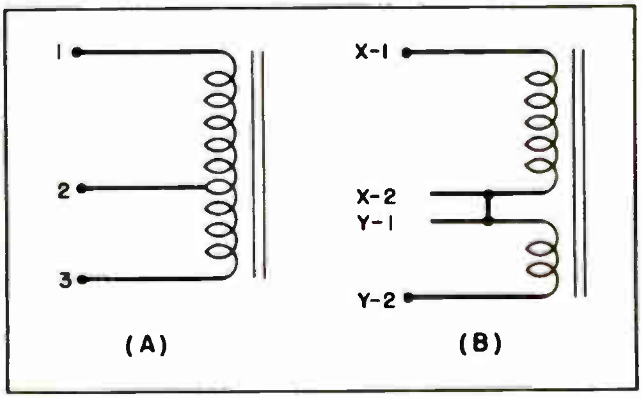

Figure 10. Comparison of electrical circuits in two types of transformers when both are working as auto-transformers.

in Fig. 10, when terminals X-2 and Y-1 are tied together, is exactly the same as that of the auto-transformer at *A*—provided, of course, the number of turns between X-1 and X-2 in the transformer at *B* is the same as between terminals 1 and 2 in the transformer at *A*. And also, provided, that the number of turns between terminal Y-1 and Y-2 at *B* is the same as between terminals 2 and 3 at *A*.

All of which brings us back to the matter of substituting a universal two-winding, vertical output transformer for an auto-transformer in a television receiver. Many universal vertical output transformers are so constructed that they can be used to replace either a two-winding transformer or an auto-transformer.

Section 10. UNIVERSAL REPLACEMENT TRANSFORMER TERMINALS

Manufacturers of universal replacement transformers make it a practice to include instructions with their transformers to show how they can be connected, or re-connected, to replace any of several different types of original transformers. All the serviceman has to do when using one is to observe the manufacturer's instructions.

A little earlier in this lesson we mentioned that a vertical output transformer may have a step-down ratio of 10:1. That is a common step-down ratio; one that is used in many television receivers.

But not all receivers use that ratio. Some use a step-down ratio of 11.4:1, or 18:1, or some other ratio. These three are the most common, but are not the only ratios used. Some use step-down ratios as high as 25:1 and 30:1, but these are unusual. A few extreme cases use a step-down ratio as high as 50:1.

The step-down ratio is of little concern to a serviceman, other than the fact he must know the transformation ratio when it becomes necessary to install a replacement output transformer. That ratio must be observed. Fortunately, technical manuals either provide the step-down ratio, or provide the exact model number of a universal transformer which can be used as a replacement.

The exact step-down ratio necessary in any given receiver depends on the type of power tube used as the vertical output amplifier, and upon the type of deflection coil used with the tube. Here again, the manner in which that ratio is calculated and determined is a problem for an engineer, not for the serviceman.

Some idea of the internal construction of universal replacement transformers is given in Fig. 11. There are three connections to the primary of the transformer, and two to the secondary.

This transformer could probably be used to replace either a two-winding transformer or an auto-transformer when the step-down ratio is either 10:1 or 11.4:1. These are the most frequently encountered step-down ratios.

When the primary connection is made to terminals X-1 and X-3 and the secondary circuit is connected to terminals Y-1 and Y-2, the step-down ratio would be 11.4:1. If the primary is connected to terminals X-2 and X-3 the step-down ratio would be 10:1.

If the windings are used separately the transformer would replace any two-winding vertical output transformer which has a step-down ratio of either 11.4:1 or 10:1. By tying terminals X-3 and Y-1 together it can be used to replace any original auto-transformer having either of those step-down ratios.

Thus, a single universal replacement transformer can be used to replace four different types of original transformers. These four types are the ones most frequently encountered in actual service work.

Some universal replacement transformers have one or more additional taps on the primary. This makes it possible to use them as replacements for even more types of original transformers.

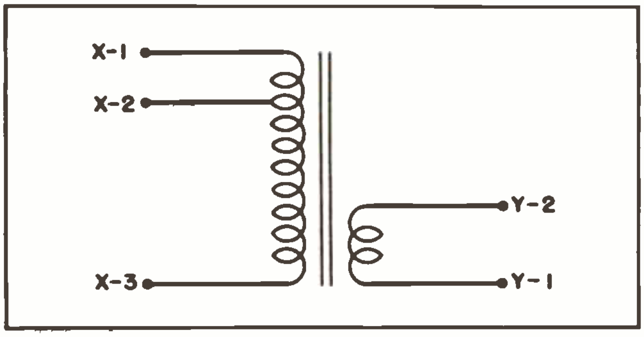

Figure 11. Terminal connections on universal replacement transformer.

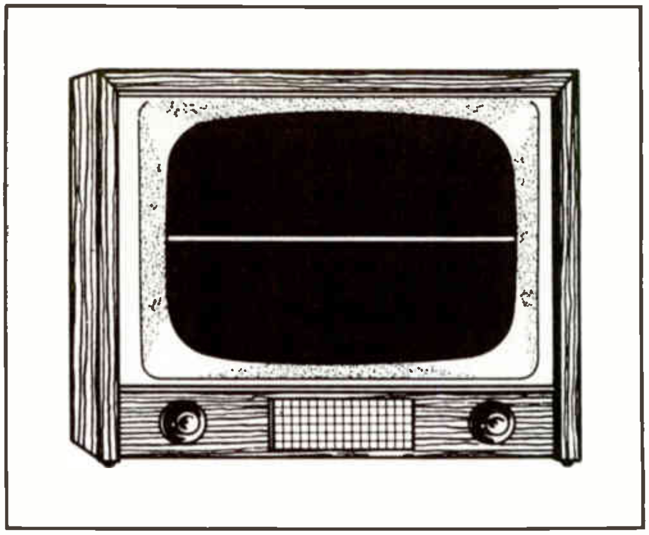

Figure 12. Pattern on screen when there is no vertical deflection.

If, after replacing a vertical transformer, the picture is upside down, it is because the transformer has been connected wrong. Either the primary connections or the secondary connections should be reversed. But not both.

Section 11. SYMPTOMS OF A DEFECTIVE OUTPUT TRANSFORMER

Whenever something serious goes wrong in the vertical deflection system it often happens that all vertical deflection ceases. The electron beam continues to move from side to side in the picture tube, but there is no vertical movement.

When that happens there is a single bright line horizontally across the screen of the picture tube. The pattern on the screen is like that in Fig. 12.

The reason the pattern is as shown in Fig. 12 seems reasonably evident. The electron beam continues to move back and forward horizontally. It continues to trace a repeated line over the same horizontal path, thus keeping it bright. But the beam does not touch any other part of the screen area because the vertical deflection system no longer moves the beam above or below that single horizontal line.

A pattern such as that in Fig. 12 clearly indicates the trouble is located in the vertical deflection system, but does not necessarily point out the exact source of the trouble. It might be a defective tube, an open or short-circuited capacitor, an open resistor, or something else. It might even be a defective output transformer.

Defects in the vertical output transformer do not occur so frequently in modern receivers as in earlier models. The insulation in some earlier models was not as good as it should have been and there was much trouble with short-circuited windings, and with grounded windings.

A glance at the circuits around a vertical output amplifier, and the output transformer, does not always disclose the true nature of the sharp peak voltages which are often present. Nevertheless, peak voltages during the retrace action frequently build up higher than 1000 volts.

Current from the output power amplifier builds up slowly to a peak during the trace interval of the vertical sweep cycle. Suddenly, at the instant the beam reaches the bottom of the screen, that current stops flowing.

During the interval in which that current is building up there is also a magnetic field building up in the space surrounding the coil windings, and in the iron of the transformer core. Comparatively speaking, that is a strong magnetic field.

When the current suddenly ceases to flow at the end of the trace period that magnetic field suddenly collapses. When it suddenly collapses the magnetic lines of force cut back across the windings of the primary, cutting across them at high speed, thus inducing a sudden peak voltage.

This action is almost identical to that which takes place in the induction coil of an automobile to generate the necessary high voltage needed to jump the gap in the spark plugs. A high voltage is desirable in an automobile spark coil, but in the vertical transformer of a television receiver the peak voltages often do more harm than good.

Engineers apparently did not fully appreciate the magnitude of these peak voltage surges when they designed the early model television receivers. Transformers which were frequently used could not long stand up under the peak voltage pressures, and often broke down the insulation after the receivers had been in operation for a period of time. Once that happened there was no solution except to remove the old transformer and install a new one.

This weakness has been pretty well overcome in later model receivers. Vertical transformers do not break down nearly so frequently as was formerly the case. But the fact remains that they do sometimes break down. When that happens there is no satisfactory repair except to replace the transformer.

Defects in the vertical output transformer make themselves known in several ways. Much depends on the exact nature of the defect.

If the insulation breaks down so badly that one or both coils are short-circuited to ground it may burn out the power amplifier tube, and will probably kill the vertical sweep. In that case there will be the familiar horizontal line on the screen, as shown in Fig. 12.

When that symptom appears the first job is to discover just what is wrong. It may be the transformer; it may be something else.

Before going to the trouble of replacing the transformer it is well to first try a new set of tubes, and make other voltage and resistance measurements. It is easier to make these changes first than replace the transformer.

But if the tests do not correct the trouble it is a safe bet the transformer is defective. Sometimes it is possible to make specific tests of the transformer which disclose the trouble. This is especially true if the transformer windings are open, or completely short-circuited or grounded.

Quite often the transformer is defective, yet neither resistance nor voltage checks reveal the defect. This is because the insulation between the windings has been punctured by high-voltage peaks, but the metal of the wires where the insulation is bad is not in contact with each other; and is not short-circuited to ground.

Ordinary voltages can be applied to the windings and everything appears normal. Even normal B+ voltages, and operating voltages can often be applied, yet everything checks all right. But the high-voltage peaks continue to arc across from one winding to another through the punctured insulation. And when they arc across they create disturbances in the pattern on the picture tube.

The exact nature of the disturbances in the

Figure 13. Foldover at bottom of pattern caused by defective vertical transformer.

picture pattern differ from one receiver to another, and differ further as a result of differing types of defects. In many cases there is a fold-over at the bottom of the picture. The pattern in Fig. 13 is typical of those which often appear when the vertical transformer is defective.

A fold-over, such as that in Fig. 13 can be caused by other circuit defects. It can be caused by leakage across the coupling capacitor in the grid circuit of the output amplifier. But a common cause is a defective transformer.

The exact nature of the defect in the transformer usually determines the exact pattern which appears on the screen. Sometimes the

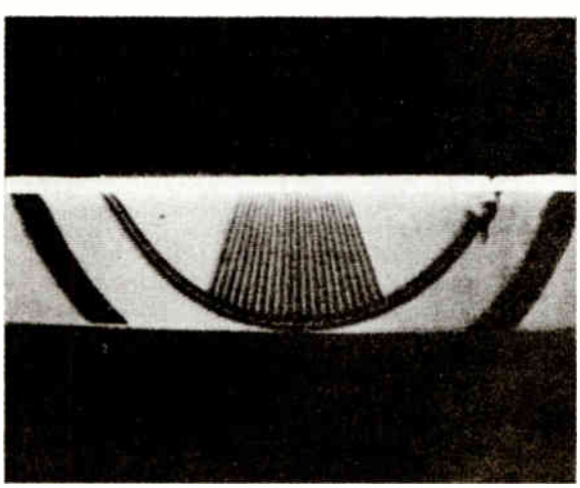

Figure 14. Pattern caused by defective vertical transformer.

pattern is foreshortened as much as that which is shown in Fig. 14. Sometimes the pattern is nothing more than a horizontal line like the one shown in Fig. 12.

Section 12. MODIFIED SAW-TOOTH WAVEFORMS FOR INDUCTIVE LOADS

Earlier in this lesson we said that when working with electrostatic deflection picture tubes we could apply pure saw-tooth waveforms to the final voltage amplifier, but the signal would have to be modified when working with inductive loads.

When working with magnetic deflection picture tubes the load on the output amplifier is inductive. This is because the deflection yoke coils have inductance as well as resistance.

Current can be caused to flow in an inductive load so its rise and fall can be graphed in the familiar saw-tooth pattern. But the driving voltage on the output amplifier tube must be modified, and the voltage directly behind the current in the load must be modified.

To better understand the problem which confronts us in a case of this kind let us examine the action in a circuit when a voltage causes a current to flow.

You will recall from our earlier lessons that when a sine-wave voltage is applied to a pure inductance the current does not immediately rise in phase with the voltage. On the contrary, the current lags 90° behind the voltage.

That is the case when the voltage is applied to a pure inductance. When the inductance contains some resistance the situation changes somewhat. There is some degree of lag, but it is not a full 90°.

If the applied voltage is in the form of a square-wave the current in a pure inductance will rise in a linear manner. If the square waves are separated by short, sharply negative, pulses, the current in the inductance can be forced to flow in the form of a saw-tooth current.

The graph in Fig. 15 shows this action a little more clearly than words alone. The sharply rising voltage at the leading edge of the square-wave acts to begin overcoming the inductance immediately, instead of later as in the case of a

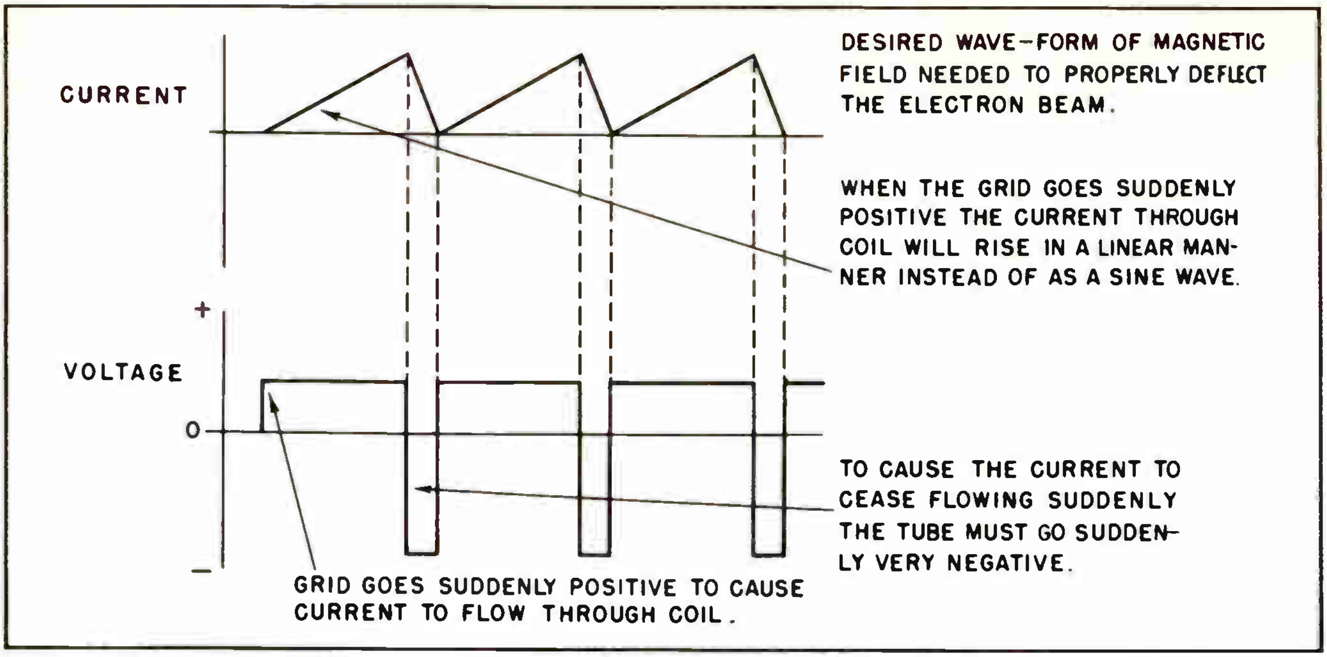

Figure 15. Current through inductance can be caused to flow in saw-tooth form by applying square-wave voltage.

sine-wave voltage. Even the sharply rising square-wave voltage does not immediately overcome all the reactance of the inductance, but it does force some current to begin flowing.

After the square-wave *voltage* has risen to its peak, then maintains a stable level, the *current* will continue to rise in a linear manner.

If a saw-tooth current waveform is desired, as is true in television, the voltage must go sharply negative at the end of the square-wave. It must go negative far beyond the zero level.

The principal point which concerns a service technician is the fact that a square-wave voltage can force current through a pure inductance and cause it to flow in the form of a saw-tooth waveform.

But a pure square-wave is not enough in the case of television deflection circuits. The deflection circuits contain much inductance, but they also contain a considerable amount of resistance. This must be considered when designing the voltage waveform for driving a power amplifier in a deflection circuit.

Fortunately, this can be done by adding a saw-tooth voltage waveform to the square-wave voltage wave. Fig. 16 shows how this is done, and what is accomplished. The bottom of Fig. 16 shows the resultant waveform which is actually applied to the control grid of the output amplifier to force the current to flow in the inductive deflection circuit in a way necessary to sweep the electron beam in a linear manner.

You might find it interesting to compare that voltage waveform with those shown on the diagram in Fig. 6. The voltage waves shown in Fig. 6 are those that are seen on the screen of an oscilloscope when those waveforms are being studied.

If you have access to schematic diagrams of actual television receivers you will find it interesting to observe the voltage waveforms at various locations in the vertical and horizontal deflection systems, then compare those with the waveform at the bottom of Fig. 16.

The voltage wave actually present on the grid of the output amplifier in any given receiver may vary somewhat from that at the bottom of Fig. 16. The variations are accounted for by the fact that some deflection systems have more inductance than others, while some have more resistance.

The waveform in any given receiver is that which has been determined as being best for that

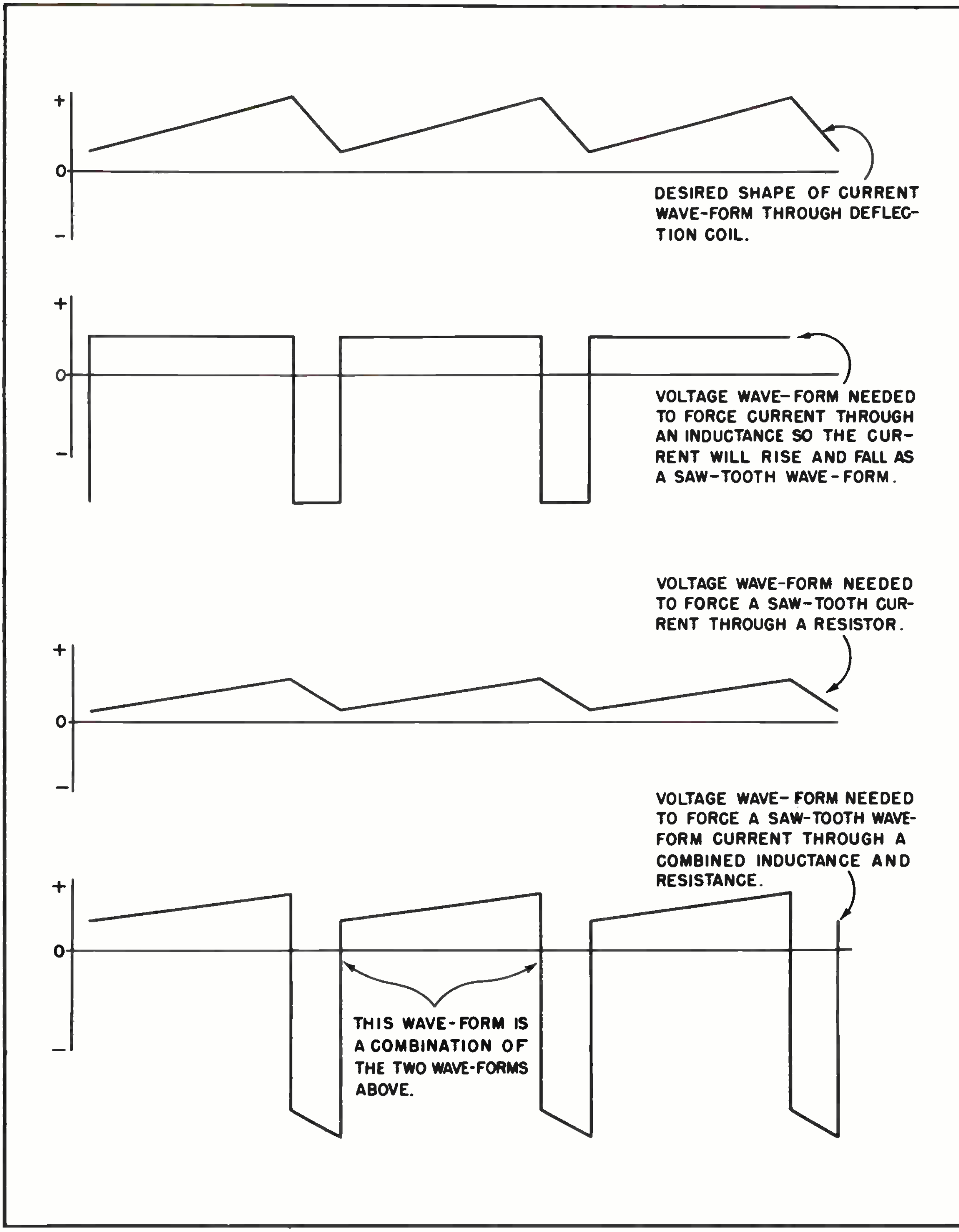

Figure 16. Saw-tooth voltage is combined with square-wave voltage to force current through deflection circuit as saw-tooth wave.

particular receiver. The exact shape of the wave depends on the resistance in the circuit, the inductance, the type of amplifier tube, length of the leads, and other items!

It is because the waveforms vary somewhat in the circuits of one receiver from those in other receivers that technical manual publishers include that information in the technical manuals. It is also the reason manufacturers include that information in the manuals for each of their receivers.

By checking the waveforms in any given part of the deflection circuits on an oscilloscope, then comparing the waveform on the scope with those in the technical manual, a service technician can determine if there is any serious defect in the circuit, or if he should look elsewhere.

There are various ways in which the waveform can be shaped to fit the need. Probably the most simple is to include a resistor in series with the discharge capacitor.

You will recall that we have already explained how the charging and discharging of the discharge capacitor can be used to generate a sawtooth wave. That is all very true, and is exactly the way the waveform is usually generated in electrostatic deflection circuits.

But in magnetic deflection systems it is necessary to shape the driving voltage waveform so it resembles the one at the bottom of Fig. 16. That is done by adding a resistor in series with the discharge capacitor, connecting it between the capacitor and ground, as shown in Fig. 17. A saw-tooth wave is generated across the capacitor, while a square-wave voltage is generated across the resistor. Combining the two creates the proper waveform voltage for driving the output amplifier.

When that voltage wave is applied to the grid of the vertical output amplifier the current through the deflection coils rises and falls in a sawtooth manner.

Section 13. SHOCK OSCILLATIONS AND DAMPING CIRCUITS

By their very nature, the deflection circuits in a magnetic deflection system are highly inductive. This is because of the coils and other windings present in the circuit. Something of the nature of the output circuits in a magnetic deflection system is shown in Fig. 18.

The deflection coils in the deflection yoke have inductance. So do the secondary windings of the output transformer. In some cases other coils are deliberately inserted in the circuit to create special effects.

During the retrace action high voltages build up in those coils due to the sudden changes in the magnetic fields resulting from the sudden reversal of the current. Those peak voltages sometimes set up oscillating currents as a result of the

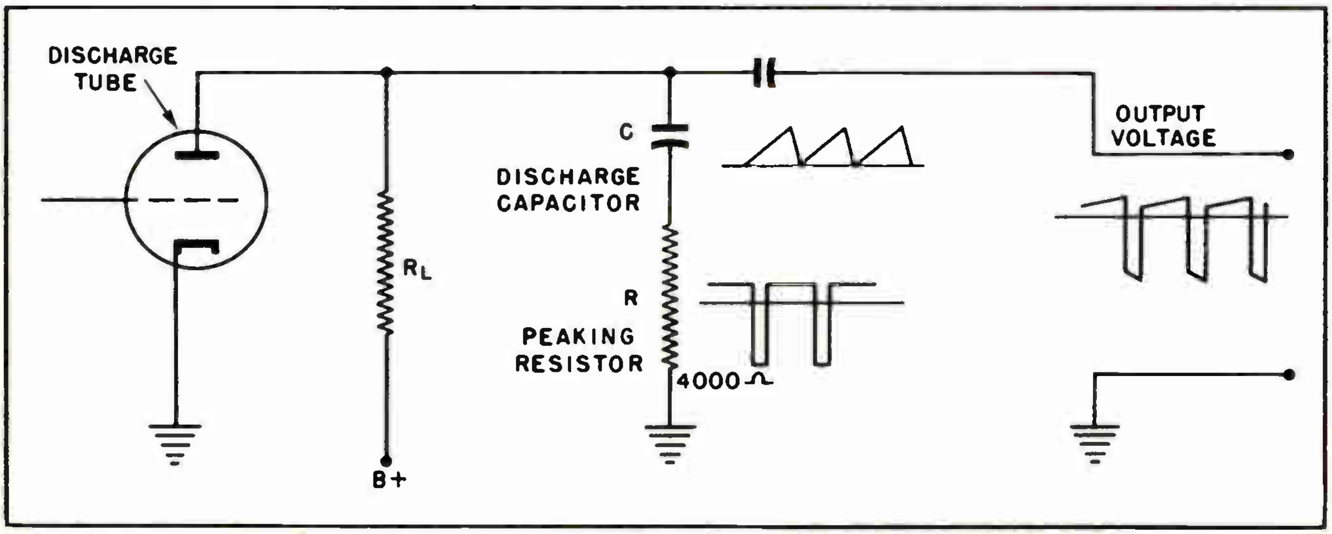

Figure 17. Combining voltages across resistor and capacitor to develop correct waveform for driving output amplifier.

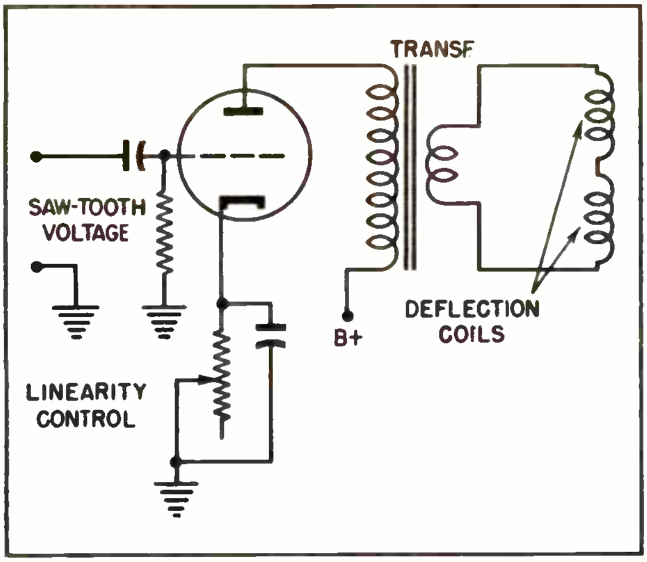

Figure 18. Output deflection circuits.

shock action, and this results in non-linear operation of the sweep.

It is necessary to damp out those oscillations before they get started, or the pattern of the picture on the screen is distorted.

Different methods are used to damp those oscillations in the vertical and horizontal circuits. In horizontal circuits it is necessary to include a special "damper tube" and capacitor because of the relatively high frequency involved.

Damping is much more simple in vertical deflection circuits. It can usually be accomplished by merely connecting a resistor across the deflection coils, as shown in Fig. 19.

The rapidly decaying magnetic field around the deflection coils during the retrace action is what sets up shock oscillations. The shock oscillations start with a high amplitude, but decay rapidly because, after the initial shock, there is nothing to keep them going. The graph in Fig. 20 shows the shape the shock oscillations would take if nothing is done to stop them.

The trouble is that the shock oscillations, if not damped out, affect the deflection coils. They act to set up peculiar effects in the pattern of the picture on the screen. Often the picture is seriously compressed and distorted at the top.

Presence of a resistor across the deflection coils, as shown in Fig. 19, provides a circuit for the currents set up by the induced voltage in the deflection coils. Current caused to flow by the high voltage induced in the deflection coils flows through the resistor, where the oscillations are rapidly damped out.

Present tendency is to place a separate resistor across each half of the vertical deflection coils instead of a single resistor across both sections of the coils. Figs. 6 and 7 show the manner in which such resistors are connected across the individual windings of the vertical deflection coil.

The resistors shown in Figs. 6 and 7 have a resistance of 560 ohms each. That is a value commonly used. Probably at least half of all television receivers using magnetic deflection use damper resistors of 560 ohms each.

But other values of resistance can be used.

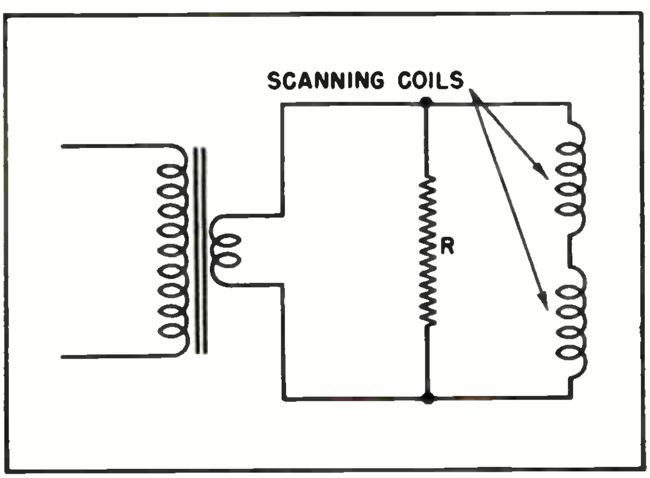

Figure 19. Resistor across deflection coils damps out shock oscillations.

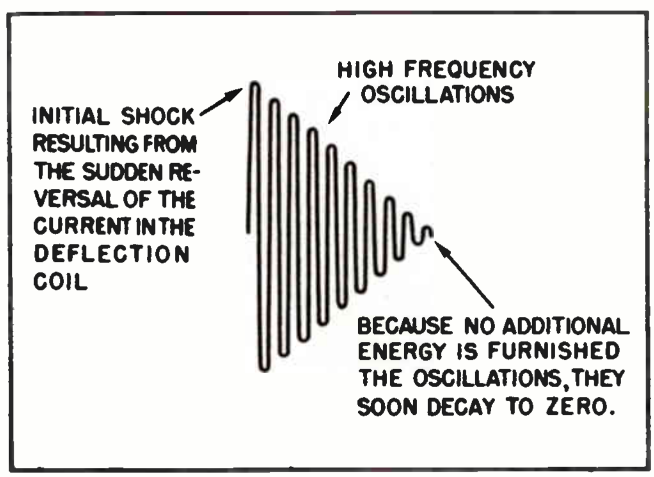

Figure 20. Shock oscillations set up by sudden reversal of sweep current.

Some receivers use 1200-ohm resistors, others use 2200-ohm resistors. Still other values are used in other receivers.

Designers try to use values of resistance high enough to prevent serious shunting of the current from the deflection coils during the trace action, yet low enough to permit current to flow through them when the magnetic field collapses.

This is not a problem for a technician to worry about. Should one of the resistors become defective, all a technician needs to do is replace the defective resistor with another of similar value. But it is well to know why the resistors are used, and why those values of resistance are chosen.

In some TV receivers the vertical damping resistors are mounted under the chassis, and so connected electrically as to be shunted across the deflection coil. This method was used most widely in earlier model receivers.

Present tendency is to connect the resistors directly across the terminals of the deflection yoke windings. Usually the resistors are covered by the outer protective covering of the deflection yoke when it is in place. When that is done the resistors cannot be seen unless the covering is removed from the deflection yoke to expose the resistors.

Fig. 21 shows the cover partially removed to expose one of the damping resistors and show how it is connected across a pair of terminals on the deflection yoke. Only one resistor is shown in Fig. 21. The other damping resistor is on the opposite side of the deflection yoke.

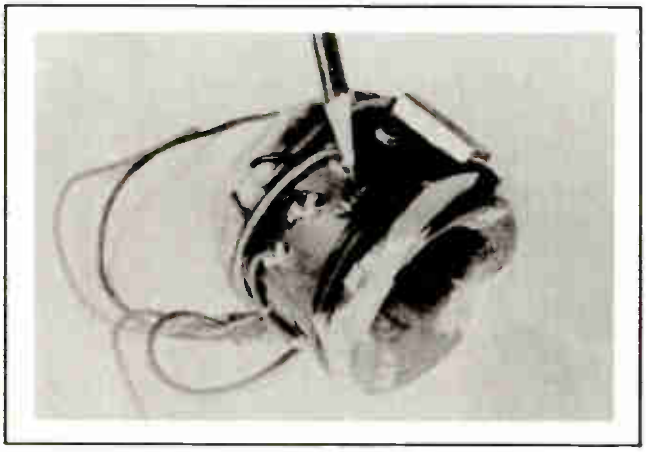

Figure 21. Damping resistor across terminals of one vertical coil on deflection yoke.

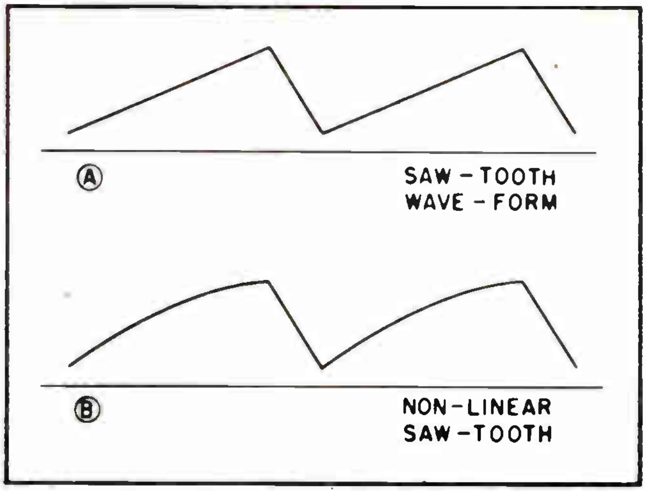

Figure 22. Linear and non-linear saw-tooth waveform.

Section 14. LINEARITY CONTROL

Despite all the precautions which can be taken by the designer, there always arises the possibility of non-linear action in the movement of the electron beam inside the tube. In most cases of non-linear movement the beam moves downward quite rapidly from the top of the screen, then slows as it moves toward the bottom.

The practical effect of this non-linear movement is for the upper part of the picture to be stretched out of proportion, while the lower portion is compressed. This causes characters in the picture to have long heads and short legs. Other objects are similarly distorted.

This non-linearity of beam movement is caused by non-linearity in the saw-tooth waveform. Instead of the saw-tooth wave rising linearly, as at *A* in Fig. 22, it rises in the manner shown at *B* in Fig. 22.

To compensate for possible linearity distortion in the saw-tooth wave, it is a customary practice to include a linearity control in the vertical deflection system. The linearity control can take any of several forms. But the most simple, and the one most widely used, is a simple potentiometer in the cathode circuit of the output amplifier tube. Usually the potentiometer is connected to act as a rheostat. The output amplifier circuits in Figs. 6 and 7 and 18 makes this rather clear.

If the saw-tooth wave used to drive the output amplifier has a linear rise, and is not distorted, the amplifier tube is caused to operate on the linear portion of its characteristic curve. This is the manner we usually consider the normal operating position. It is shown graphically in Fig. 23.

It is no secret that feeding a linear signal into an amplifier tube when that tube is operating on the non-linear portion of its characteristic curve results in distortion. This has been mentioned many times in previous lessons.

But for the purpose of review, so you will fully appreciate the action at this time, we have prepared a graph of the amplifying action when a tube is operating into the lower "knee" of its characteristic curve. This is shown in Fig. 24.

The signal is linear when fed into the amplifier tube. But it is non-linear at the output of the tube.

This distortion is caused by various amplitudes of the signal being amplified by varying percentages of amplification, rather than all original amplitudes being amplified by the same percentage. The lower amplitudes of the original signal are amplified to a lesser degree than the higher amplitudes of the original signal.

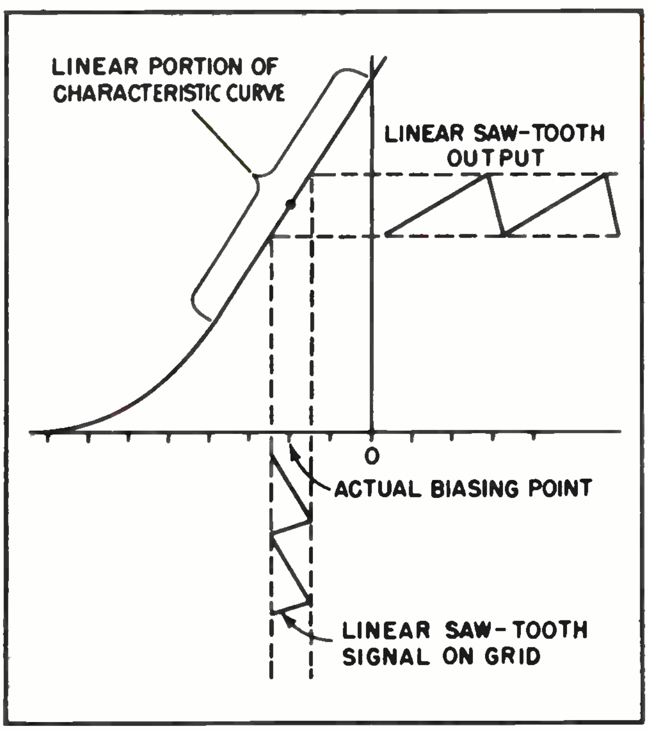

Figure 23. Using linear portion of characteristic curve to amplify linear saw-tooth signal.

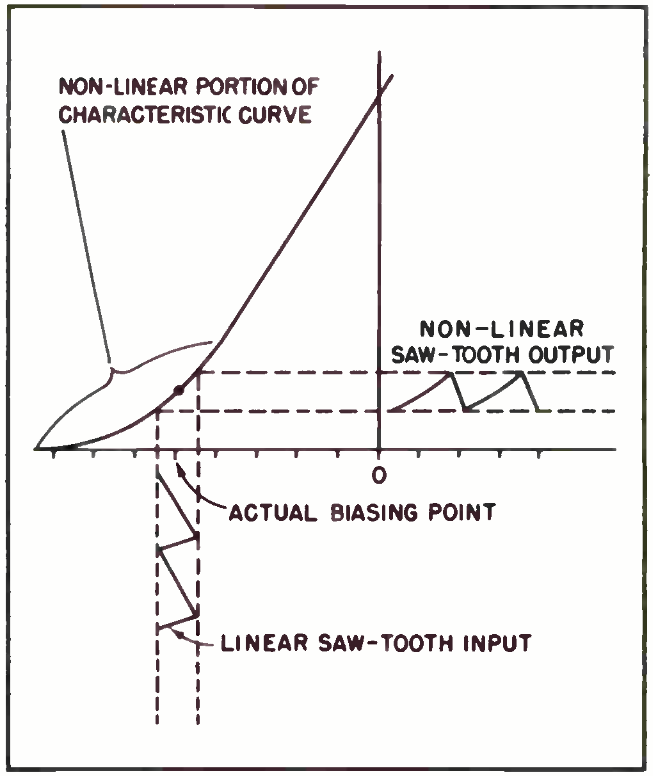

Figure 24. Distortion results when a tube operates into "knee" of characteristic curve.

This distorting action of the amplifier tube, when operating into the non-linear portion of the characteristic curve, can be used to correct the distortion in a supposedly linear signal which is not actually linear. This can be said another way. If a signal is supposed to have a waveform like *A* in Fig. 22, but actually is like *B*, the distortion can often be corrected by introducing a counter-distortion in the amplifier. This is done by deliberately operating the amplifier tube into the lower "knee" of its characteristic curve.

The graph in Fig. 25 shows how a distorted saw-tooth signal, like the one at *B* in Fig. 22, is introduced into an amplifier which is operating into the lower "knee" of its curve. The counter-distorting action of the amplifier restores the original linear saw-tooth waveform needed.

The operating point on the characteristic curve at which an amplifier works is controlled by the amount of biasing on the control grid. The amount of negative bias on the control grid is controlled by the amount of resistance in the cathode resistor of the tube. When the cathode resistor is made variable as in Fig. 18, the variable resistor acts as a *linearity control.*

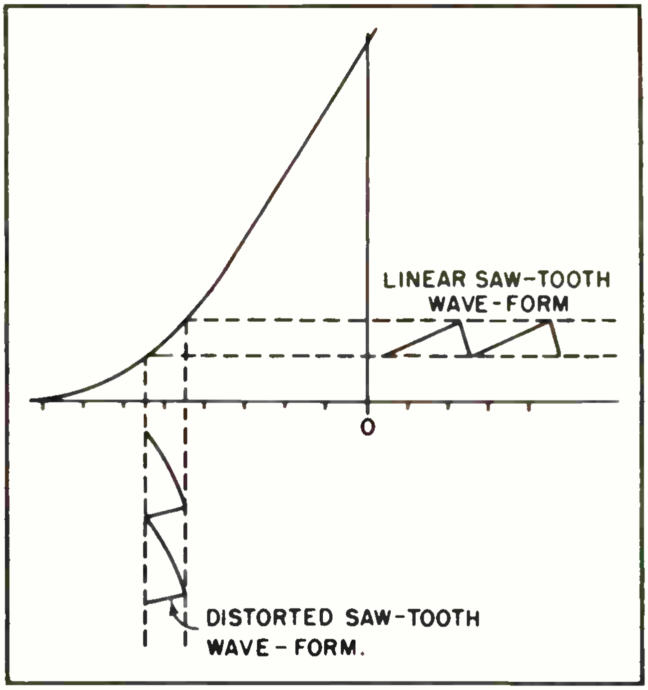

Figure 25. Counter-distortion during amplification can restore linearity to distorted waveform.

Section 15. HEIGHT CONTROL

The circuit diagrams in Figs. 6 and 7 show a variable resistor in the anode circuit of the vertical oscillator tube. This resistor is called the *height control.* Its purpose is to control the magnitude of the saw-tooth signal which is used to drive the output amplifier.

In a previous section of this lesson we mentioned that the 0.1 mfd. capacitor would charge up with a voltage through the 2.7 megohm fixed resistor and the 2.5 megohm variable resistor. The charging voltage is supplied by the B+ power supply.

The speed with which the capacitor charges is controlled by the capacity of the capacitor and the resistance of the two resistors.

The capacitor is discharged each time the oscillator tube conducts.

The action goes something like this: — when the tube conducts it supplies plenty of electrons to the capacitor, thus equalizing the charge across it. Since the tube conducts only in a series of pulses, its conduction period does not last long.

As soon as the tube ceases conducting the B+ power supply voltage begins removing electrons from the capacitor, and thus begins restoring a charge to it. The rate at which electrons are removed from the plate of the capacitor to build a charge is determined largely by the resistance in the anode circuit.

The resistance in the anode circuit, and the capacity of the capacitor are carefully calculated by the designer so the charge on the capacitor becomes just positive enough during each trace movement of the sweep cycle to cause the output tube to pass enough current to move the electron beam all the way to the bottom of the screen of the picture tube.

Too much resistance prevents the capacitor from obtaining high enough positive charge to cause the beam to move all the way to the bottom of the picture tube before the oscillator tube conducts for the next retrace to return the beam to the top of the screen. This means the picture does not reach all the way to the bottom of screen.

Insufficient resistance, on the other hand, permits the capacitor to become too positive too soon, thus sweeps the electron beam beyond the bottom of the screen. This action causes part of the lower picture to be lost.

By including a *height control* in the vertical oscillator circuit it is possible to adjust the resistance in the anode circuit so the height of the picture can be controlled. This makes it possible to "pull" the picture down to the bottom of the screen if there is a tendency for part of the screen to be black and unused at the bottom.

It also becomes possible to adjust the height control in the other direction if there are symptoms that part of the picture is being cut-off at the bottom because the beam is sweeping beyond the bottom of the screen.

Section 16. RESPECTIVE EFFECTS OF LINEARITY AND HEIGHT CONTROLS

From a strictly technical point of view the linearity control and the height control act to bring about differing types of action. One acts to improve the linearity of the sweep, while the other acts to control the height of the picture.

Because of their practical effects on the raster on the screen of a picture tube, television technicians tend to look upon the two controls in a slightly different manner. Because the linearity control tends to act upon the upper picture, and because it has considerable effect on raising or lowering the upper edge of the raster, service technicians have come to look upon the linearity control as being one which affects the upper part of the picture. This includes regulating the height of the upper part of the picture.

In the same way, they have come to look upon the height control as affecting only the lower part of the picture.

Because of these factors, service technicians have come to look upon the linearity control as being an adjustment of the raster height at the top of the screen, and the height control as affecting the height of the raster at the bottom of the screen. From a purely practical point of view their attitude toward these controls is well taken.

In most receivers the vertical linearity control and the height control are located on the back panel of the chassis. In a few cases they are positioned differently, but that is where they will be found in fully 95% of all TV receivers, and it is probable the percentage is even higher than that.

Section 17. VERTICAL HOLD CONTROL

A variable resistor in the grid circuit of the vertical oscillator in the circuits shown in Figs. 6 and 7 is designated as the *vertical hold control.* The principal purpose of this resistor is to control the frequency of the vertical oscillator.

Because it is necessary for the vertical oscillator to have a free-running frequency slightly below the 60-cycle frequency of the vertical sync pulses, if the receiver oscillator is to be synchronized with the camera sweep circuits, it is necessary to have a control to adjust the frequency of the vertical sweep oscillator. The frequency of the vertical oscillator is adjusted so it is slightly lower than the sync pulse frequency. The sync pulses then trigger the vertical oscillator at the end of each cycle, and thus maintain synchronism.

Probably the most convenient method for controlling the free-running frequency of the vertical oscillator is to control the resistance in the grid-

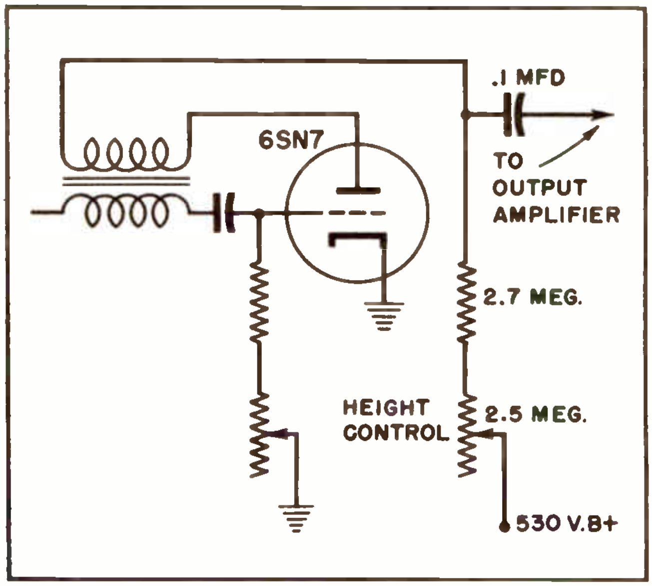

Figure 26. Vertical height control circuit.

return resistor. This adjusts the level of the grid bias voltage since the oscillator almost invariably depends on self-biasing for the bias voltage.

Increasing the resistance of the grid return resistor increases the time/constant of the circuit, thus slowing down the frequency of the oscillator. By the same token, reducing the resistance in the grid-return resistor reduces the time/constant of the circuit, and this raises the free-running frequency.

Not all receivers use exactly the same methods to control the frequency of the vertical oscillator, but the one shown in Fig. 27 is probably the most common. The circuit is simple, and it is reliable.

The frequency of a blocking oscillator, such as the one used in Fig. 27, is controlled by the length of time needed for the negative bias to leak from the control grid of the oscillator tube to permit the beginning of a new cycle. The length of time required for the negative bias to leak off the control grid depends on the capacity in the circuit and the resistance of the grid-return resistor. One or the other should be variable.

At the frequency at which the vertical oscillator operates it is easier to install a variable resistor than a variable capacitor.

Therefore, the control element by means of which the free-running frequency of the vertical

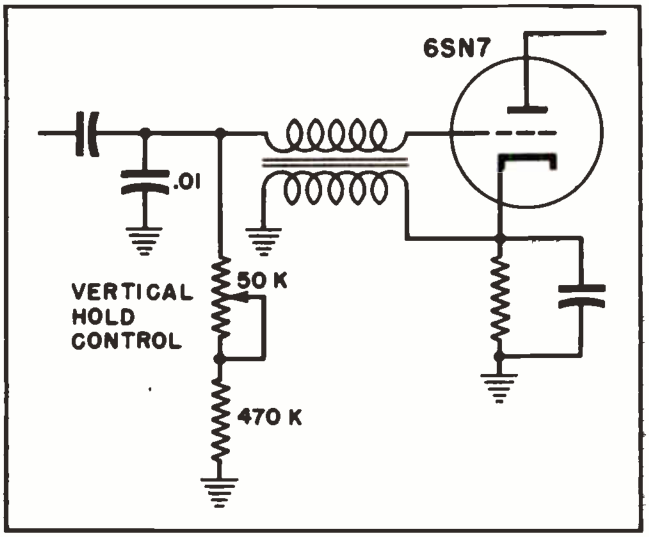

Figure 27. Vertical Hold Control.

oscillator is controlled is almost invariably a variable resistor. By adjusting the frequency of the vertical oscillator to that which is exactly right to permit the oscillator to synchronize with the sync pulses we provide a means whereby the vertical sweep is held in step with the camera sweep circuits.

Therefore, the frequency control variable resistor in the vertical oscillator is called the *hold* control, or more correctly, the *vertical hold control.*

Even though the vertical sweep oscillator in all television receivers must operate at the same frequency it does not follow that the resistance of the vertical hold control will always be exactly the same in all receivers. Other factors enter into the choice of the exact amount of resistance needed by a given circuit.

The voltage on the anode of the oscillator tube is an important factor. When the B+ supply voltage is high the resistance of the vertical hold control must be greater than when the anode voltage is lower — provided the other controlling factors do not change.

The amount of capacity in the grid circuit also has an important effect on the amount of resistance in the hold control resistor. If the capacity is high the resistance can be less than when the capacity is low. Different types of tubes require different values of resistance.

These things are not factors immediately concerning service technicians. The values of the resistance and capacity in the grid circuit of any given vertical oscillator have been calculated by the design engineers at the factory. If any of the components become defective all a technician has to do is replace the original with another of similar value.

Nevertheless, the reasons why there are variations in the values of resistance in the grid circuits of vertical oscillators from one model receiver to another is a convenient bit of information for a service technician to know. By understanding the reason why each particular value has been selected for the original circuit one is given a better insight into the operation of the circuit.

Section 18. SERVICING VERTICAL SWEEP SYSTEMS

Operating defects in the vertical sweep circuits are usually quite easy to detect. Either the vertical deflection system is completely dead, or it is only partially effective. In either case existence of the defect is clearly evident through observation of the pattern on the screen.

If the circuit is completely dead there is no deflection at all. In that case the symptom is a single horizontal bright line, like that in Fig. 12.

When there is no sweep at all, the prime suspect is one or the other of the vertical tubes. It is a pretty good bet that either the vertical oscillator tube, or the vertical amplifier tube, has gone bad and must be replaced. Replacing one, or both, of the vertical tubes clears up the trouble in about nine out of ten cases.

When a single tube acts as both the oscillator and the amplifier the replacement job is even more simple. Replacing the single tube nearly always clears up the trouble.

Occasionally the trouble cannot be cleared up by replacing the tubes. In that case there is usually some other defective component in the vertical circuit. Such trouble is usually located in the amplifier tube curcuits, or the coupling from the oscillator. If the coupling capacitor between the oscillator tube and the amplifier tube is open it is impossible for the saw-tooth signal to reach the grid of the amplifier tube. In that case the amplifier tube is not working, and there is no vertical deflection.

Such trouble must be sought out with a V-O-M or multimeter, just as similar defects must be sought out in any other kind of electronic amplifier circuit.

There is also the possibility the output transformer has become defective, and will have to be replaced. The transformer will have to be checked to determine its condition. If there is no vertical deflection at all, and the trouble is traced to the output transformer, it will usually be found that one of the transformer windings is open. That can be ascertained by using an ohmmeter, which acts as a continuity checker.

If there is full vertical deflection, but it is impossible to prevent the picture rolling upward or downward, the trouble may be traced to lack of a sync pulse for the oscillator tube, or to an excessively weak oscillator tube. It is more common for the oscillator tube to get so weak that it cannot be synchronized than for the tube to fail altogether.

When the oscillator tube becomes weak the only correction is to replace it with another known to be good. This is the same correction used to end trouble caused by a dead oscillator tube.

When the oscillator tube becomes weak it is unable to maintain its correct frequency. When that occurs it becomes impossible to synchronize the oscillator. That is what causes the picture to roll up or down.

If the picture cannot be made to reach all the way to the top of the screen, or all the way to the bottom of the screen, the trouble is usually a weak vertical amplifier tube. The only correction is to replace the amplifier tube.

Changing conditions in the oscillator and amplifier tubes bring about slow changes in the operation of the vertical deflection system. So long as the tubes do not become too bad the changes can usually be compensated by adjusting the hold control, the height control or the linearity control.

But when the tubes deteriorate still further, so it is no longer possible to compensate for the changes with the variable controls, it becomes necessary to replace the weak ones with new ones.

This condition is usually evidenced by finding one or more of the controls adjusted to the extreme end of the adjustment. When the tube becomes so bad it can no longer be corrected by adjusting the controls the only solution is to replace the tube.

Extreme adjustment also occurs when the B+ voltage is low. If both the vertical and horizontal circuits are affected the trouble may be in the power supply.

We can pretty well sum up this lesson with a relatively few remarks. Troubles in the vertical circuits show up quite clearly on the screen of the picture tube. The most common types of symptoms are:

1. Inability to make the raster stretch to the top of the screen, or to the bottom of the screen, or both.

2. "Foldover" of the picture at the top or the bottom.

3. No raster at all, only a single bright line horizontally across the screen.

4. Inability to prevent the picture rolling upward or downward.

These represent the overwhelming majority of symptoms shown on the screen when there is trouble in the vertical deflection system. In most cases the solution for the trouble is quite simple.

Inability of the raster to reach the top or bottom of the screen may be due to improperly adjusted *height* and *linearity* controls. If readjustment of those controls does not correct the trouble, the next most likely suspect is a weak output amplifier tube. Replacing the output amplifier tube with a new one will nearly always correct the trouble.

No raster at all may mean the oscillator tube is dead, or the output amplifier tube is dead. One or both should be replaced. If that does not correct the trouble the entire vertical deflection circuit should be checked with a V-O-M or multimeter to see what else may be causing the trouble. If the tubes are not bad, then one of the resistors, capacitors or transformers in the circuit must have developed a defect. The defect must be found and corrected.

Inability to prevent the picture rolling upward or downward indicates the oscillator tube is not synchronizing. In most cases the tube has become weak and must be replaced. Replacing the oscillator tube with a new one will correct this condition in fully nine cases out of ten.

If a new tube does not correct the trouble it is possible the sync pulses are not reaching the oscillator. The connection between the integrator circuit and the oscillator must then be checked, preferably with an oscilloscope, to see if the sync pulses are present at the input to the oscillator. If they are not, the integrator circuit must be checked to see where the sync pulses are lost.

If sync pulses are reaching the oscillator in good condition, and the tube has been replaced, the next step is to check the grid circuit of the oscillator to see if one of the resistors or capacitors in that circuit has changed value. This isn't a common occurrence, but it is not unknown. It does occur from time to time, and is always a definite possibility.

Before closing this lesson there is one other bit of advice we would like to pass along. We have mentioned this several times, but it is well worth mentioning again.

When a tube in a television receiver is suspected of being defective it should be replaced with another known to be good. This is by far the most effective way to check tubes in a television receiver. The results of a tube checker test cannot be relied upon, because tube checkers are not able to provide adequate information about some of the most important operating characteristics of tubes as they relate to television circuits.

However, merely replacing an existing tube with another known to be *new* is not *conclusive* proof the new tube is good. Requirements imposed upon some tubes used in television circuits, especially sweep circuits, are so critical that even a brand new tube is not always equal to the task placed upon it. Experienced television technicians make it a habit to try a new tube in place of the old one; then, if the new tube fails to work, they try another.

Most every experienced technician can recite experiences in which it has been necessary to try two or even three tubes before finding one that will work. This is especially true if the technician is using so-called "bargain" tubes. Experienced technicians rarely attempt to use such "bargain" tubes in television work, although they are often fully satisfactory in radio repair work.

NOTES FOR REFERENCE

Vertical sync pulses are used to "trigger" the vertical sweep oscillator.

The vertical deflection system consists of the vertical oscillator, the vertical amplifier, and the vertical deflection coils in the deflection yoke.

The integrator circuit can also be considered a part of the vertical deflection system.

Either a blocking oscillator or a multivibrator can be used as the vertical oscillator.

The vertical deflection system used in television receivers can be classified into two general groups: electrostatic deflection systems and electromagnetic deflection systems.

Electrostatic deflection is used in most oscilloscopes, and is used in some small portable television receivers and some early model, small screen, home receivers.

Electromagnetic deflection has virtually displaced electrostatic deflection in commercial television receivers.

Electrostatic deflection is rarely, if ever, found in receivers using picture tubes with larger than 10-inch screens.

Electrostatic picture tubes require an excessively high final anode voltage, and are excessively long, when built in screen sizes larger than 10 inches.

Electromagnetic deflection requires that a deflection yoke, consisting of a pair of vertical deflection coils and a pair of horizontal deflection coils, be placed around the neck of the picture tube.

Current from the vertical deflection system is forced through the vertical coils in the deflection yoke to create a varying magnetic field. That varying magnetic field acts to deflect the electron beam inside the picture tube in a vertical direction.

During the retrace action a relatively high voltage is built up in the deflection coils as a result of the suddenly collapsing magnetic field. That high voltage is dissipated through a pair of resistors connected across the two sections of the vertical deflection coils.

The resistors connected across the vertical deflection coils are called vertical damping resistors — resistance of these vertical damping resistors must be high enough so relatively little current can flow through them during the vertical trace movement, but low enough to permit current to flow through during the retrace action to permit damping.

Because the vertical deflection output circuit consists of both resistance and inductive reactance it is necessary to modify the shape of the saw-tooth driving voltage to force the current to rise in a linear manner.

The vertical output transformer nearly always has an iron core. It is similar in many respects to an audio output transformer used in radio receivers and audio amplifiers.

The vertical output transformer may have two separate windings, or it may be an anto-transformer.

When the vertical output transformer becomes defective it should be replaced with a new one. There is little advantage in trying to repair a defective transformer.

When replacing a vertical output transformer it is best to use an original replacement, if one is available.

In most cases an original replacement transformer is not available. It is then necessary to use a universal replacement transformer.

Universal replacement vertical output transformers are so constructed that they can be used with many kinds of television receivers. Manufacturers of universal replacement transformers provide wiring instructions with them to show how they can be used in varying situations.

If the picture is upside down after replacing a vertical transformer it is because the wiring of one winding has been reversed.

An upside down picture can be corrected by reversing the connections to the primary, or to the secondary. Do not reverse both sets of connections.

It is not wise to attempt to service the vertical section of a television receiver, other than replacing tubes, unless a technical manual covering that particular model is available.

If the raster appears to fold-over at the bottom or top of the raster it is a pretty good sign of a defective transformer. Nevertheless, it should be recognized that other conditions can produce the same, or similar, symptoms.

A defective vertical output transformer nearly always results from arcing inside the transformer windings.

Very high peak voltages build up inside the vertical output transformer during the retrace action. Unless the transformer windings are well insulated there is danger this peak voltage will break down the insulation.

Often a breakdown in the insulation in the transformer windings results in a direct short-circuit. When that occurs the defect can be easily detected by using a ohmmeter. More often, the breakdown in insulation is *not* followed by a direct short-circuit; instead an arc occurs only during the high-voltage peaks. Such defects are not so easily detected.

Sometimes a breakdown in the insulation inside a vertical transformer is such that an arc occurs only irregularly. In that case there is often a noticeable vertical "jiggle" to the raster. Often there is no definite test open to a service technician which discloses the cause of such symptom, but replacing the vertical transformer will cure it.

The *vertical hold control* is used to adjust the free-running frequency of the vertical oscillator so it is just slightly below that of the sync pulses from the transmitter.

The *vertical linearity control* affects the operating point of the characteristic curve on which the tube operates. Its practical effect is most noticeable at the upper part of the raster.

The *height control* affects the peak amplitude of the amplifier current, thus determining how far down the screen the raster is caused to go. Its practical effect is to adjust the bottom of the raster to make it reach the bottom of the screen.

Failure of the raster to reach all the way to the top of the screen, or all the way to the bottom, may be caused by improper adjustment of the height and linearity controls. If that adjustment is all right, the symptoms probably point to a weak amplifier tube. The only correction is to replace the vertical amplifier tube.

If the *vertical hold control* cannot lock the vertical oscillator into synchronism with the picture the oscillator tube is probably weak and should be replaced. If replacing the tube does not correct the trouble the circuits around the vertical oscillator should be checked to see if any component has changed value.

Failure of the vertical oscillator to synchronize, even after a new tube has been inserted, may be caused by a defect in the integrator circuit. This does not happen often, but is a possibility.

Sometimes there are symptoms which point to trouble in the vertical deflection system, but the real trouble is located elsewhere.

If the B+ voltage is low, due to a weak power supply, it will affect the vertical deflection system just as though the trouble was in the vertical circuits.

The voltages at the tube sockets of the vertical system should be checked as a routine action before starting major repairs in the vertical circuits. If there are symptoms of low B+ voltage, the power supply circuits should be checked first.

Correcting low B+ voltage often corrects trouble in the vertical circuits.

NOTES

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TELEVISION AND RADIO

Vertical Deflection Systems - Part I

Underline or fill in the ONE correct answer.

1. The vertical deflection system includes the:

   a. sync separator, integrator circuit, AFC phase detector, vertical coils in the deflection yoke and the vertical amplifier
   b. integrator, AFC phase detector, vertical oscillator, drive control and the damper tube
   c. integrator circuit, vertical oscillator, vertical output amplifier, and the vertical deflection coils in the deflection yoke
   d. drive control, integrator circuit, vertical oscillator, sync separator and the AFC phase detector.

2. The power amplifier used at the output of the vertical deflection system is very similar to:

   a. an IF amplifier
   b. an RF amplifier
   c. a video amplifier
   d. an audio output amplifier.

3. Advantages of electrostatic deflection include:

   a. more simple circuits, ~~all tube operating~~ elements are inside picture tube, no external focusing necessary, no external wire-wound yoke
   b. more simple circuits, shorter picture tube, simple deflection yoke, no external focusing
   c. longer picture tube, larger screen area, more simple circuits, simple deflection yoke
   d. shorter picture tube, larger screen area, simple circuits, no external focusing, no deflection yoke.

4. The vertical coils in a deflection yoke:

   a. are positioned so one is above and other below neck of picture tube
   b. deflect the electron beam from side to side on the screen
   c. are located on each side of picture tube neck so magnetic lines of force lie in horizontal plane
   d. are placed in front and behind the horizontal coils.

5. When the electrons in the electron beam pass through the magnetic field created by the vertical deflection coils:

   a. they are deflected upward or downward
   b. nothing happens unless the horizontal coils are also energized
   c. they are deflected in the same direction as the ions in the beam
   d. some are deflected upward and others downward, depending on polarity of the electrons.

6. A special blanking circuit is often connected between the vertical deflection circuit and one of the control elements inside the picture tube. Its purpose is:

   a. to prevent vertical blanking period lasting so long as to interfere with the picture
   b. of great importance in maintaining vertical synchronization
   c. to blank out the video signal during the vertical retrace
   d. to prevent the vertical retrace lines being visible on the screen.

7. When it is impossible to prevent the picture rolling upwards or downwards:

   a. the video amplifier is probably not passing the vertical sync pulse
   b. the vertical output amplifier tube is probably defective, and needs replacing
   c. it is an indication the vertical oscillator is not synchronizing
   d. the automatic frequency control circuit is probably not passing the sync pulse.

8. Whenever a tube in a television receiver is suspected of being bad:

   a. it should be checked on a tube checker
   b. there is a good possibility it can be reactivated, especially oscillator tubes
   c. the tube should be replaced with another known to be good
   d. exchange it with any of the other tubes in the receiver chassis.

9. When the vertical oscillator is not synchronizing properly:

   a. replace vertical output transformer since it cannot be checked while in the chassis, and most other tests are not reliable
   b. trouble can usually be traced to a weak oscillator tube, or failure of vertical sync pulse to reach the vertical oscillator
   c. because of frequencies involved, it is almost impossible to check for vertical sync pulses by using an oscilloscope
   d. one of the damping resistors across the deflection coil may be open.

10. There are a number of typical symptoms which point unerringly to trouble in the vertical deflection system. Which of the symptoms below is NOT an indication of trouble in the vertical circuits?

   a. inability to make the raster stretch to top of screen
   b. inability to make the raster stretch to bottom of screen
   c. "foldover" of the picture at the top of screen
   d. "foldover" of the picture at the bottom of screen
   e. heavy diagonal bars across the face of the screen
   f. no raster at all, only a single bright line horizontally across the screen
   g. inability to prevent the picture rolling upward
   h. inability to prevent the picture rolling downward.

1. Among the items included to assemble the TV kit we send our graduates at the end of this course is a 1500 mmfd. capacitor used as an RF by-pass in the video amplifier section. Due to the fact all capacitor manufacturers do not follow the same method of marking the rating on their capacitors sometimes a student is unable to find a capacitor rated at 1500 mmfd.

   Whenever that happens we always have capacitors marked 0.15 mfd.; 0.015 mfd.; 0.0015 mfd; and .00015 mfd. Could any of these capacitors be used in place of the 1500 mmfd. needed, and if so, which one? yes - .0015 MFD
   ______________________________.

2. During recent years a new method of marking small value capacitors with colored dots has come into use. When a 6-dot coded marking has a white dot in the upper left-hand corner -- the first dot -- what does that white dot signify? ______________________________

3. When a 6-dot color coded marking has a black dot in the upper left-hand corner -- the first dot -- what does that signify? ______________________________
   ____

4. It is technically possible to control the frequency of the vertical oscillator in several ways. Probably the method most widely used is:
   a. a potentiometer in the cathode circuit of the oscillator
   b. a variable coupling capacitor between the oscillator and amplifier
   c. some form of variable inductance across the output transformer
   d. variable resistance in the grid-return circuit of oscillator.

5. From a purely technical point of view it is possible to mount the vertical damping resistors in a variety of locations. For the sake of convenience, the present tendency is to:
   a. locate them on a terminal board under the chassis
   b. connect them directly across the terminals of the deflection yoke
   c. place them across the solder lugs on the vertical hold control

6. When insulation in vertical output transformer breaks down to permit arcing:
   a. it is easy to check the condition by using an ohmmeter
   b. there is no satisfactory repair except to replace it with a new one
   c. it rarely interferes with the appearance of the picture
   d. there is usually a foldover at the left side of the screen.

7. Because of the practical effect on the raster, most technicians regard the HEIGHT control as affecting:
   a. the frequency of the vertical oscillator
   b. the top of the raster more than the bottom part
   c. the compression or expansion of the central part of the raster
   d. the lower part of the picture.

(over)

8. The frequency of a blocking oscillator is controlled by:

   a. length of time needed for negative bias to leak off control grid to permit beginning of new cycle
   b. varying the value of the cathode resistor
   c. varying the coupling between the two windings on the transformer
   d. voltage on the screen grid.

9. The vertical oscillator is properly adjusted when its free-running frequency:

   a. is slightly above 60 cycles per second
   b. is locked in synchronism with the horizontal oscillator
   c. needs no synchronizing pulses
   d. is slightly below 60 cycles per second.

10. If a vertical damping resistor should become defective:

   a. the serviceman should calculate voltage drop required, then substitute a resistor to bring about that voltage drop
   b. it is probable the original had a wrong resistance
   c. it is merely necessary to replace with another of similar value
   d. the resistor should be heated slightly, then have a high voltage placed across it.

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TELEVISION AND RADIO

Deflection Oscillators - Part I

Underline or fill in the ONE correct answer.

1. Horizontal and vertical oscillators are:

   a. always multivibrators
   b. always gaseous type relaxation oscillators
   c. sometimes omitted from the more modern TV receivers
   d. sweep oscillators.

2. Horizontal and vertical oscillators are designed so:

   a. both should have the same frequency
   b. both must be multivibrators if one is a multivibrator
   c. the vertical oscillator has a much lower frequency than the horizontal oscillator
   d. both must be blocking oscillators if one is used in either circuit.

3. Fully half the troubles in a television receiver develop in the:

   a. deflection circuits, of which the oscillators are an important part
   b. video amplifier
   c. picture tube
   d. vertical oscillator circuit.

4. The multivibrator oscillator:

   a. was developed especially as an oscillator for TV sweep circuits
   b. can be used as a vertical oscillator, but is not reliable enough for horizontal sweep circuits
   c. is an old electronic circuit which has been adapted to TV needs
   d. can be used as a horizontal oscillator but is not practical for that.

5. Basically, a multivibrator is:

   a. a sine-wave generator
   b. a two-stage amplifier which feeds a portion of the output of the second stage back into the input of the first stage
   c. a two-stage amplifier whose signal is not inverted between the two stages
   d. an oscillator which is neither self-starting nor self-perpetuating.

6. The cathode-coupled multivibrator:

   a. uses a simpler circuit, and fewer parts, than a true multivibrator
   b. couples signal from the first stage to second through cathode coupling
   c. is less frequently used than the true multivibrator because it is less dependable
   d. is a dependable circuit, but not exactly practical for TV work.

7. A flip-flop circuit is:

   a. being used more and more frequently in vertical circuits of TV receivers
   b. a free-running oscillator, but a bit difficult to synchronize
   c. often used as a horizontal oscillator when a multivibrator is used in the vertical circuit
   d. a single-cycle multivibrator.

8. Principal difference between a blocking oscillator and Armstrong oscillator is:

   a. the Armstrong oscillator is useful only at radio frequencies
   b. the blocking oscillator can be used only at the higher audio frequencies
   c. the time constant of the R/C combination in the grid circuit of the blocking oscillator tube is much longer
   d. in the values of B+ applied to the anodes of the tubes.

9. An important requirement of a horizontal oscillator is:

   a. ready accessability
   b. simplicity
   c. that it can be readily synchronized with some other signal
   d. that the tube be easily replaced.

10. Because electrical noise has a tendency to trigger the horizontal oscillator at the wrong time, many horizontal oscillators are not controlled directly by the horizontal sync pulses. Instead, they:

   a. operate as a given multiple of the frequency of the vertical oscillator, and are triggered by it
   b. depend solely on a triggering pulse being fed back from the horizontal transformer
   c. have the sync pulses fed into either the anode or the cathode of the horizontal oscillator tube
   d. are controlled by bias voltage developed in a special control tube, which acts to combine several voltages necessary to develop the proper control voltage.

1. B+ power is frequently fed through a tuned resonant circuit to the anode of the horizontal oscillator. That tuned resonant circuit is often called:

   a. frequency control circuit
   b. a multivibrator
   c. the stabilizing circuit
   d. sync separator circuit.

2. For good synchronization the "free-running frequency" of a deflection oscillator:

   a. must be slightly higher than sync pulse frequency
   b. must be stabilized by the stabilizing circuit
   c. should be carefully controlled by an AFC circuit
   d. should be slightly lower than the sync pulse frequency.

3. During servicing and adjusting jobs on the horizontal oscillator:

   a. it is often necessary to disconnect the vertical oscillator
   b. the vertical amplifier should be disconnected
   c. the stabilizing circuit is often short-circuited to permit easier adjustment
   d. it is usually necessary to remove B+ voltage from oscillator tube.

4. In figure 20 of the lesson we see an R/C circuit consisting of an 820 mmfd. capacitor and a variable resistor with a maximum resistance of 50,000 ohms. The resistance is deliberately made variable to provide a relatively wide control over the frequency of the oscillator. In terms of microseconds, what is the time constant of the circuit when the resistance is at its maximum value of 50,000 ohms? ____41.0____ microseconds

5. In figure 22 of the lesson we have a somewhat different circuit, although at first glance it seems to have quite a bit in common with the one solved in problem 4. In the cathode circuit of the first half of the 6SN7 tube we find a 0.5 mfd. capacitor and an 8200 ohm resistor in series. Figure out the time constant in terms of microseconds. ____.004____ microseconds

6. In figures 10 and 14 of the lesson we have two circuits which look very much alike. Closer study reveals a difference. In what material way does the circuit in figure 14 differ from that in figure 10?

   Fig. 10 Contains an AFC circuit + a 6BQ6 Horz. output Amp. tube

7. The manner in which the vertical synchronizing pulses are fed into the vertical multivibrator of a Zenith model H2229R differs somewhat from the method used in other brands of receivers. In this model:

   a. there is no vertical oscillator
   b. they are fed into the second section of the multivibrator instead of the first
   c. they are fed into the cathode circuit instead of the grid
   d. they control the amplifier rather than the oscillator.

(over)

8. In figure 13 we find a 47K resistor in the integrating circuit between a .001 mfd. capacitor and a 470 mmfd. capacitor. If that resistor should happen to become open:

   a. it would stop the vertical multivibrator oscillating
   b. the picture tube would have a single bright line horizontally across the screen
   c. the picture would probably roll from side to side
   d. vertical sync would be lost so the picture would roll vertically.

9. The vacuum discharge tube:

   a. is a true oscillator often found in modern receivers
   b. must always be used with a multivibrator
   c. is not a true oscillator, but was used with a blocking oscillator in the horizontal circuits of many early model receivers
   d. is growing in popularity, and will probably replace the blocking oscillator.

10. Multivibrator circuits are:

   a. sometimes used in the audio circuits of radio receivers as push-pull amplifiers
   b. rarely used as a vertical oscillator in a TV receiver
   c. must have special wave-shaping circuits to correctly shape the wave-form of the output signal
   d. sometimes used in both the vertical and horizontal circuits of the same receiver.

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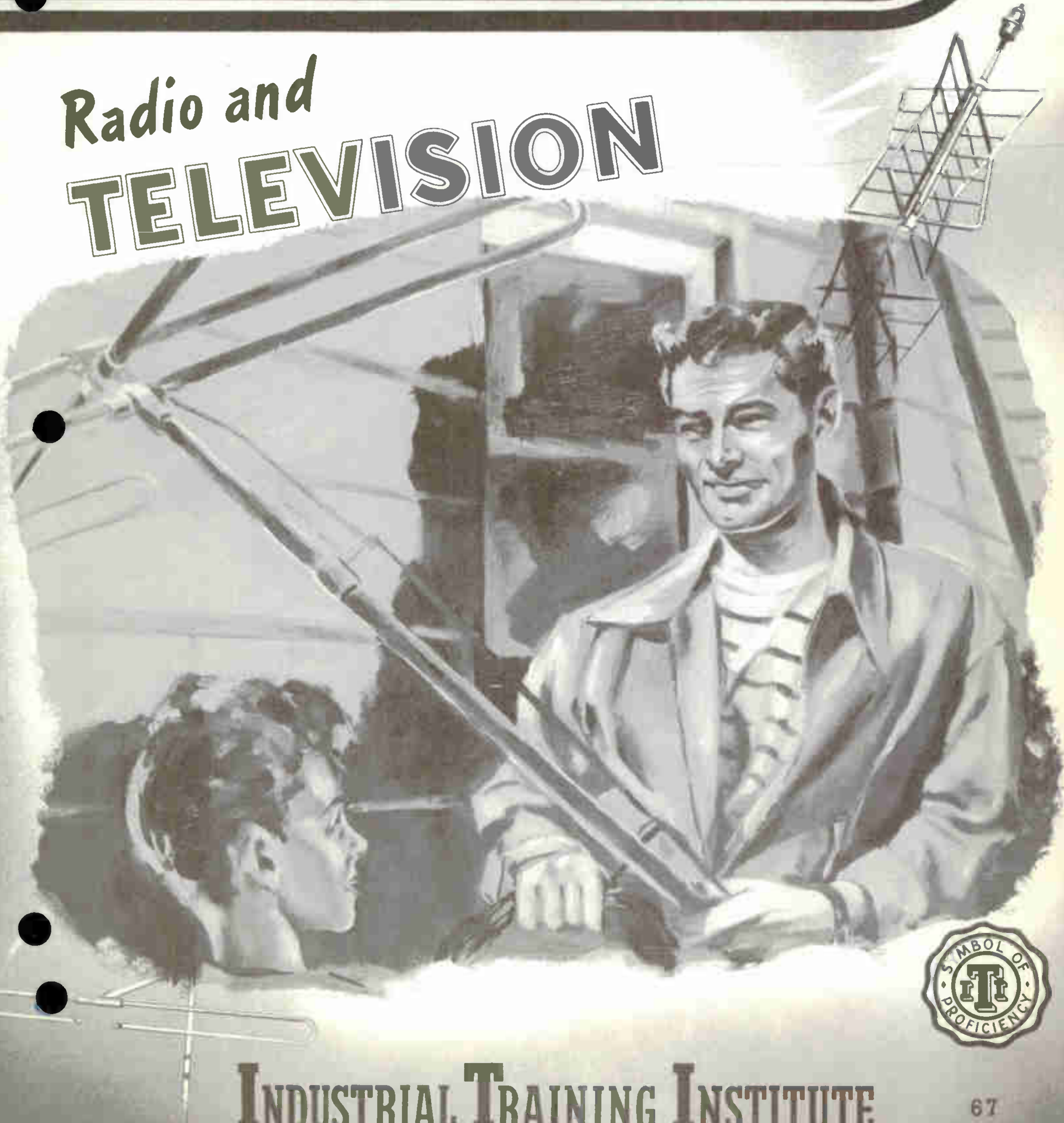

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REVISED 1957

RADIO TELEVISION

HORIZONTAL AMPLIFIERS

Contents: Horizontal Amplifiers used with Electrostatic Deflection System — Horizontal Amplifier for Magnetic Deflection System — Horizontal Amplifier Tubes — Biasing the Horizontal Amplifier Tubes — Biasing the Horizontal Amplifier—Shock Oscillations—Damping the Shock Oscillations — Damping Action and Trace Movement — Horizontal Drive Control — Horizontal Output Transformer — Connections to the Transformer Secondary — Why there are Different Connections to the Secondary — Producing High Voltage — Coupling into the Deflection Yoke — Types of Damper Tubes — Notes for Reference.

Section 1. INTRODUCTION

The horizontal oscillator creates the voltage waveforms necessary to sweep the electron beam across the face of the picture tube, but it is the horizontal amplifier which converts that voltage into power for actually performing the sweep movement. This lesson is devoted to the peculiarities of the circuits involved in the horizontal amplifier.

In all probability, the subject of horizontal amplifiers should include an explanation of amplifiers used with both electrostatic and electromagnetic deflection systems. As a practical matter, most of this lesson is devoted to the types of amplifiers used with magnetic deflection systems.

This does not mean that electrostatic deflection systems are completely ignored. There are many TV receivers still in use which employ electrostatic deflection, and limited numbers of them will probably continue to be manufactured and used for many years. Therefore, it is only right and proper that they be considered.

Horizontal amplifiers used with electrostatic deflection systems are relatively simple. This means there is no need to go into a lengthy discussion concerning them.

They consist of little more than a simple voltage amplifier. The signal from the horizontal oscillator is fed into the amplifier; then is amplified to sufficient magnitude so it can be applied to the deflection plates located inside the electrostatic picture tube. That is about all there is to it.

Amplifiers used with magnetic deflection, on the other hand, are much more complex. They are made even more complex by reason of the other duties they perform in addition to the relatively simple one of sweeping the beam across the screen of the picture tube.

These extra duties imposed on magnetic deflection amplifiers consist of such things as generation of high voltage, and boosting the voltage in the B+ power supply.

Section 2. HORIZONTAL AMPLIFIERS USED WITH ELECTROSTATIC DEFLECTION SYSTEM

A typical circuit of a horizontal oscillator and horizontal amplifier used in early model electrostatic deflection system is shown in Fig. 1. A 6N7 is used as a blocking oscillator and discharge tube. One half of the 6N7 is used as the oscillator and the other half as the discharge tube.

The 6N7 has been pretty well discarded for

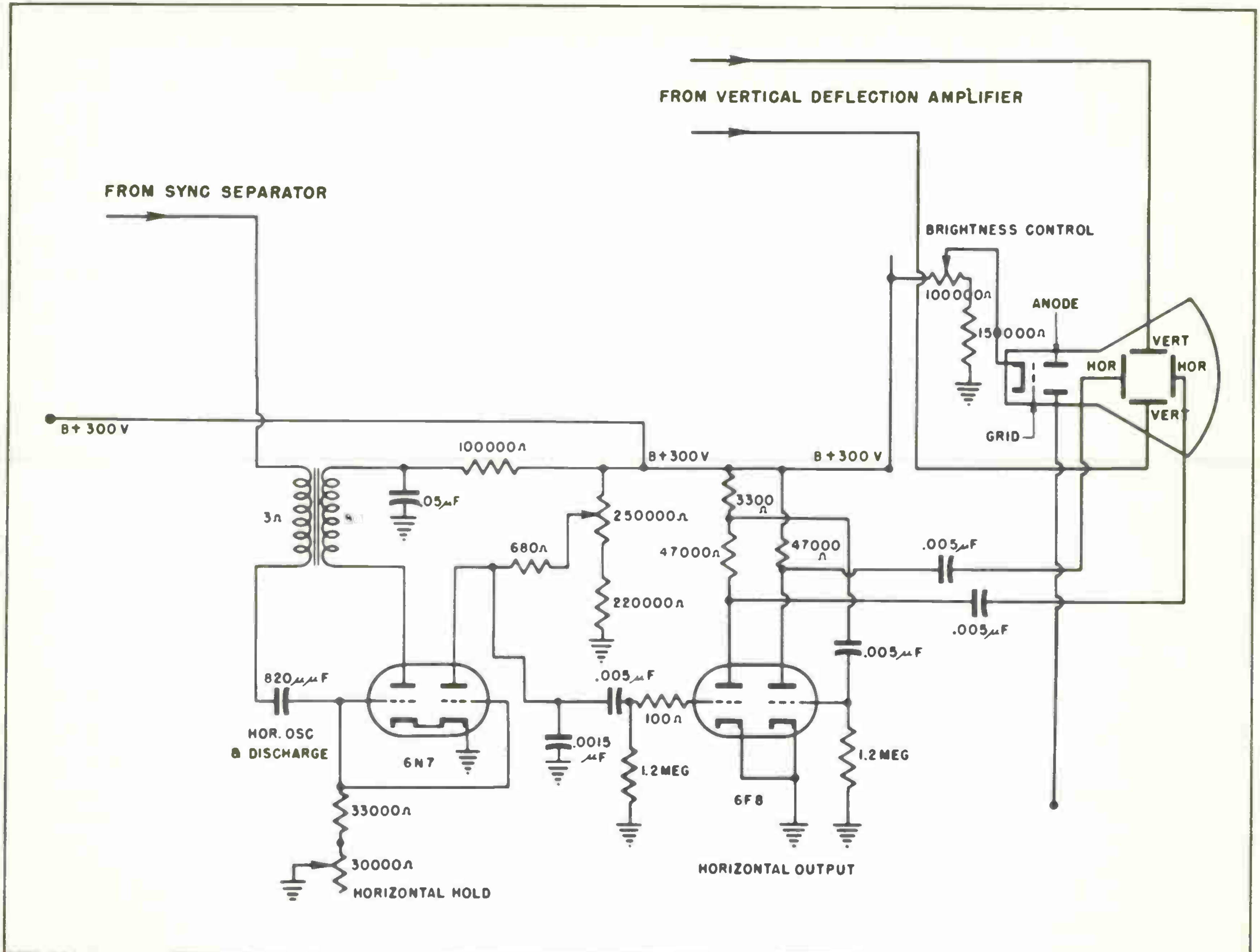

Fig. 1. Horizontal circuits used with electrostatic deflection.

this type of service. It has been replaced by the 6SN7, but was used in many of the early model, small-tube receivers.

Principal difference between the 6N7 and 6SN7 is that the 6N7 uses a common cathode for both sections of the dual tube, whereas the 6SN7 has a separate cathode for each section. There are other minor differences between the two tubes.

The horizontal amplifier in the circuit in Fig. 1 is a 6F8. This is a tube which has been widely used as a voltage amplifier in many kinds of radio and other electronic circuits. The 6F8 is also a twin-triode, but has somewhat different characteristics from the 6N7 and 6SN7.

The amplified voltage present at the anode of one section of the 6F8 is applied to one of the horizontal deflection plates, while the amplified voltage from the anode of the other section is applied to the opposite deflection plate. The voltages on the two anodes are 180° out of phase with each other, which means that as the voltage on one is rising that on the other is declining. The reverse is also true.

This means that as the voltage on one of the two anodes becomes more positive that on the other becomes more negative. Since these two voltages are applied to opposite deflection plates they act upon the stream of electrons which pass between the two plates on their way from the electron gun to the screen of the picture tube. As one deflection plate becomes increasingly negative, and the other more positive, they act to bend the electron beam so it partially inclines in the direction of the more positive plate.

By alternately making first one, then the other, of the two plates either positive or negative the electron beam is swept back and forth across the screen of the picture tube.

A similar deflection circuit used in an early model electrostatic deflection TV receiver is shown in Fig. 2. It is the circuit used in Hallicrafters Model T-54. It is rather interesting to note that this model Hallicrafters, together with a similar receiver built by Motorola at approximately the same time, must be given credit for making television popular, and bringing television out of the laboratory and into the homes of the American people.

This does not mean these were the first television receivers offered to the public. Television had been in existence, and had been practical, for a number of years before these two receivers made their debut in 1948. But the prices had been so high that television was found in few places, other than taverns and a few similar public places, until Hallicrafters and Motorola introduced their 7-inch, table model receivers in 1948.

Those two receivers were the first offered to the public for less than $200, and they sold faster than the companies could make them. They showed there was a market for television receivers if manufacturers could build them at a price the public could afford to pay.

These little table model receivers sold by the tens of thousands, and quickly made television a part of the American way of life.

It is true that these two models did not long remain popular. But they were the first mass-produced receivers. Within a few months other radio manufacturers began offering less expensive receivers of their own, and most of them also offered larger screens.

For several months several companies vied with each other in offering 10-inch receivers, then the trend quickly turned to receivers using still larger tubes.

By that time the 7-inch Hallicrafters and 7-inch Motorola had served their purpose, and they were replaced by the larger screen receivers. But while they were being made they found their way into many, many thousands of homes. Many of those early receivers are still in use. They were sturdy, reliable, and very nearly trouble free.

The horizontal deflection circuit in Fig. 2 is quite similar to that in Fig. 1. There are some differences, but they are minor. They use different tubes, and slightly different values of resistance and capacitance in some of the circuits. The manner in which the "hold control" operates differs slightly. But in most respects the circuits are quite similar.

All things considered, the horizontal deflection system is relatively simple in a television receiver using electrostatic deflection. It is as straightforward as any kind of electronic circuit ever is.

The oscillator generates the correct waveform

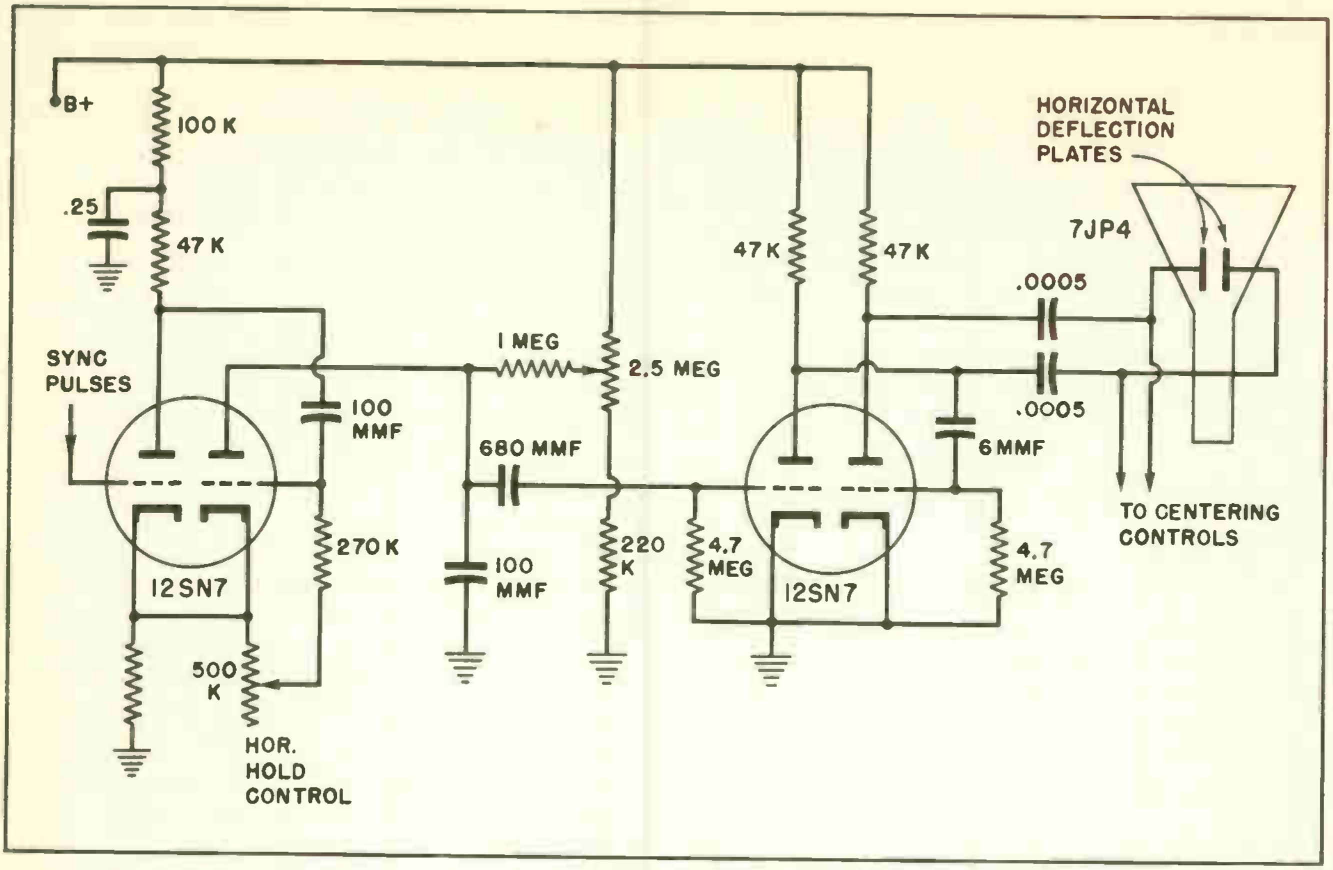

Fig. 2. Horizontal oscillator and amplifier used in early model 7-inch receiver.

voltage. The amplifier does little more than amplify that voltage to the magnitude needed to energize the deflection plates sufficiently to sweep the electron beam across the picture tube screen.

In short, the horizontal amplifier used in an electrostatic deflection system is a simple voltage amplifier. True, it can be classed as a push-pull voltage amplifier, but it is still a simple voltage amplifier.

Section 3. HORIZONTAL AMPLIFIER FOR MAGNETIC DEFLECTION SYSTEM

In contrast to the simplicity of the horizontal amplifier used with an electrostatic deflection system, the one used with magnetic deflection is considerably more complicated.

The horizontal amplifier in a magnetic deflection system must perform the function of converting a *voltage* waveform into electrical *power*. Power is needed to energize the deflection coils in a magnetic deflection system; voltage alone is not enough.

This means the amplifier tube used in a magnetic deflection system must be a power amplifier, not a voltage amplifier. In modern receivers the horizontal amplifier often delivers as much power as a small transmitter.

Furthermore, the inductance in the output circuit of the horizontal amplifier tends to distort the voltage waveform. This distortion must be taken into account, and steps taken to counteract it, or compensate for it.

When we were explaining vertical deflection systems we mentioned this matter of distortion, but we must enlarge upon it somewhat more in our present discussion of horizontal deflection circuits.

To make the horizontal amplifier circuits in a magnetic deflection system even more complicated, designers have imposed additional tasks on the horizontal deflection system in addition to the relatively simple one of sweeping the electron beam horizontally within the picture tube. This has been mentioned before, but we cannot emphasize the fact too strongly.

The most important additional function concerns generation of high voltage for the final anode of the picture tube. This was touched upon in our lesson on high voltage power supplies, but we cannot ignore it in this lesson. The interdependence of the H-V power supply and the horizontal amplifier upon each other accounts for much of the service work connected with TV receivers.

The sudden peak voltage which develops in the horizontal output transformer during the retrace movement is used to generate high voltage needed by the picture tube. Those high peak voltages are applied to a rectifier tube, then filtered with a special filter circuit.

A third job imposed on the horizontal amplifier circuit deals with boosting of the B+ voltage. This circuit is used most widely in the less expensive AC-DC receivers, but can be found in many of the more expensive receivers. It is found with increasing frequency, even in those receivers using straight A-C power supplies.

Action of the "boosted B+ power supply voltage," as the circuit is referred to technically, was described in our previous lesson on high voltage power supplies, and will be touched on again in a later lesson. But it will not be completely ignored in this lesson. It is difficult to discuss horizontal amplifier circuits without bringing boosted B+ circuits into the discussion, since they are often so closely interwoven with each other.

Presence of the high voltage power supply circuit and the boosted B+ as parts of the horizontal amplifier circuit tends to complicate what was originally a relatively simple circuit. But, since these circuits are so intertwined with each other in so many modern receivers it is necessary to discuss them together.

Section 4. HORIZONTAL AMPLIFIER TUBES

The prime requirement for a horizontal amplifier in a receiver using magnetic deflection is that it be capable of converting voltage waveforms into electrical power. As has been previously suggested, those power requirements are high.

The horizontal sweep frequency is 15,750 cycles per second. That is a relatively high frequency when compared with normal audio frequencies. It is pretty close to the upper limit of what we ordinarily look upon as audio frequencies.

To convert the sharp voltage reversals in the saw-tooth oscillator signal into sufficient power to suddenly reverse the current in the deflection coils requires considerable reserve power. The need is made even greater by requirements of the high voltage power supply, and the boosted B+ power supply.

All of which means the horizontal amplifier should be capable of converting the signal voltages from the horizontal oscillator into considerable power. Such requirements can be met best by some type of beam power tube.

Furthermore, peak voltages present in the anode circuit of the tube during retrace action rise to high amplitudes. Those peak voltages are present for short intervals only, but they frequently and regularly rise into the thousands of volts. This means the tube must be capable of working with high voltages without permitting internal "flash-back" or internal arcing.

Several types of tubes have been used as horizontal amplifiers since magnetic deflection came into regular use in TV receivers. Old reliable types such as the 6V6 and 6L6 have been used for that purpose.

But present tendency is to use power amplifier tubes especially designed to handle the peculiar demands of horizontal deflection. The most widely used of these are the 6BQ6 and the 6BG6, with the 6CU6 a close competitor for favor. The 6CD6 is also used in some receivers.

The 6CU6 is a more powerful tube than either of the first two, and is often used where maximum power is desired. It is closely comparable to the 6BQ6, but has somewhat higher electrical ratings, and is more rigidly constructed mechanically.

Some tube manufacturers are building an exceptionally rugged tube they call 6BQ6-GTA. It has the same electrical characteristics as the 6BQ6, and can be used in any circuit originally designed for the 6BQ6. It can be used as a direct replacement.

In most cases the 6CU6 can be substituted for the 6BQ6 without any changes being made in the circuit originally designed for the 6BQ6. However, the ordinary 6BQ6 cannot always be directly substituted for the 6CU6 because the 6BQ6 is not quite so good a tube as the 6CU6. In an emergency, the 6BQ6 can often be substituted for the 6CU6 without any electrical changes being made in the circuits. Before making such a substitution it is well to check the circuit involved, then check the requirements of the circuit against the tube manual which shows the characteristics of the two tubes.

The 6BG6 cannot be substituted for either of the other tubes just mentioned. It does not have nearly so high electrical ratings as the 6BQ6, the 6CU6, or the 6CD6. Furthermore, the electrical connections to the base pins are different in the 6BG6 from those in the other tubes.

The most powerful tube of any of those just mentioned is the 6CD6. It can operate at higher plate voltage, and can withstand higher peak voltages. But it requires more driving voltage, and costs more. It also dissipates more heat.

Another beam power tube often used as a horizontal amplifier in AC-DC receivers is the 25BQ6. It is similar in most respects to the 6BQ6 except for the filament ratings. The 25BQ6 requires a filament voltage of 25 volts instead of the 6.3 volts required by the 6BQ6.

When used in AC-DC operation, the filament of the 25BQ6 is connected in series with the filaments of other tubes in the receiver.

The earlier models of type 6BQ6 were marked as type 6BQ6G or 6BQ6Gt. Later, these two were combined as type 6BQ6G-Gt. Electrically, there was no difference among them. The only difference was in the shape of the glass envelope. The glass envelope of the GT tube was slightly smaller than the other.

Because a tube really takes a beating when used as a horizontal amplifier, and the tube would frequently fail, some tube manufacturers came up with the still newer version we mentioned earlier. That is the 6BQ6GTA. Electrically, this tube is the same as its predecessors. It can be substituted in any circuit where either of the older tubes were used. However, its inside structural construction makes it a much more rugged tube. It stands up under much harder usage, and will last longer.

Another tube sometimes used as a horizontal amplifier is the 6AV5. It has never come into widespread usage for that purpose, but will be found in some receivers. The 6AV5 is not so strong a tube as some of the others we have mentioned. For that reason a pair of them are sometimes used in parallel.

The 6AU5 is a similar tube, and is often interchangeable with the 6AV5.

Horizontal amplifier tubes always dissipate much power. For that reason they are always very hot. Usually they are so hot they cannot be touched without one's fingers being burned.

Section 5. BIASING THE HORIZONTAL AMPLIFIER

Any of several methods can be used to bias the horizontal amplifier. But grid-leak self-biasing seems to be the method favored almost universally.

A few manufacturers combine grid-leak biasing with cathode biasing, but the cathode resistor they use is usually relatively small. Few manufacturers use a cathode resistor with more than 100 ohms. Most depend entirely on grid-leak biasing.

Tube manufacturers recommend that the grid bias resistor not exceed 470K in resistance, but several receiver manufacturers use greater resistance than that in the grid circuit.

A typical circuit which uses a grid-leak bias of 470K is shown in Fig. 3. That is a circuit used in Sentinel Model 1U420B.

There is a 100-ohm resistor directly in the grid circuit. It is intended to act as a parasitic suppressor. Presence of that low-resistance resistor in series with the grid presents sufficient impedance to extremely high-frequency parasitic A-C voltages to keep them from forming, and to keep them from being amplified and continuing if they do form.

The 470K resistor between the control grid and ground acts as the grid-return resistor, and develops the grid-leak bias voltage.

In action, the horizontal oscillator generates A-C voltages. These are saw-tooth waveform

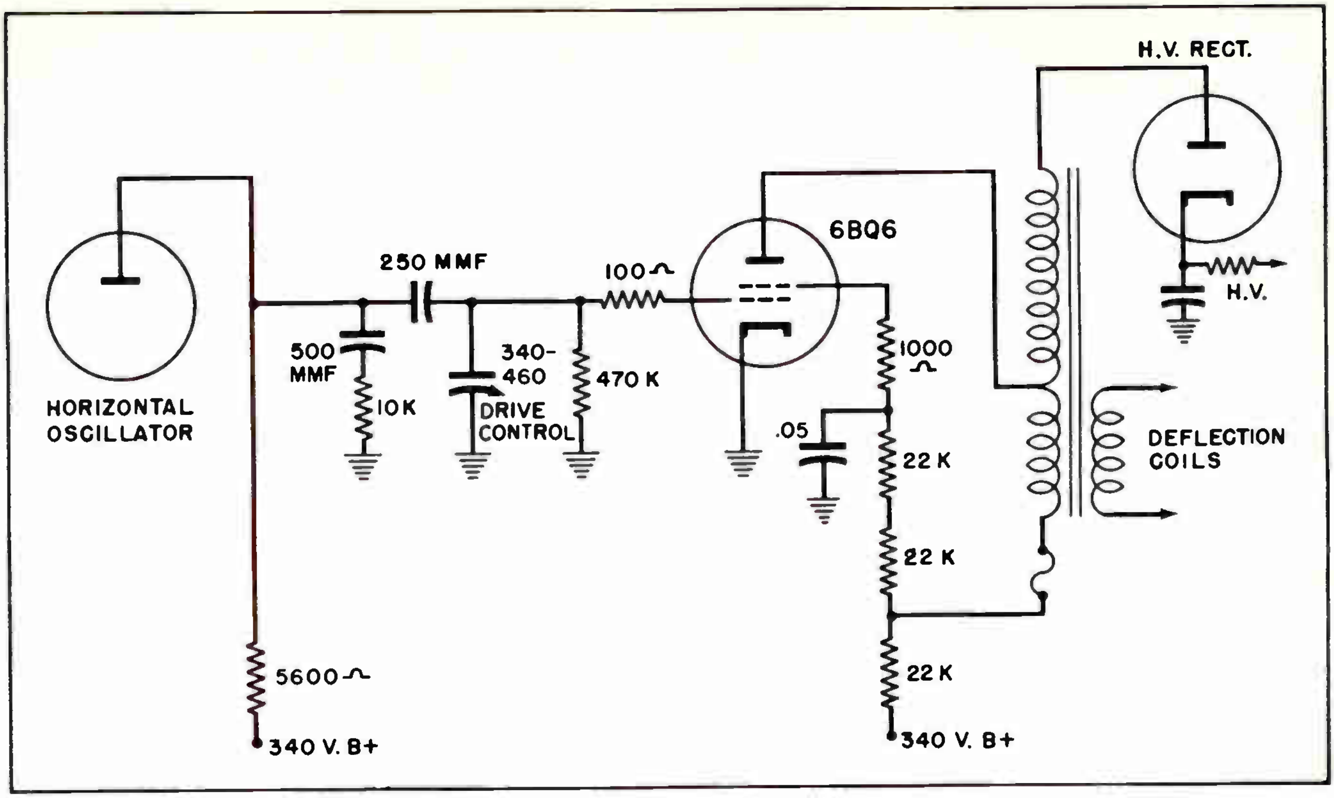

Fig. 3. Circuit of grid-leak bias for 6BQ6.

voltages, or modified saw-tooth waveforms, but they are A-C *voltages.*

As the saw-tooth voltages tend to go positive they place an increasingly positive signal voltage on the control grid of the 6BQ6 amplifier. Presence of that positive voltage tends to attract electrons from the space charge within the tube. It attracts electrons to the control grid.

Once electrons strike the control grid they are trapped. They cannot escape except by passing through the 470K resistor to ground. Passage of that electron current through the resistor acts to maintain the control grid with a negative bias.

Action of the circuit in this particular receiver is such that the trapped electrons, plus the resistance of the grid-leak resistor, maintains the control grid approximately 23 volts negative. This means the signal voltage from the horizontal oscillator must attain a magnitude of 23 volts before it can overcome the negative bias on the control grid and cause it to attract additional electrons.

The circuit in Fig. 3 does not have any resistor in the cathode circuit of the 6BQ6. The grid-leak resistor is depended upon to maintain sufficient bias to prevent the tube overloading and overheating. The circuit is reliable enough that it is used in many other receivers with very little change in the circuit constants.

The purpose of the DRIVE CONTROL variable capacitor in parallel with the 470K grid-leak resistor is to control the strength of the driving voltage from the horizontal oscillator.

The DRIVE CONTROL acts to shunt part of the oscillator signal to ground. When the capacity of the drive control is reduced less signal is shunted to ground; thus more signal can be applied to the control grid of the horizontal amplifier. By increasing the capacity of the drive control capacitor more signal is shunted to ground; thus less reaches the control grid of the horizontal amplifier.

All of which means that by increasing or decreasing the capacity of the drive control capacitor it is possible to control the strength of the signal applied to the control grid of the horizontal amplifier. Due to the relative size of the capacitor, this shunting action is most effective during the initial portion of the trace movement.

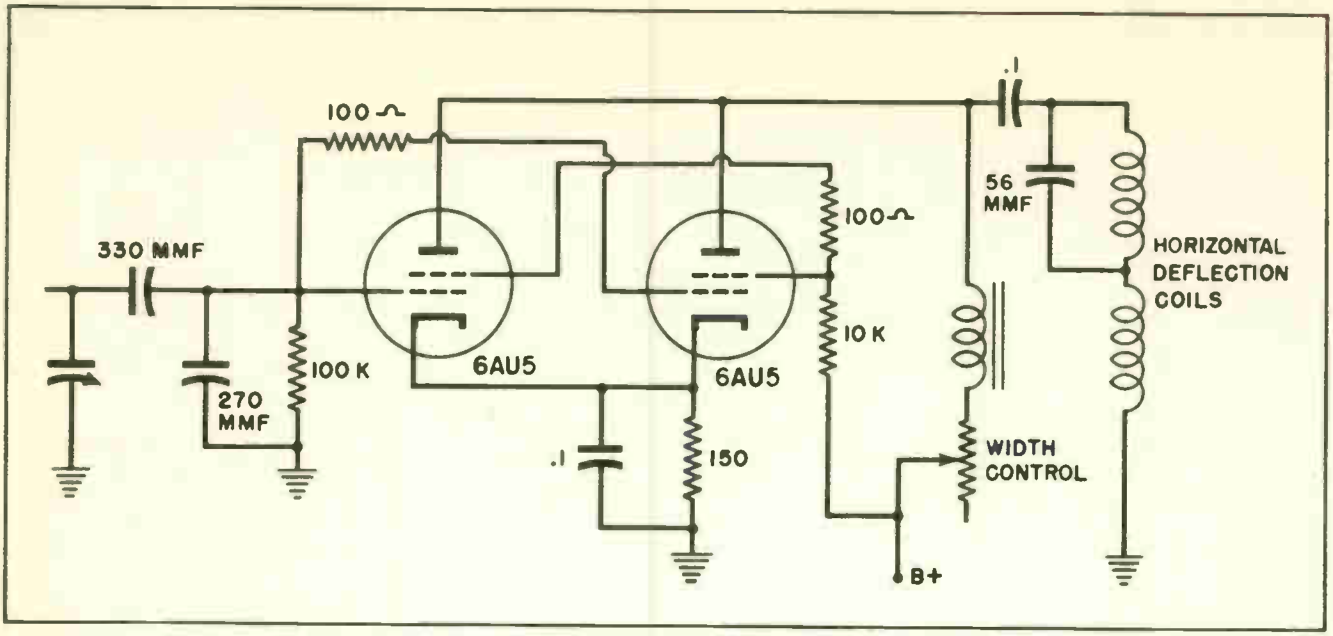

Fig. 4. Horizontal amplifier using two tubes.

A somewhat different horizontal amplifier is shown in Fig. 4. It uses a pair of 6AU5 beam power tubes connected in parallel. The two tubes feed directly into the deflection coils in the deflection yoke, the power for the coils being coupled through a 0.1 mfd capacitor.

The circuit in Fig. 4 does not use a horizontal output transformer. Thus the horizontal amplifier has nothing to do with the generation of high voltage for the final anode of the picture tube.

This particular circuit was used in Westinghouse model H-611C12. It was introduced to the public in 1950.

This circuit never received much attention from the manufacturers. It used too many tubes, and had no particular advantage over other circuits which were more widely used.

The grid-leak resistor in this circuit has a resistance of only 100K. This is a rather low resistance for this type of circuit, being considerably less than is generally used for that purpose. But there is 150 ohms of resistance in the cathode circuit of the two tubes.

The grid bias on the output amplifier tubes in this circuit is relatively low. Much lower than that used with most other tubes, especially with tubes like the 6BG6 and 6BQ6. However, this is accounted for by the fact that these tubes work directly into the deflection coils without the power passing through an output transformer. Therefore, the anode current from the tubes must be somewhat greater than when the tubes work into a transformer, and the full deflection load is carried by the amplifier rather than being shared with the damper tube as is the more modern practice.

A horizontal amplifier circuit, which is probably somewhat more typical than those mentioned previously, is the one shown in Fig. 5. It is a circuit used in RCA model 21-S-348, in 1954, and copied in several of their other models. It has also been used by a number of other manufacturers who operate under RCA patents.

This particular circuit uses both cathode bias and grid-leak bias. The grid-leak resistor has a resistance of 1 megohm, which is considerably in excess of that usually recommended for use with the 6BQ6, but which is, nevertheless, frequently used with that tube.

In addition to the grid-leak bias there is a cathode resistance of 180 ohms. It would hardly seem necessary to have cathode resistance in addition to such a high grid-leak bias resistor, but they use it.

One of the distinguishing features of RCA circuits is that they are usually quite elaborate. They usually incorporate more components than

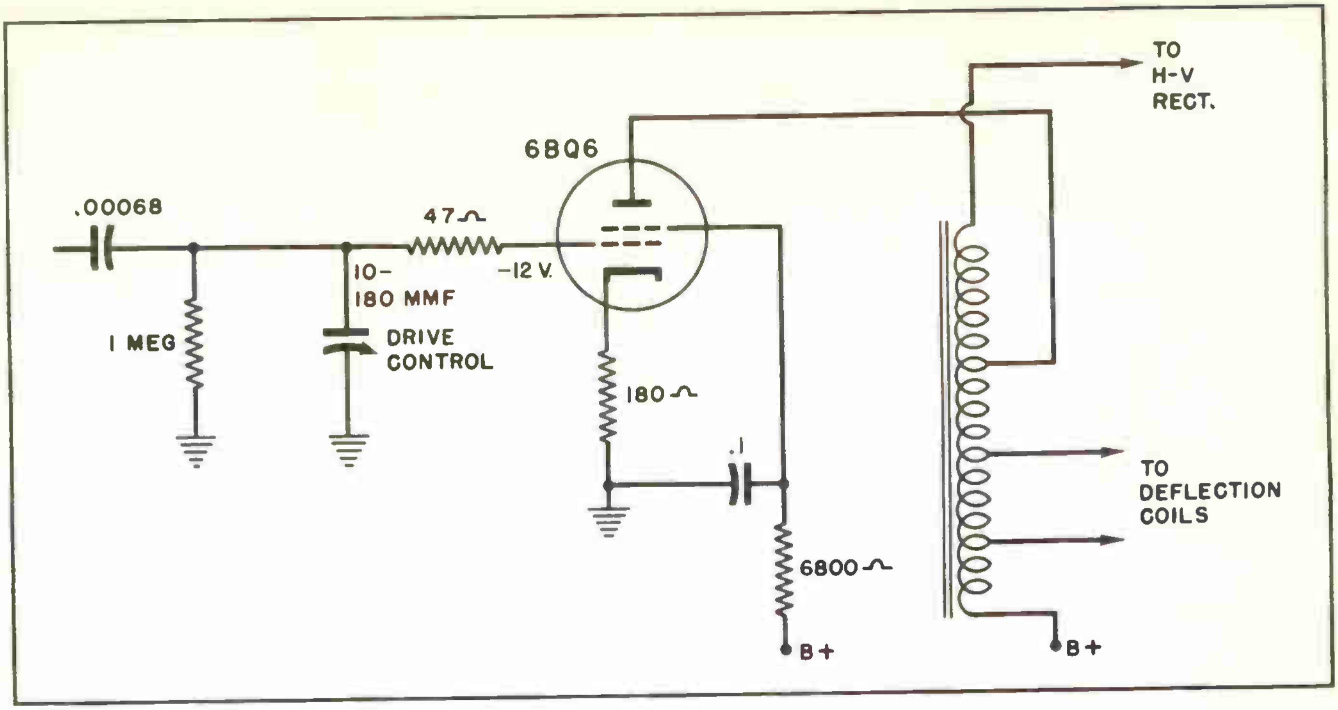

Fig. 5. RCA Horizontal Amplifier.

some of the other manufacturers appear to consider necessary.

In contrast to the circuits we have just described is that used in Truetone Model 2D1415A. It uses a 25BQ6, and the tube is really worked quite hard. The circuit is shown in Fig. 6.

This particular model has an AC-DC power supply. The only transformer used in the power supply system is a small one to supply filament heating current for some of the amplifier tubes. No power transformer is used in connection with the B+ power supply.

The 25BQ6 uses a 470K resistor as the grid-leak resistor. But the driving voltage is so strong the tube normally develops a bias voltage amounting to 32 negative volts. This may seem rather high for a negative bias, but it is not at all uncommon for a 25BQ6 or a 6BQ6.

When trouble is suspected in a horizontal system it is always well to check the grid bias voltage on the amplifier. A low negative bias often points to a weak signal from the oscillator.

Section 6. SHOCK OSCILLATIONS

By the very nature of its construction a magnetic deflection circuit contains a considerable amount of inductance. There is no escape from this fact, so it must be accepted, and taken into account. The effects of the inductance must be compensated in some manner if the sweep is to remain linear.

Furthermore, considerable distributed capacitance also exists in the deflection circuit. When we thus speak of the "deflection circuit" we are referring specifically to the secondary windings of the output transformer and the deflection coils on the deflection yoke.

This distributed capacity in the deflection circuit exists between the various turns of the windings in the coils. Fig. 7 shows how the distributed capacity exists between the several turns in the coil windings.

It should be kept in mind that this distributed capacity is not included in the circuits for any particular purpose. It is not there because the designer so intended. It is present because it is unavoidable. It is there because a fundamental law of electricity decrees that capacity exists wherever metallic conductors are separated by an insulating material.

Coils on the secondary of the transformer consist of turns of insulated wire wrapped around a central core. The insulated conductors are ad-

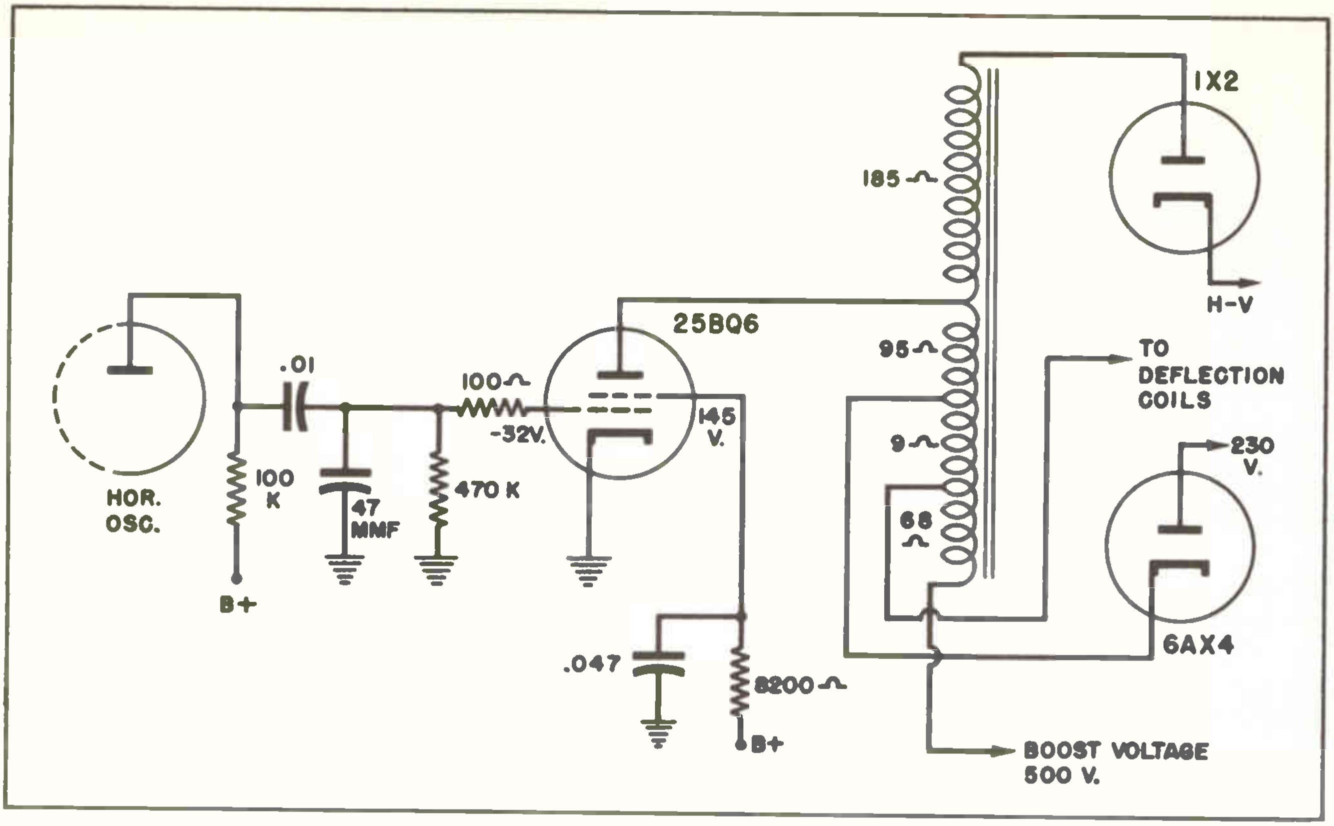

Fig. 6. Horizontal amplifier using 25BQ6 and boosted B+.

jacent to each other. Electrical capacity exists between the adjacent turns because of the insulation which separates them.

Fig. 7 shows in a diagrammatic manner the capacity which exists between the adjacent turns of the winding. Actually, the capacity is distributed throughout the entire coil, and exists between all parts of the adjacent turns.

In addition, capacity exists between one end of a coil and the other. This distributed capacity exists because of the manner in which a coil must necessarily be constructed. Fig. 8 makes this point a little more clear.

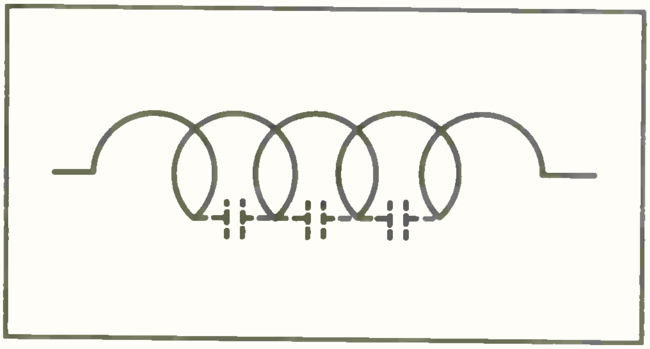

Fig. 7. Distributed Capacity.

As a matter of fact, the distributed capacity which exists between one end of a coil and the other could be shown as in Fig. 9, and would be perfectly accurate. For the purpose of our present explanation it will probably be better to think of it in that manner, and so represent it.

Since a coil, by its very nature and construction, contains inductance, and also, by its very construction, contains some distributed capacity, we have what amounts to a resonant circuit. What we are trying to say is that every coil, by the very nature of its construction, contains those elements necessary to make it a resonant circuit. It can become a resonant circuit without the addition of any external capacity.

Engineers often take advantage of this fact in various types of electrical and electronic circuits. That circuit property is also used in the deflection circuits of television receivers.

To prepare our thinking for the action which takes place in a deflection circuit suppose we turn our attention to the diagram in Fig. 10. That diagram is intended to illustrate the manner in which magnetic lines of force expand outward from a coil of wire as current begins to flow

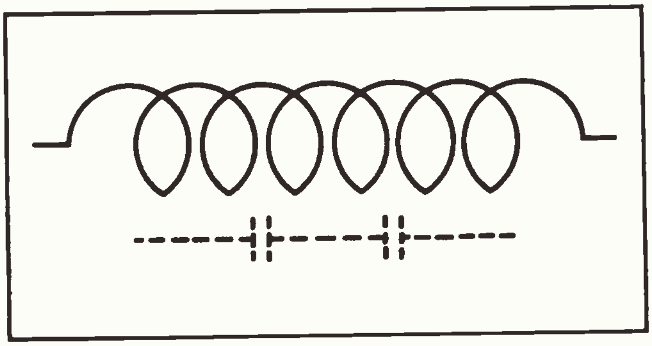

Fig. 8. Capacity distributed between one end of coil and the other.

through the conductor from which the coil is composed.

Those lines of force move outward only during the time in which the current in the coil is increasing. Once the current reaches its maximum the magnetic lines of force become static; they no longer move. The lines of force move only during those instants of time while the current is *changing* — either increasing or decreasing.

In the case of the coils in a deflection circuit we find a magnetic field being built up during the period of time in which current is increasing. This is particularly true during the period of time in which the current is increasing in the deflection coil to create the magnetic field needed to move the electron beam from the left side of the picture tube screen to the right side. That is the interval we call the trace period.

If the current through the coils increases at a steady, stable rate, as it should increase, the beam is moved at an even rate from one side of the screen to the other. The item of importance at the moment is the fact the current through those coils increases at a stable rate.

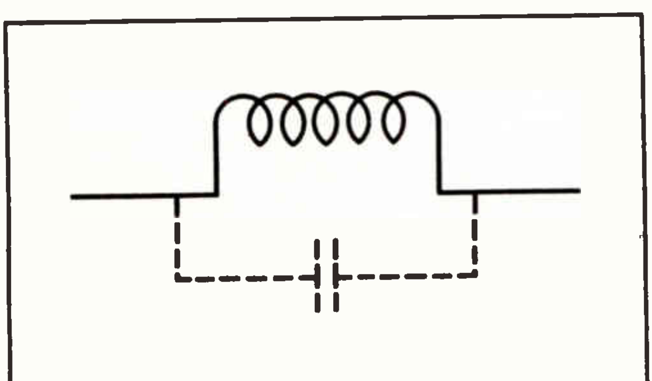

Fig. 9. Total distributed capacity in coil.

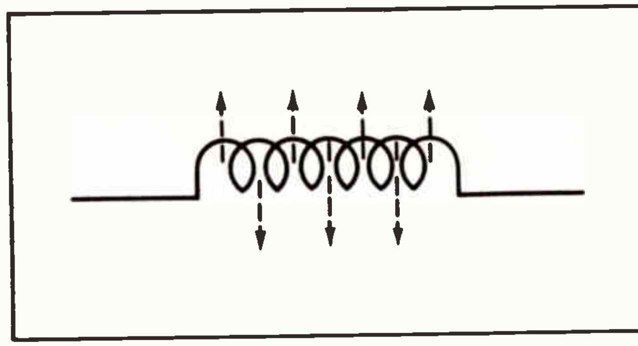

Fig. 10. Magnetic lines of force expand outward from coil when current begins to flow in it.

The current increases in the deflection coils, and increases in the secondary winding of the transformer. Both sets of coils are in series and, of course, both have inductance.

At the end of the trace period, the current is suddenly reversed through the deflection coils. This is a sharp, abrupt action; and while it is occurring a peak voltage is built up in and around the coils in the deflection circuit. That sudden reversal of the current induces a sharp counter-voltage in all the turns of the coils in the deflection circuit. Something of the action is shown by Fig. 11.

That sudden, sharp peak voltage shocks the resonant properties of the circuit into oscillation. The frequency at which the circuit oscillates depends on the amount of inductance in the coils, and the distributed capacity present. But, since both capacity and inductance are present, the circuit will oscillate.

The peak voltage induced in the coils sets up an oscillatory voltage between the inductance of the coil and the distributed capacity between the turns of the coil. Fig. 12 gives a good idea how this takes place.

These shock oscillations do not persist for a very long period of time. They are self-damped after a short interval. They are damped by the electrical resistance which is always present in the conductors.

They start at a relatively high amplitude, then rapidly decay. Since there is no power to maintain the oscillations they are not self-perpetuating, thus do not last long.

A graph of the oscillatory voltages, and the

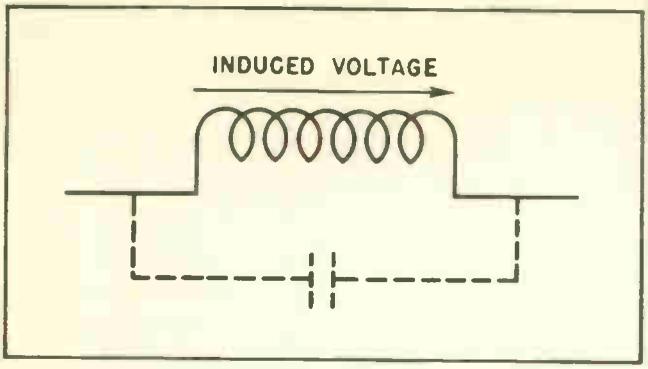

Fig. 11. Counter-voltage induced in coils of deflection circuit.

manner in which they quickly decay is shown in Fig. 13. The magnitude of the beginning cycle is relatively high, but each succeeding cycle has less amplitude than the one which preceded it. After a given number of cycles the oscillations die.

If these parasitic shock oscillations are not controlled they seriously affect the appearance of the picture on the screen. This results from the fact the oscillatory currents flow back and forth in the deflection coils, and create magnetic fields which also oscillate at relatively high frequencies.

Since these oscillatory voltages and currents are caused by the sudden shocking effects created during the retrace action, it follows that they make themselves apparent immediately after the end of the retrace movement. In point of time and position this means that the effects of the oscillatory currents make themselves apparent at the beginning of each trace movement of the beam.

For all practical purposes, therefore, this means the oscillatory currents affect the picture immediately after each trace movement begins; or, to be exact, affects the left side of the picture. The picture will look very much like the illustration in Fig. 14.

Unless controlled, the shock oscillations move the beam back and forth several times immediately after the trace begins. This is the reason their presence disturbs the picture at the left side of the screen.

Obviously, such a condition cannot be permitted to exist. The picture is so badly distorted, especially at the left side, there is little pleasure in viewing it.

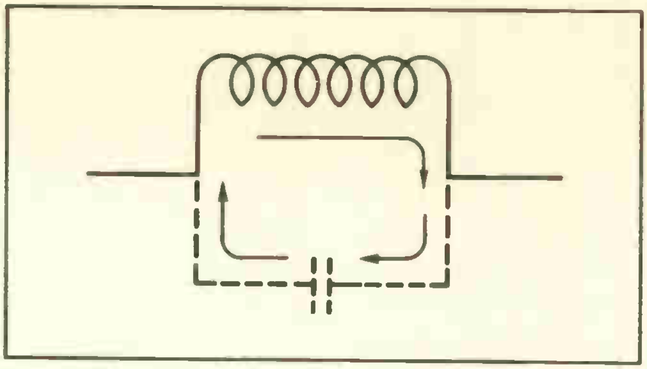

Fig. 12. Oscillatory action in coil resulting from shocking action of peak voltage.

The correction is to damp out the oscillations before they have a chance to get started. In order to do that it is well to study the actions of the oscillatory voltages a little more closely, then see just what can be done to correct them.

The relationships of the oscillatory voltages to the horizontal saw-tooth sweep voltage is shown in Fig. 15. At the beginning of the horizontal sweep the oscillatory voltages have considerably greater amplitude than the sweep voltage. At this instant they have more influence on the movement of the electron beam in the picture tube than the sweep voltages which are intended to control it.

As the sweep voltage increases in magnitude the oscillatory voltages progressively decay and die. By the time the sweep voltage has progressed one-quarter to one-third of the way across the screen the oscillatory voltages have decayed to a point where they are no longer important.

The actual manner in which the oscillatory cur-

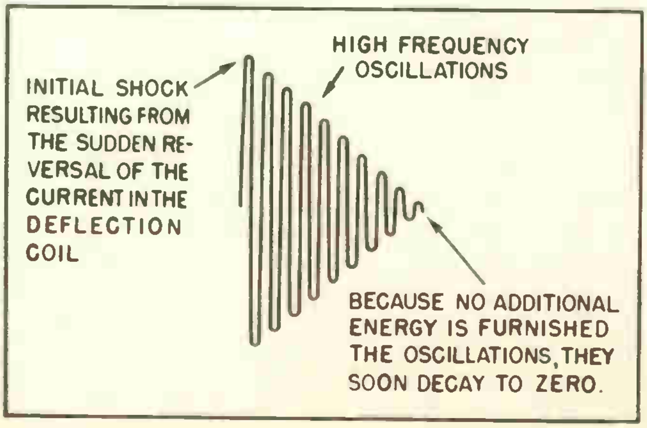

Fig. 13. Decay of high frequency oscillations when no additional energy is fed to keep them going.

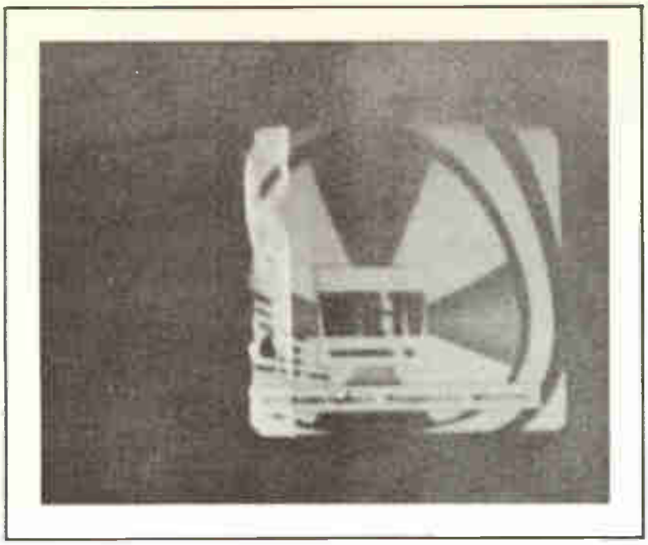

Fig. 14. Picture distortion caused by uncontrolled oscillations in deflection circuits.

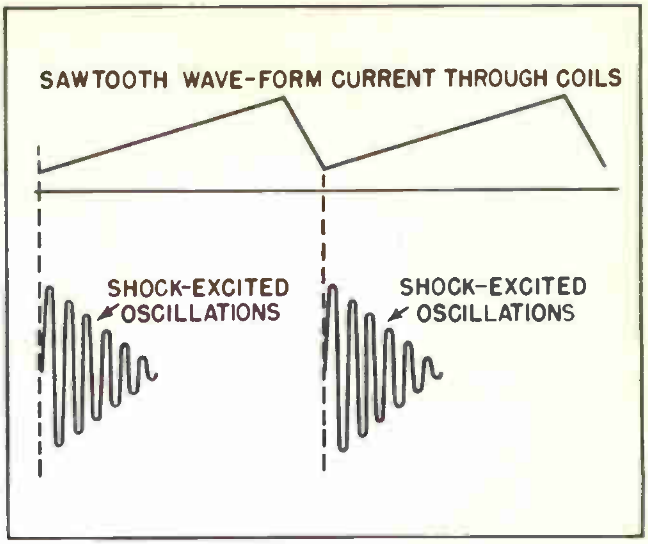

Fig. 15. Relationship of oscillatory voltages to horizontal sweep voltage.

rents are superimposed on the horizontal sweep voltage at the beginning of the sweep can be understood by studying Fig. 16. Just at the instant the beam should begin its sweep across the screen it comes under the influence of the oscillatory currents. Instead of moving steadily across the screen the beam is moved rapidly back and forth for a short interval, then permitted to continue its way to the right side of the screen.

It is the rapid back and forth movement under the influence of the oscillatory currents which causes the pattern on the screen to appear like the illustration in Fig. 14.

Section 7. DAMPING THE SHOCK OSCILLATIONS

In a previous lesson we found a somewhat similar situation when we were studying the action of the vertical deflection circuits.

In the case of the vertical circuits the situation was much the same, but the magnitude of the problem was not nearly so great as with horizontal circuits. The peak shocking voltage in the vertical circuits is not so great as in the horizontal circuits. Therefore the peak of the oscillatory currents is not so great.

Furthermore, the downward movement of the beam is not nearly so rapid as it is in the horizontal direction. The oscillatory currents decay before the beam has progressed downward far enough for their effects to be noticeable.

The condition can be controlled in the vertical circuits by merely connecting one or two resistors across the deflection coils. The resistors place a load across the coils, and thus act to dampen the oscillations very rapidly.

The situation is considerably different in the horizontal circuits. The sweep frequencies are much higher. The magnitude of the oscillations is

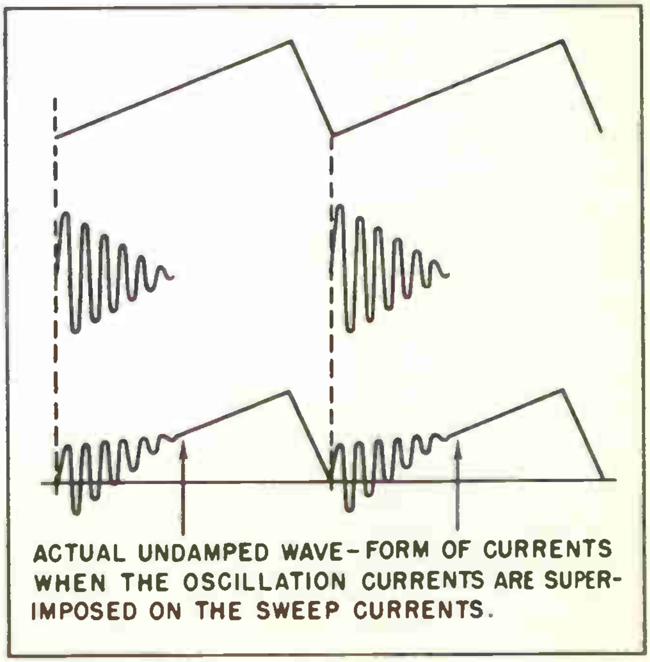

Fig. 16. Combination of oscillatory currents with sweep current.

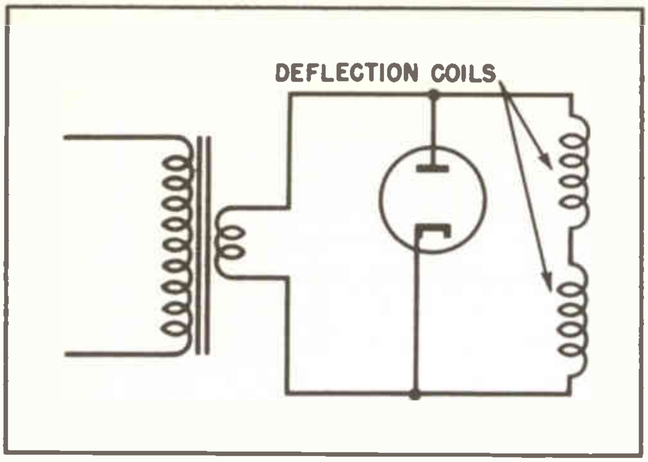

Fig. 17. Diode tube connected across deflection coils to damp out oscillations.

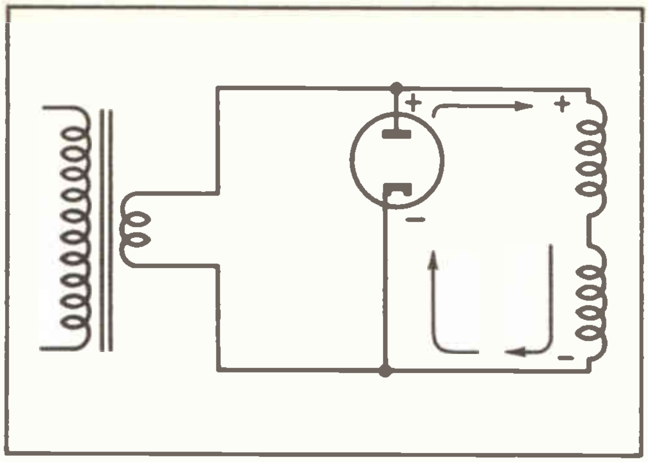

Fig. 19. Current flow during first half-cycle of oscillation.

much greater. Damping resistors alone cannot damp the oscillations fast enough. This means that some other means must be provided to damp out the oscillations, and thus keep them from being troublesome.

In the early days of television it was found that the only practical way to damp out the unwanted oscillations in the horizontal deflection circuits was to connect a diode tube across the deflection circuit. Presence of the diode tube permits currents to pass in one direction, but prevents their movement in the opposite direction.

In the earlier TV receivers which used magnetic deflection the diode tube was connected very much as shown in Fig. 17.

Action of the tube was quite simple. During the trace interval the voltages were as indicated by the polarity marks in Fig. 18.

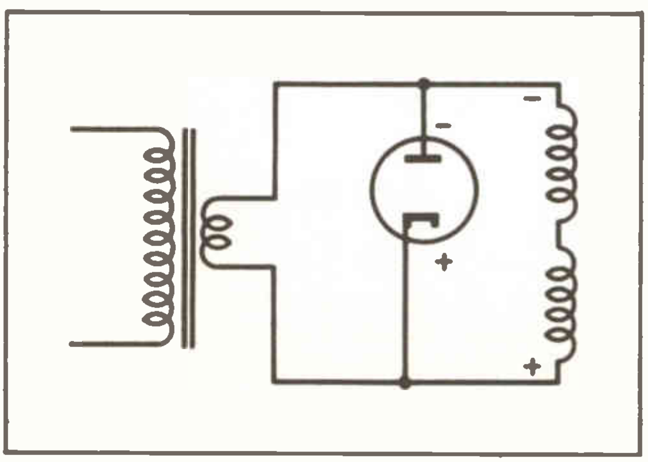

Fig. 18. Voltage polarities during trace interval.

Voltage polarities were such that the tube did not conduct during that interval. The voltage on the anode was negative, while that on the cathode was positive. The voltages were such as to prevent the tube conducting.

During the retrace movement the voltages were reversed. During the retrace interval the tube would conduct. However, its conduction during this interval was of little importance, since conduction neither aided the retrace action nor seriously impeded it.

At the end of the retrace action the shocking action sets up the oscillatory voltage and current. The polarity of that initial half-cycle of oscillation is as shown in Fig. 19. The voltage is generated in the deflection coils, and is applied to the diode tube. Current flows as shown by the arrows.

Electron current can flow through the diode tube in only one direction. There can be no reverse movement. Therefore, the tube acts to quickly damp out the oscillations which would otherwise seriously affect the picture at the left side of the screen.

Section 8. DAMPING ACTION AND TRACE MOVEMENT

It is interesting to note that the movement of current through the tube during the first half-cycle of the parasitic oscillations is exactly the same as would result if the current was being built up by the action of the output amplifier tube. To put this in other words, the movement of current through the deflection coils in the yoke is the same as would occur if the current was caused to move under the influence of the horizontal amplifier tube.

Engineers noticed this action, and took advantage of it. Since the action of the damper tube was such as to begin the trace movement, they deliberately designed the deflection circuits so the damper tube would control the trace movement during the initial period of the trace.

What they did was apply greater grid bias to the output amplifier tube, thus preventing that tube from conducting during the initial period of the trace. The idea was to permit the current through the damper tube to act as the current needed for the initial movement of the trace.

To make this action even more effective, the engineers redesigned the deflection yoke and other components in the deflection circuits. They deliberately created the circuit so inductance and distributed capacity was such that the circuit would resonate at a frequency approximately four times as high as the normal sweep frequency. In plain words, they designed the yoke and horizontal deflection circuit so it had a resonant frequency slightly higher than 60,000 cycles per second.

The result of this is that the current flowing in

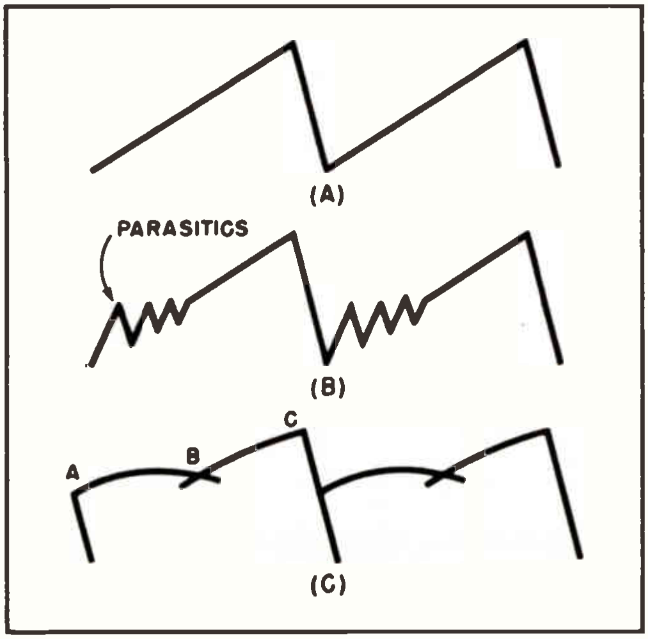

Fig. 20. How action of damper tube combines with that of horizontal amplifier to create sweep voltage.

the damper tube and the deflection yoke was sufficient to move the electron beam approximately one-quarter to one-third the way across the screen.

Applied voltages can be understood somewhat better by studying Fig. 20. The waveform at *A* in Fig. 20 is ideal waveform of the saw-tooth current applied to the deflection coils in the yoke. The waveform at *B* is the manner in which the current would actually flow if there was no damper tube in the circuit.

The third waveform is actually the one which is present in nearly all receivers using magnetic deflection. Oscillations are rectified by the damper tube and the resultant current applied to the deflection coils. This starts the electron beam on its trace movement across the screen.

After the trace has started, and just at the instant the first half-cycle of the shock oscillations end, the horizontal amplifier tube begins conducting, takes over, and continues the trace movement. Thus, the beam is moved across the face of the screen.

Using current from the damper tube in this manner makes the work of the horizontal tube somewhat easier. It is permitted to rest during the beginning of the cycle. This added rest permits the horizontal amplifier tube to stand up under the heavy duty to which it is subjected; stand up longer than it could otherwise.

The so-called "cross-over point," at which the damper tube ceases to move the beam and arranges for the horizontal amplifier to take over, is controlled by the HORIZONTAL DRIVE control. That control can be adjusted so the movement of the beam is smooth and even and constant, and there is no evidence in the appearance of the picture that the power to move the beam is divided between the action of two tubes.

Section 9. HORIZONTAL DRIVE CONTROL

The drive control is a variable control, thus there is a smooth transition of its effectiveness over a relatively wide range. This is desirable, otherwise it might be difficult to hit upon the exact position of the sweep movement at which the change from one tube to the other is effected.

Were the drive control not variable there

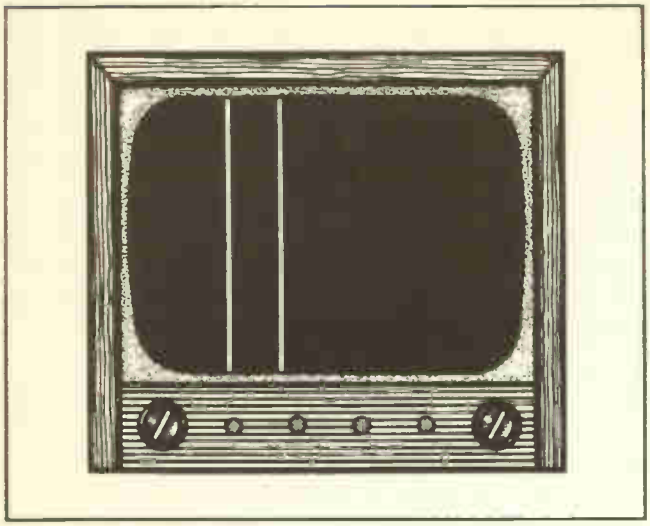

Fig. 21. Vertical bright streaks caused by improper setting of DRIVE CONTROL.

would always be the possibility the damper tube's effectiveness would end before the horizontal amplifier tube took over the action. Or, there would be the alternate possibility the horizontal amplifier would take over the beam movement control before the damper tube relinquished it.

Since the drive control is variable, its adjustment is the simple one of rotating the shaft of the control until the correct position is attained.

Improper setting of the drive control creates a clearly recognizable pattern on the screen of the picture tube. In most cases an improper setting acts to create two points during each sweep cycle in which the horizontal movement of the beam is halted, or the movement hesitates.

This interaction of influences from two tubes causes the beam to linger somewhat longer at each of two positions than at other locations in the sweep. The hesitation causes the beam to concentrate at those positions for slightly longer periods of time, thus making the screen somewhat brighter as a result.

Since this happens during each horizontal trace, we find a condition in which a bright spot in successive lines occurs all the way from the top of the screen to the bottom. Each of the bright spots occurs the same distance from the left edge of the raster, thus they are all in a vertical line.

These bright spots cause a vertical bright line to appear on the left side of the screen. In most cases there are two bright lines which extend from the top of the screen to the bottom. Usually they have an appearance which resembles rather closely the pattern shown in Fig. 21.

While in most cases there are two bright lines, as shown in Fig. 21, it should be remembered that in some cases there is only one line. If there are more than two lines the pattern is usually caused by some other circuit defect.

The horizontal drive control may take any of several forms. That which seems the most favored is shown in Fig. 22. It is merely a variable capacitor which is so connected that it shunts part of the oscillator driving voltage to ground before the signal reaches the grid of the output amplifier tube.

The variable capacitor shown in the diagram in Fig. 22 has a relatively high capacity. It is usually composed of several layers of conductive material which are separated from each other by layers of mica. Variations in the amount of capacity is obtained by rotating a screw arrangement which acts to compress the layers tighter together. The more tightly the layers of conductive material are pressed together the greater the amount of capacity present. The capacity is reduced by reducing the pressure on the layers of material.

Of course, such a variable capacitor does not have nearly the degree of variation as that in a variable gang tuning capacitor, nor in some of the other types of capacitors which are variable with respect to capacity. But there is sufficient variation for the purpose for which they are em-

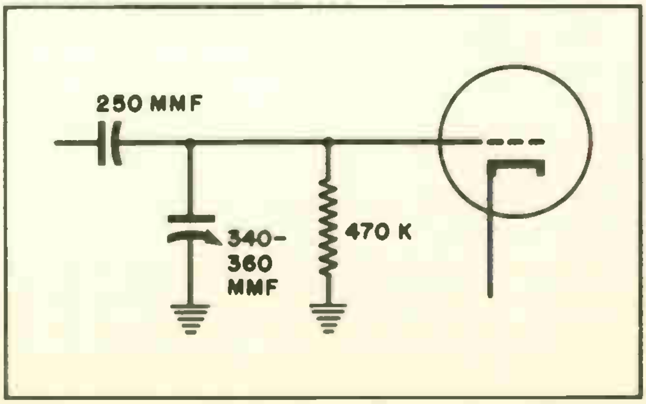

Fig. 22. Drive control consisting of variable shunting capacitor.

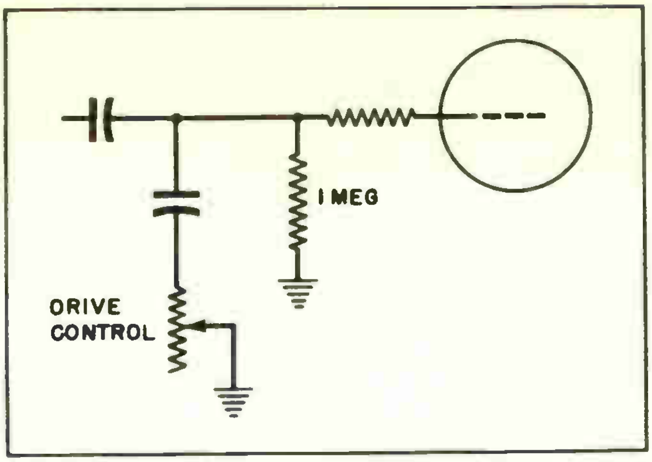

Fig. 23. Drive control composed of variable rheostat and fixed capacitor.

ployed. The degree of variation in the case of a drive control does not normally need to be great.

Another type of horizontal drive control consists of a fixed capacitor in series with a variable resistor, or rheostat. Such a circuit is shown in Fig. 23. The circuit in Fig. 23 is slightly less expensive for the manufacturer than the one in Fig. 22, but its action is not quite so positive, nor quite so smooth. Nevertheless, it is found in many receivers. There are also variations of it.

Section 10. HORIZONTAL OUTPUT TRANSFORMER

The horizontal output transformer is the link which couples the amplifier tube with the other parts of the deflection circuit consisting of the coils in the deflection yoke. It is also the link which serves as a voltage increasing device for connecting the horizontal amplifier to the input to the high-voltage rectifier.

Largely because of this latter factor, which permits the use of rectification of peak voltages developed during the retrace or "flyback" action, the horizontal output transformer is often called by a different name. It is being called, increasingly, the "flyback transformer."

Primarily, the purpose of the horizontal output transformer is to provide a means by which power in the anode circuit of the amplifier tube can be converted to a form of power which can energize the deflection coils in the deflection yoke. As such, it acts to transform the relatively high-voltage-and-low-current form of power in the anode circuit to a relatively low-voltage-and-high-current form of power for use in the deflection coils.

In this latter respect its action is closely similar to the action of the audio output transformer in a radio, or other audio amplifying device. An audio output transformer also acts to convert the type of power present in the anode circuit of the tube into the type of power needed to drive a loud-speaker.

The diagram in Fig. 24 shows the essential elements present in a horizontal output transformer. Insofar as the transformation action between the amplifier tube and deflection coils is concerned it acts merely as a primary and secondary pair of windings.

The diagram in Fig. 24 shows the primary winding as having a resistance of 90 ohms between terminal lugs 1 and 2. That is the part of the transformer we can look upon as the primary winding, since it is the winding which is in the anode circuit of the horizontal output amplifier. While this value of resistance in the primary winding can be considered typical, the fact remains that resistance in such winding may range from half that amount to twice the amount.

For this purpose we can look upon the winding to the right of the vertical iron core as being the secondary. It consists of a simple coil with a total resistance of 9 ohms, a coil that is tapped in two places. Here again, the value of resistance shown in the coil is typical, but other coils show varia-

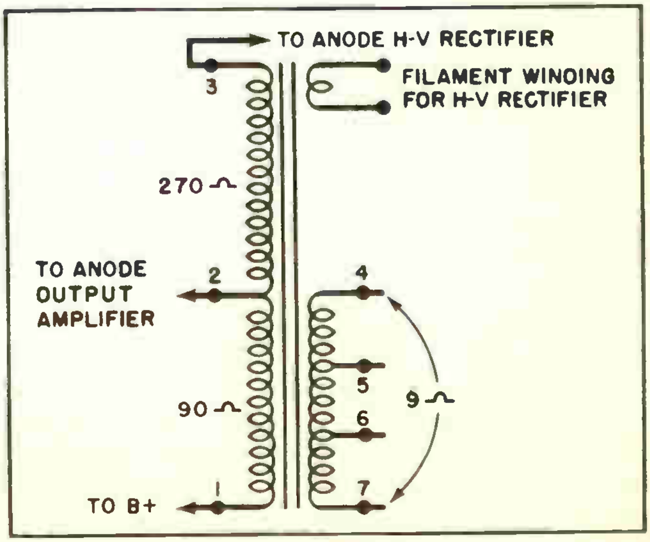

Fig. 24. Horizontal Output Transformer.

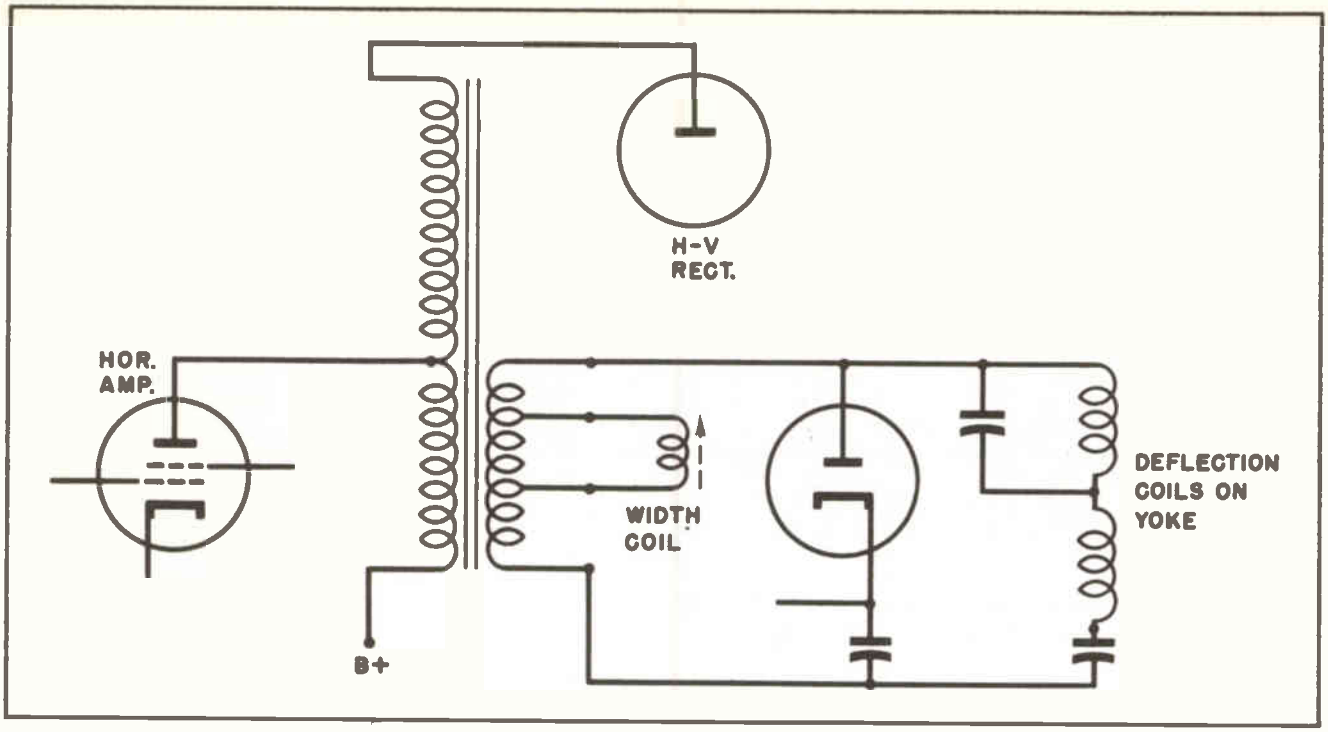

Fig. 25. Connections to horizontal transformer, showing taps to width coil and deflection coils.

tions above and below that amount. The exact amount of resistance depends on the size of wire used in the winding.

Section 11. CONNECTIONS TO THE TRANSFORMER SECONDARY

A transformer of this type provides a number of methods for connecting it to its respective circuits. Leads to the deflection yoke may be connected between terminal lugs 4 and 7, or they may be connected to two other points on the secondary winding.

Often the taps on the secondary winding are used for other purposes. Sometimes a second small coil is shunted between a pair of those taps so the power fed to the deflection coil can be controlled. Such a coil is usually referred to as the "width coil," or merely as the "width control."

The manner in which connections are made to the taps on the secondary winding is shown in Fig. 25. Those connections can be considered as being typical, but it should not be understood that all connections are made in exactly that manner.

The "width coil" is shown as being a coil having variable inductance, and as being connected between the two center taps on the secondary of the transformer. The width coil is often connected in exactly that manner.

Furthermore, the leads to the deflection yoke are shown as being connected to the two outside terminals of the transformer secondary. That method of connection is also used quite regularly.

But they are certainly not the only ways in which connections can be made to the transformer secondary.

In the circuit shown in Fig. 26 we find only three of the four terminals of the secondary winding in use. Even part of the secondary winding coil is not in use. This method of connecting the wires and leads to the transformer is used in many cases.

Still a third method of connecting the various leads to the transformer secondary is shown in Fig. 27. There we find only a small part of the secondary winding used to feed power into the lines to the deflection yoke. The width coil is connected across portions of the secondary winding not used for the supply of power to the deflection yoke.

Although we have shown three different methods in which the various leads can be connected

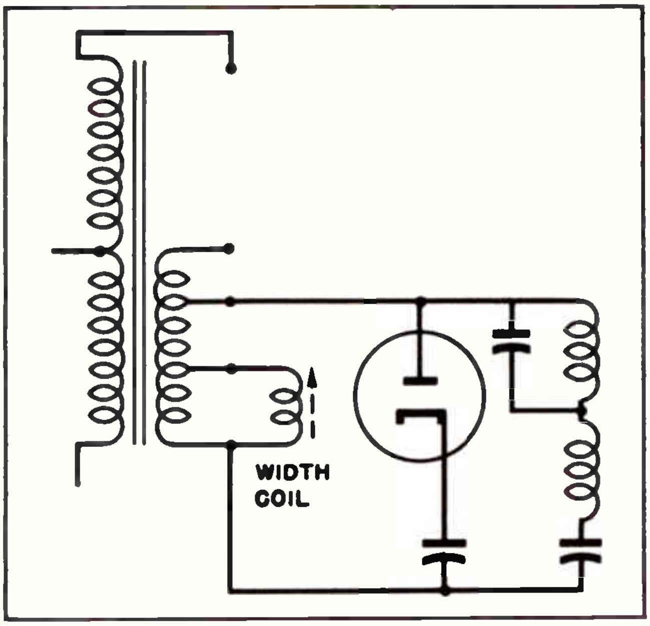

Fig. 26. Secondary connections which do not use all of secondary winding.

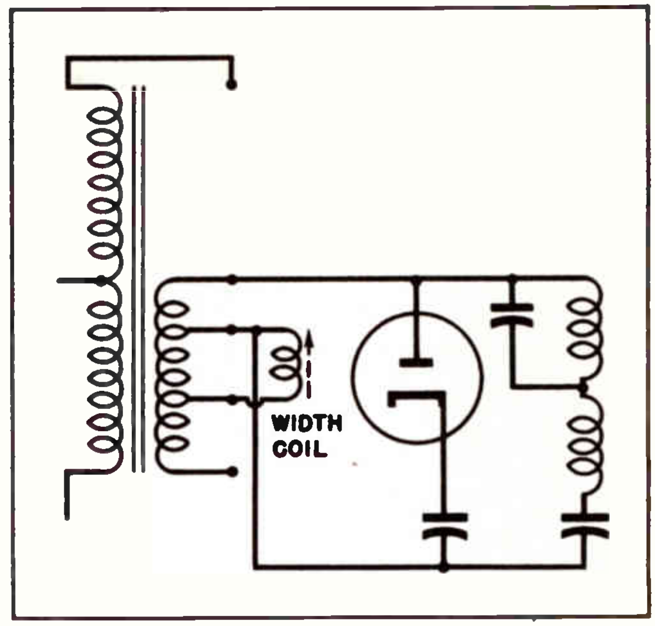

Fig. 27. Alternate method of connecting leads to transformer secondary.

to the secondary of the transformer, there are several other ways in which they can be connected.

Section 12. WHY THERE ARE DIFFERENT CONNECTIONS TO THE SECONDARY

The thought has probably come to you that the various methods of connecting leads to the secondary of the transformer can be rather confusing. Yet, it need not be.

Various taps are provided on the secondary winding of the transformer to make its use more flexible than would be the case if no such taps were present. This is much the same situation which prevails with respect to tapped windings on any other kind of a transformer.

It is nothing new to you—at least, it should not be—that a variety of voltages can be tapped off the secondary of any transformer by providing a variety of positions on the winding where the power can be tapped off.

If the power is tapped off the extreme ends of the secondary winding the voltage is somewhat higher than would be present if the power is tapped off a pair of terminals which are closer together on the secondary winding. However, in this case, the amount of current which could be tapped off would be somewhat less than could be tapped off terminals closer together.

The reverse is also true. If the secondary is tapped at terminals closer together than the extreme ends, the current available is greater than at the extreme ends. The voltage will not be so great, however.

In a case, such as the one presented by the horizontal output transformer, we are concerned with the problem of stepping down the voltage and stepping up the current, so more current is available for application to the coils in the deflection yoke. But it is usually desirable to have some degree of control over the exact amount of current or voltage which can be tapped off.

It should be kept in mind that all deflection yokes are not alike. Some are designed to operate with 53° angle picture tubes, others with 70° deflection angles, and others with deflection angles in picture tubes as high as 90°, and even higher. Some of the newer types of tubes have extremely wide angles of deflection.

Each of these various deflection angles call for differing amounts of current to provide the necessary magnetic field strength for deflecting the electron beam.

By providing taps on the secondary winding of the output transformer the manufacturer makes it possible for the transformer to be used in more kinds of receivers than would otherwise be possible. He does not restrict use of the transformer to a single application.

In practice it will often be found that using one pair of terminals on the secondary winding does not spread the sweep of the beam to the full width of the picture tube, or conversely sweeps the beam far past the edge of the picture tube screen. By choosing a different pair of secondary terminals to which the leads to the deflection yoke are connected the sweep can be brought more nearly in line with the needs of the picture tube.

Most modern horizontal transformers are so designed that they can be used with a variety of models of television receivers, so long as the primary winding is designed to work with the particular output amplifier tube used in that receiver, and the physical dimensions can be accommodated. One set of secondary taps may be used with one receiver, but a different set of taps may have to be used with a different receiver.

The matter of physical dimensions of the transformer should not be overlooked nor neglected, since the transformer is often mounted inside a metal-enclosed compartment on the top of the chassis. If the physical dimensions of the transformer are too large to permit it to fit within that metal enclosure it can not be used as a replacement for an original transformer which may have become defective.

The illustration in Fig. 28 provides a pretty good idea of the appearance of the metal enclosure which often surrounds the compartment within which the horizontal transformer is housed.

The reason for housing the transformer within such compartment is because the transformer is also used to generate high voltage needed by the final anode of the picture tube. This means that very high voltages are present in and around the transformer, thus making it highly desirable to isolate, and protect it. The metal enclosure provides that protection.

Another factor accounts for the desirability of housing the transformer within the metal enclosure. That is the matter of radiations of high-

Fig. 28. Cover removed from high-voltage compartment reveals horizontal transformer and tubes.

frequency signals from the horizontal deflection circuits. These radiations can create serious interference in nearby television receivers, and even in some kinds of AM radio receivers.

Some cities have special ordinances which require the horizontal transformer to be shielded by such a metal enclosure. TV receivers which do not have such shielding cannot be sold in those cities.

Section 13. PRODUCING HIGH VOLTAGE

We have gone into the subject of TV high-voltage circuits quite extensively in earlier lessons. One entire lesson was devoted exclusively to that subject, and other lessons touched on various aspects of it. There seems little need to go into the subject very extensively at this time, since to do so would be little more than a repetition of subject matter already covered.

Nevertheless, since the production of H-V in modern TV receivers is so closely tied with the action of the horizontal deflection systems it seems fit and proper that we again mention the subject. It seems only right that we mention it again, if for no other purpose than to tie the two subjects together in such manner as to point out very clearly their interdependent relationship to each other.

In action, the output amplifier tube feeds a steadily rising current into the primary winding of the output transformer. This steadily rising current flow occurs during the trace action. The steadily rising current acts to provide the magnetic field needed to move the electron beam across the face of the picture tube.

That current flows from the anode of the output amplifier tube, as shown by the solid arrow in Fig. 29. It flows through the lower section of the primary winding, flows toward the B+ voltage source.

By the time the end of the trace movement is reached the current flowing in the primary winding of the transformer has reached its peak value. In most cases the amount of current flowing through the winding is just about the maximum the tube is capable of passing.

The very instant following that in which the current flow reaches its maximum the current suddenly ceases to flow. It stops.

Suddenly stopping the flow of current through a coil of wire in that manner causes the magnetic field, which had previously built up around the coil, to collapse very suddenly. This occurs in any situation, and is not restricted to the action in this particular type of transformer.

Because the magnetic field collapses very suddenly, it produces a sharp peak voltage within all parts of the coils through which the magnetic lines of force cut.

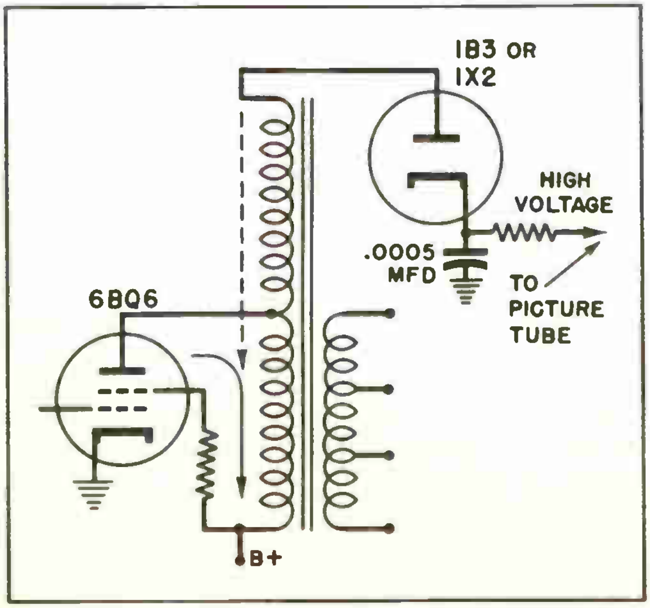

Fig. 29. High-voltage produced by horizontal deflection circuit.

The sharp, peak voltage is induced in the portion of the primary winding between B+ and the connection to the anode of the amplifier tube, but an even higher peak voltage is induced in the upper portion of the winding which is connected in series with the regular primary winding. The direction and polarity of that voltage is indicated by the dashed arrow in Fig. 29. This is the portion of the winding which is connected to the anode of the H-V rectifier tube. The H-V rectifier in Fig. 29 is shown as being either a 1B3 or a 1X2.

Those two voltages are in series with each other, thus they add together. The total voltage applied to the anode of the H-V rectifier tube during that short instant of time is equal to the sum of those two voltages, plus the normal B voltage. This means that the voltage applied to the anode of the H-V rectifier tube is quite high, usually ranging upward into many thousands of volts.

The full magnitude of the voltage present at the anode of the H-V rectifier can be better appreciated when it is remembered that the peak voltage which is appplied to the anode of the output amplifier tube during this action is often in excess of 5000 volts. That applied to the anode of the H-V rectifier is normally several times that high.

Section 14. COUPLING INTO THE DEFLECTION YOKE

The manner in which the output of the horizontal transformer is coupled into the deflection coil has been touched on in a number of previous lessons. It is well that we touch on a few additional points of interest at this time.

Horizontal deflection coils are mechanically included with the vertical deflection coils in an electro-mechanical device which has come to be universally known throughout the television industry as the *deflection yoke.*

The deflection yoke is slipped over the end of the picture tube neck, and moved up against the flaring bulb of the tube so it fits there as snugly as possible. A photograph of a deflection yoke is shown in Fig. 30. In most receivers the yoke must

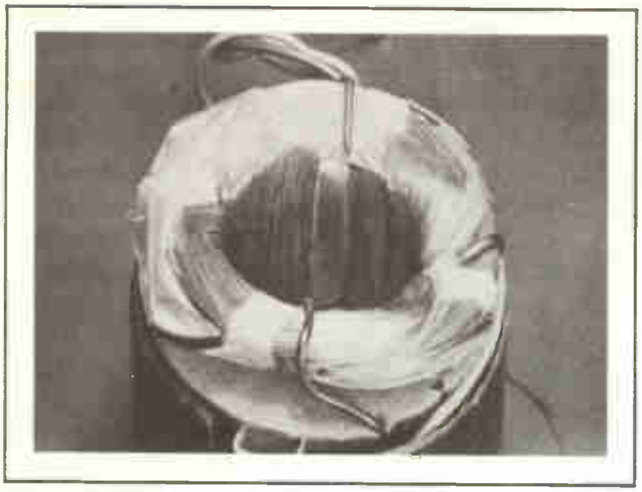

Fig. 30. Deflection Yoke.

press tightly against the flaring bulb, otherwise part of the sweep is lost, and sometimes shadows form on the raster.

The deflection yoke is so positioned that the vertical coils are located on each side of the neck of the tube, while the horizontal coils are positioned so one is above the neck and the other below it. By placing the vertical coils on each side of the tube neck the magnetic lines of force between them pass through the neck in a horizontal plane. When the electrons in the beam pass through the horizontal lines of force they are deflected up or down, depending on the instantaneous polarity of the magnetic field.

When the horizontal deflection coils are positioned so one is above and the other below the neck of the picture tube, magnetic lines of force pass between them in a vertical direction. When the electron beam then passes through that magnetic field the electrons in the beam are deflected to the right, or to the left, in a horizontal direction. The direction in which the beam is deflected at any given instant of time depends on the instantaneous polarity of the magnetic field at that given instant.

Electrical connections to the horizontal deflection coils are shown in Fig. 31. Usually, the coils are isolated at one end by the presence of a large capacity capacitor. This prevents passage of D-C. The one shown in the diagram in Fig. 31 has a capacity of 0.5 mfd. This is a relatively common value.

While presence of the capacitor is intended to prevent passage of direct current through deflection coils, it also helps isolate the coils for other purposes.

An interesting item in connection with the horizontal deflection coils is the presence of a small capacitor across one section of the horizontal coils. The one in the diagram in Fig. 31 is shown to be 56 mmfd. This is a common value for that capacitor, but slightly differing values are found occasionally. Sometimes the capacitor has a value of 47 mmfd, but there is not much variation from one or the other of these two values.

There is a certain amount of *leakage inductance* present in the output transformer. That is unavoidable, it is always present.

Presence of leakage inductance tends to set up a rippling disturbance in the appearance of the picture on the screen unless it is counteracted and controlled. That is the purpose for the small capacitor shown connected across the horizontal deflection coil in Fig. 31.

Should that capacitor happen to become open, or otherwise defective, the picture on the screen will take on a rippling appearance not greatly different from that of a flag rippling in the breeze. Therefore, wherever such a rippling appearance occurs in a television picture an experienced service technician immediately looks for a defect in that little capacitor.

In the older TV receivers that capacitor was

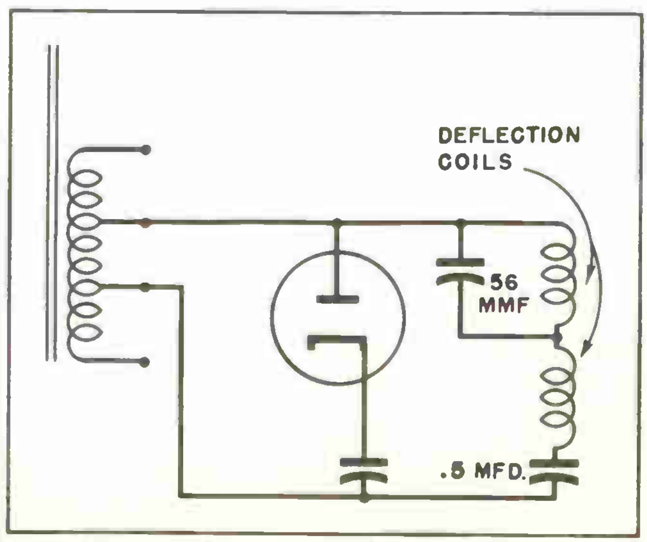

Fig. 31. Connections to horizontal coils on deflection yoke.

often connected across a terminal strip under the chassis. The more modern tendency is to connect it directly to the terminals of the deflection coil, covering it up with the cover of the deflection yoke when it is in place. Often the capacitor lies closely adjacent to the resistors which are connected across the two vertical coils on the deflection yoke.

Fig. 32 gives a good idea of how the capacitor appears when it is mounted on the body of the deflection yoke.

Section 15. TYPES OF DAMPER TUBES

Demands upon the damper tube are relatively severe. The tube used for that purpose must be a power rectifier tube, capable of passing relatively large currents.

It is hard to designate the most widely used tube which can be found in this circuit. The 6W4 has proven very popular, but so have some of the other 6-volt rectifier tubes which have an indirectly heated cathode. A tube with *an indirectly heated cathode* is highly desirable for this operation, since the cathode must be separated from filament circuits common to other tubes.

Some manufacturers have used a rectifier with a *directly heated cathode*, such as the 5V4 and 5U4, but when they do they must provide a separate filament winding on the power transformer. Furthermore, that isolated heater winding must be well insulated to prevent voltage breakdown.

The voltage present on the cathode of the damper tube often exceeds 500 volts and, in some receivers, goes much higher than that. Therefore, there must be protection against that voltage.

One tube that has achieved some degree of popularity as a damper tube is the 12AX4. It is especially popular in AC-DC receivers.

Another rectifier tube which is found in a good many AC-DC receivers is the 25W4. It is similar to the 6W4 except for the filament voltage and current rating.

One important requirement of the tube which is used in the damper circuit is that the cathode be isolated, or that the tube can be used so the cathode is subject to being isolated. In most cases this means that the tube is an indirectly heated

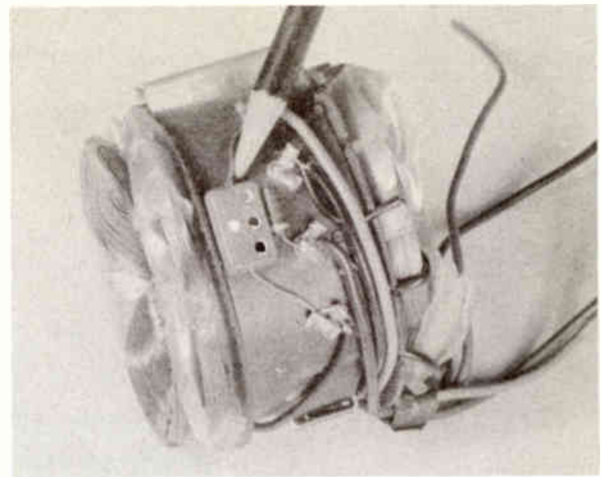

Fig. 32. Position of capacitor connected across one of horizontal deflection coils.

cathode tube, as was mentioned previously.

The peak voltages which appear between the cathode and the filament of the damper tube are often quite high. A normal voltage is often as high as 500 or 600 volts, but the peak voltages can easily be much higher.

One of the most serious troubles experienced with damper tubes is their tendency for the insulation to break down between the filament and cathode. By their very nature the filament must be close to the cathode in order for the filament to heat the cathode. But if they come too close together the high voltage which exists between the filament and cathode can bring about arcing between them.

Because of the tendency for some filaments to sag slightly when they are heated this is a danger which is always present. Usually the failure of a damper tube can be traced to eventual breakdown of the insulation between those two elements.

Quite often the breakdown between the filament and cathode is clearly visible when the tube is observed during its operation. Sparks can actually be seen arcing between the two elements.

In most cases such a defect can *not* be checked on a tube checker. Unless the breakdown creates an actual short circuit between the filament and cathode the defect does not show up on a tube checker. Very often the tube checker test shows the tube to be good.

But just as soon as a high voltage is placed across the two elements arcing occurs, and the tube will not work in the damper circuit.

The only solution for trouble of that type is to replace the damper tube with another known to be good. Experienced technicians often try a routine substitution of a new damper tube whenever visible symptoms suggest the possibility the damper tube might be defective.

NOTES FOR REFERENCE

Purpose of the horizontal amplifier is to convert electrical saw-tooth voltage from the oscillator into adequate power to energize the horizontal coils in the deflection yoke.

Horizontal amplifiers used with electrostatic deflection systems are simple voltage amplifiers.

Electrostatic deflection is much more simple than magnetic deflection, but it is practical only with small size picture tubes.

Power from the horizontal amplifier provides the needed energy to move the electron beam in a horizontal direction.

In a magnetic deflection picture tube the deflection system requires considerable current to create the necessary magnetic field for deflecting the electron beam.

Horizontal amplifier circuits in modern television receivers are complicated by the fact they are required to perform other duties besides the simple one of deflecting the electron beam in the picture tube.

The horizontal amplifier is usually depended upon to provide power needed to create high-voltage for the picture tube.

Another duty often placed on the horizontal amplifier is that of providing a boosted B+ for some of the amplifier circuits requiring a higher voltage.

A boosted B-supply is obtained by filtering the high voltage pulses which appear at the cathode of the damper tube.

The horizontal amplifier develops a lot of power, therefore a powerful tube must be used for that purpose.

A tube used in the horizontal amplifier circuit of a TV receiver often develops as much power as a small transmitter.

The two most widely used beam power tubes in horizontal amplifier operation are the 6BG6 and the 6BQ6.

The 6BQ6 is a much more powerful tube than the 6BG6.

Another tube often used as a horizontal amplifier is the 6CU6. It is interchangeable with the 6BQ6, but has better operating characteristics, and somewhat higher electrical ratings.

Another beam power tube, the 6CD6, is even more powerful than those others named.

A beam power tube often used as a horizontal amplifier in AC-DC receivers is the 25BQ6. It is identical with the 6BQ6 except for filament ratings.

The horizontal amplifier is usually self-biased. In most cases the biasing takes the form of a grid-leak bias; but sometimes a modified form of cathode bias is also used.

The *drive control* acts to control the strength of the oscillator signal fed to the grid of the horizontal amplifier.

Initial horizontal movement of the electron beam during the trace period is handled by the damper tube.

After the damper tube has moved the electron beam one-quarter to one-third the distance across the screen of the picture tube the horizontal amplifier takes over and moves it the balance of the way.

The point at which the horizontal amplifier tube takes over from the damper tube the movement of the beam is controlled by the *drive control.*

Improper adjustment of the drive control results in a characteristic pattern on the screen. It consists of a pair of vertical bright streaks on the left side of the raster.

Principal need for the damper tube is to damp out the shock oscillations set up in the horizontal circuits by the retrace action.

The damper tube performs other functions beside that of damping out shock oscillations. One is to assist the initial movement of the beam during the horizontal trace interval, another is to provide boosted B-voltage supply.

The damper tube often breaks down because of the high voltage peaks which occur intermittently between the filament and cathode.

When insulation between filament and cathode of a damper tube breaks down, the tube must be replaced.

Such breakdowns often cannot be detected by checking on a tube checker, but the trouble can be corrected by replacing the old damper tube with a new one.

Quite often arcing breakdown between filament and cathode in a damper tube can be observed through visual inspection.

If the small capacitor connected across one of the horizontal deflection coils becomes open it will interfere with the pattern on the screen.

When a wavy pattern, similar to a waving flag, appears in the picture the trouble is usually caused by an open capacitor across one-half the deflection coil.

Most horizontal transformers have several connections to the secondary winding so it can be used in several different types of receivers.

Additional control over the width of the pattern on the screen can be obtained by connecting a small variable inductance coil between two secondary terminals on the horizontal transformer.

High-voltage for the final anode of the picture tube is obtained by rectifying and filtering the peak voltage which appears across the horizontal transformer during retrace action.

NOTES

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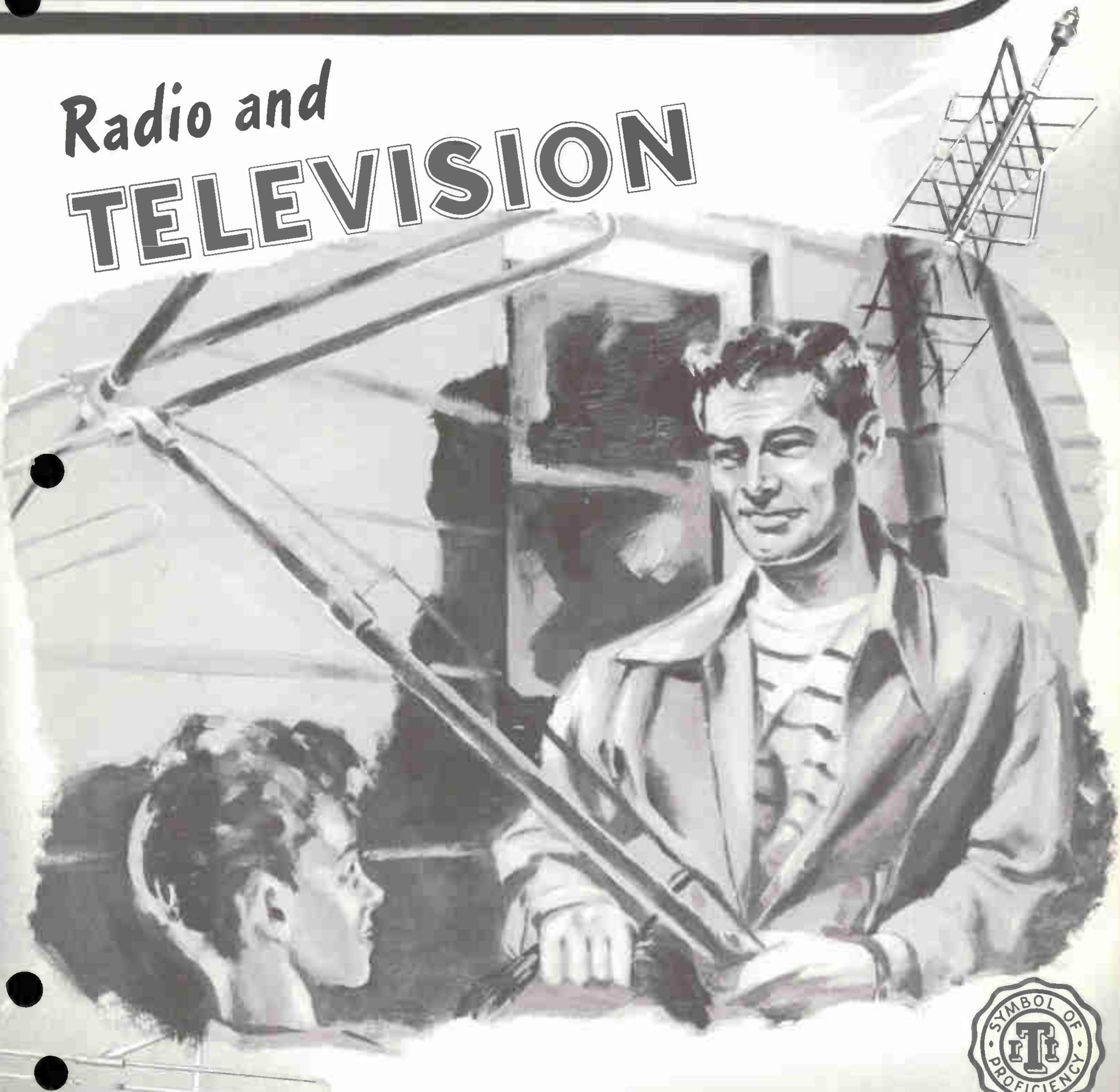

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HORIZONTAL DEFLECTION SYSTEMS

Contents: Introduction — Circuits Included in Horizontal Deflection System — Action in Horizontal Deflection System — Types of Automatic Frequency Control Circuits — Synchro-Lock System of AFC — Phase Detector Circuit used as AFC — Frequency Control by Pulse-Width-Modulation — The Synchroguide AFC Circuit — Common Troubles in Horizontal Deflection System.

Section 1 INTRODUCTION

Discussions in previous lessons have made you familiar with many of the component circuits which are a part of the horizontal deflection system.

In this lesson we will examine the manner in which these various components are integrated into a complete operating system. For the most part we will center our attention on those circuits included in the ventilated metal enclosure in Fig. 1.

In various places we have mentioned briefly the matter of automatic frequency control circuits. These are electrically located between the sync separator circuits and the horizontal oscillator.

Those brief references in the past have been little more than introductions; they served only to make known the existence of such circuits without getting into any technical explanation of them.

In this lesson we go into automatic frequency control circuits in much greater detail. An understanding of these automatic circuits is important since they provide a connecting link between the incoming sync pulses and the synchronization control of the horizontal oscillator.

Automatic control circuits are used only on the *horizontal* oscillator. They are not needed as an isolating circuit ahead of the *vertical* sweep oscillator.

The *horizontal* oscillator, as you well know, is triggered by a short, sharp voltage pulse. It is maintained in synchronism by the regular horizontal sync pulses which ride as a modulating component on the composite video signal.

Unfortunately, the composite video signal also contains other short electrical voltage pulses which originate as electrical "noises." The exact

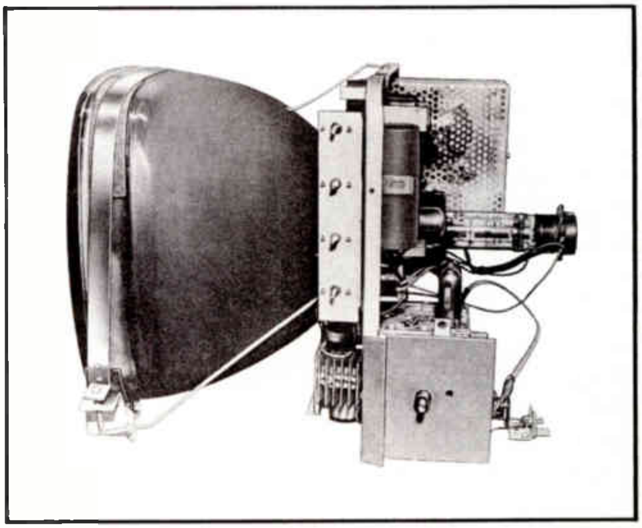

Fig. 1. Vertical type chassis showing ventilated metal shielding which encloses Horizontal Deflection System circuits.

origin may be the ignition system of an automobile, a fluorescent lamp, a food mixer, an electric razor, or any of a hundred other sources. Almost every kind of electrical apparatus is capable of originating some form of electrical noise, and most of that noise is in the form of irregular electrical voltage pulses.

Such irregular electrical noise pulses are capable of triggering the horizontal deflection oscillator under certain conditions when they reach the control of the oscillator tube. If they trigger the horizontal oscillator a few microseconds ahead of the regular sync pulse it results in erratic action of the oscillator, and the picture is adversely affected.

Since the horizontal oscillator is triggered by a sharp electrical voltage pulse of short duration, and since, to provide regular sweeps of the electron beam, it is desirable to trigger it *only* with the regular sync pulses and not ambient (local or surrounding) noise pulses, some means must be provided to screen noise pulses from the sync pulses. This is the function of the automatic frequency control circuits which serve as a link between the sync separator and the horizontal oscillator.

Hints on servicing the horizontal deflection system are also included in this lesson. We should point out that instructions for trouble-shooting this section of a television receiver fills a later lesson which is devoted to that subject.

Section 2. CIRCUITS INCLUDED IN A HORIZONTAL DEFLECTION SYSTEM

It is not possible to outline the exact circuits which are used in the horizontal deflection system of every TV receiver on the market. There are too many; and some are much more complicated and involved than those in other models.

Some inexpensive receivers make little attempt to filter the synchronizing pulses through an automatic frequency control circuit. Some do not include a Boosted B+ circuit in the horizontal deflection system. Still other models omit certain other special circuits.

Most of the more modern receivers incorporate the high-voltage power supply as a part of the horizontal deflection system, but a few isolated models continue to use a completely separate H-V power system. Some use a single output amplifier tube, others use a pair of tubes in parallel.

Some receivers use a modified phase detector as the frequency control circuit, others use a system which compares the width of pulses, thus giving it the name pulse-width-modulation. Both of these circuits can be used to control the horizontal oscillator. Both have advantages; both disadvantages. One method is favored by some manufacturers, the other by other manufacturers.

However, the television industry has finally settled down so the majority of modern receivers follow a reasonably consistent pattern. By learning how each of the various circuits function, then learning to recognize each when it is found in a given receiver, servicing work is much easier.

Section 3. ACTION WHICH TAKES PLACE IN HORIZONTAL DEFLECTION SYSTEM

It is sometimes a little difficult to decide just which circuits should be included in a discussion of a complete horizontal deflection system, and which should be omitted.

Probably the best way is to include all those circuits which perform any duties in connection with the horizontal movement of the electron beam. Those which are closely connected with that action, so as to physically or electrically act in conjunction with that action, should also be included. By right, it is proper to include the horizontal AFC circuit since it is so much a part of the deflection system.

The prime purpose of the horizontal deflection system is to move the electron beam horizontally. Since that is true it seems right and proper that we begin our examination at that point.

The beam is deflected under the influence of an electrostatic field between two deflecting plates, or by the influence of an electromagnetic field surrounding the magnetic deflection coils and existing between them. Since magnetic deflection is so very common it is right and proper that we devote more of our attention to it.

In a magnetic deflection system the magnetic field is built up by the passage of current through a pair of coils which are physically placed above

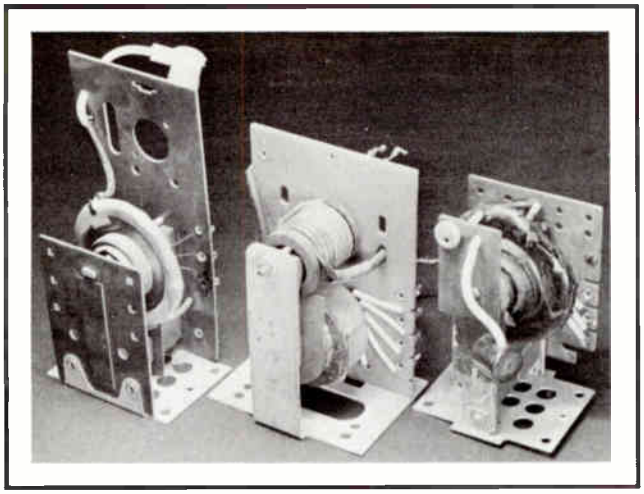

Fig. 2. Typical Horizontal Deflection Transformers.

and below the neck of the picture tube. Energizing current to create the necessary magnetic field is supplied by the secondary of the horizontal output transformer.

To perform its primary function of providing the necessary current to generate the varying magnetic field around the neck of the tube, the horizontal output transformer acts as a step-down transformer. The high-voltage-low-current relationship in the primary is transformed into a low-voltage-high-current relationship in the secondary. Such transformers assume many physical shapes; the more common types are shown in Fig. 2.

Of course, we are also aware that the output transformer performs other functions, one of which has led it to be commonly called the "flyback" transformer. But, in a sense, that is incidental to its original and principal function as a step-down transformer.

Power is fed into the primary of the output transformer by the output amplifier tube—or tubes. As has been explained in previous lessons, these amplifier tubes must be capable of delivering relatively large amounts of power. Therefore, these tubes must be ruggedly built.

In this connection it must be kept in mind that the output amplifier tubes perform the function of translating a specially shaped, voltage waveform into electrical power. This means the grid of the amplifier tube must be fed an electrical signal voltage of the proper magnitude and the proper shape to enable the power amplifier tube to deliver the correct amount of power to perform the job it is intended to do. Figure 3 shows the basic essentials of the circuits involved.

The driving voltage on the control grid of the amplifier tube is supplied by the horizontal oscil-

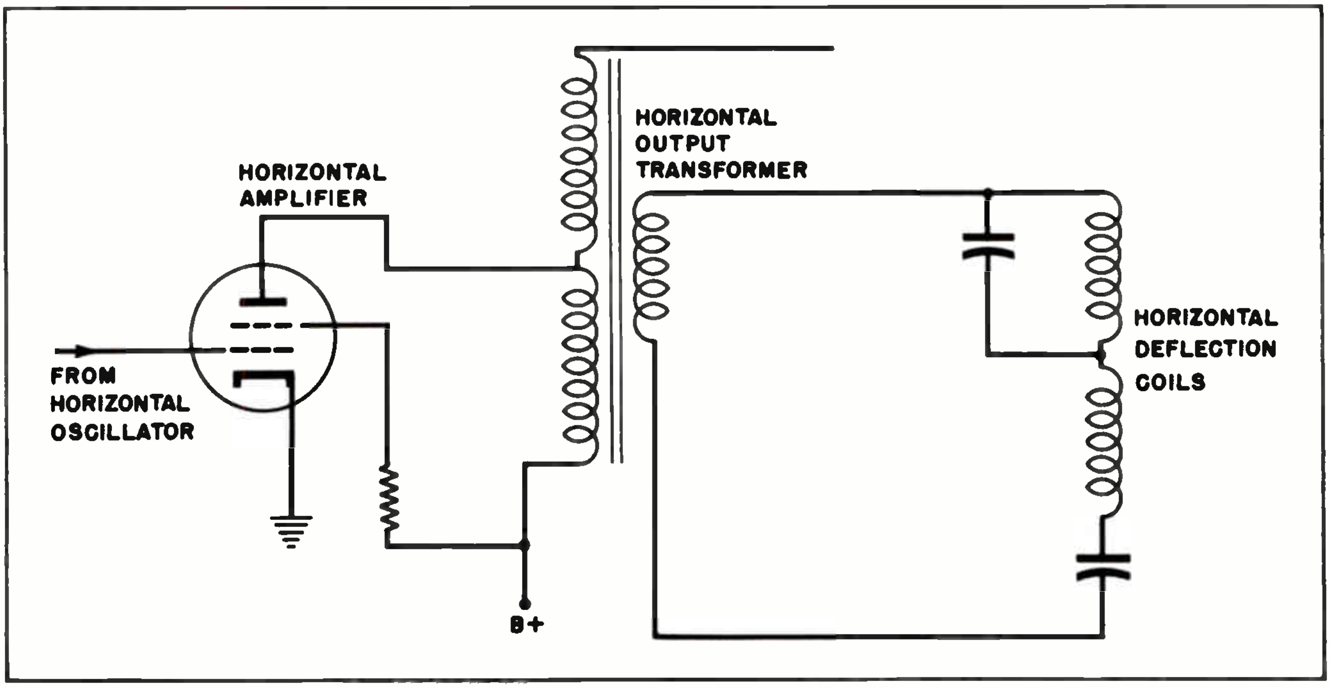

Fig. 3. Essential circuits involved transforming oscillator signal into deflection power.

lator stage. Usually it is coupled into the control grid of the amplifier through a coupling network which aids in shaping the voltage waveform into its correct shape. Often, adjustable controls are included in that coupling network, the most common of which is the *horizontal drive control.*

The action of the horizontal drive control has been described in previous lessons, so there is little need to go into a detailed discussion of it at this time. Its location in the horizontal deflection system can be pretty well visualized by studying Fig. 4.

All receivers do not include a horizontal drive control between the horizontal oscillator and amplifier. Yet, most receivers do have such control.

Nor are all such controls designed exactly the same. Most are simply a shunting capacitor which possesses some degree of adjustability or variability. Such a control circuit is shown in Fig. 4. Its purpose is to shunt some of the signal to ground before it can reach the grid of the amplifier.

Others consist of a capacitor in series with a variable rheostat. This was explained in a preceding lesson.

The principal purpose for using a drive control is to aid in establishing the so-called "cross-over point" in the horizontal sweep. During the first portion of each horizontal sweep the power is supplied by the damper tube. Then the action is transferred to the horizontal amplifier tube. It is the function of the *drive control* to determine the exact position on each sweep at which that transfer is brought about.

Making the shunting capacitor slightly variable, or placing a fixed capacitor in series with a variable resistor, provides sufficient adjustment to bring about some degree of control over the *cross-over-point.*

There seems little need for going into another discussion of the horizontal oscillator. One entire lesson was devoted to that subject, and several others touched on isolated aspects of the circuit. It will be discussed still more in a later lesson which describes trouble-shooting of those circuits.

Suffice it to say that the oscillator creates the special type of voltage waveform needed to drive the horizontal amplifier so it can deliver the correct amount of power to the output transformer and the deflection coils.

Several types of oscillator circuits can be used for this purpose. At this time the television industry has pretty well settled on two general types. One is the *blocking oscillator* and the other is the *multivibrator.*

The blocking oscillator is used most widely by

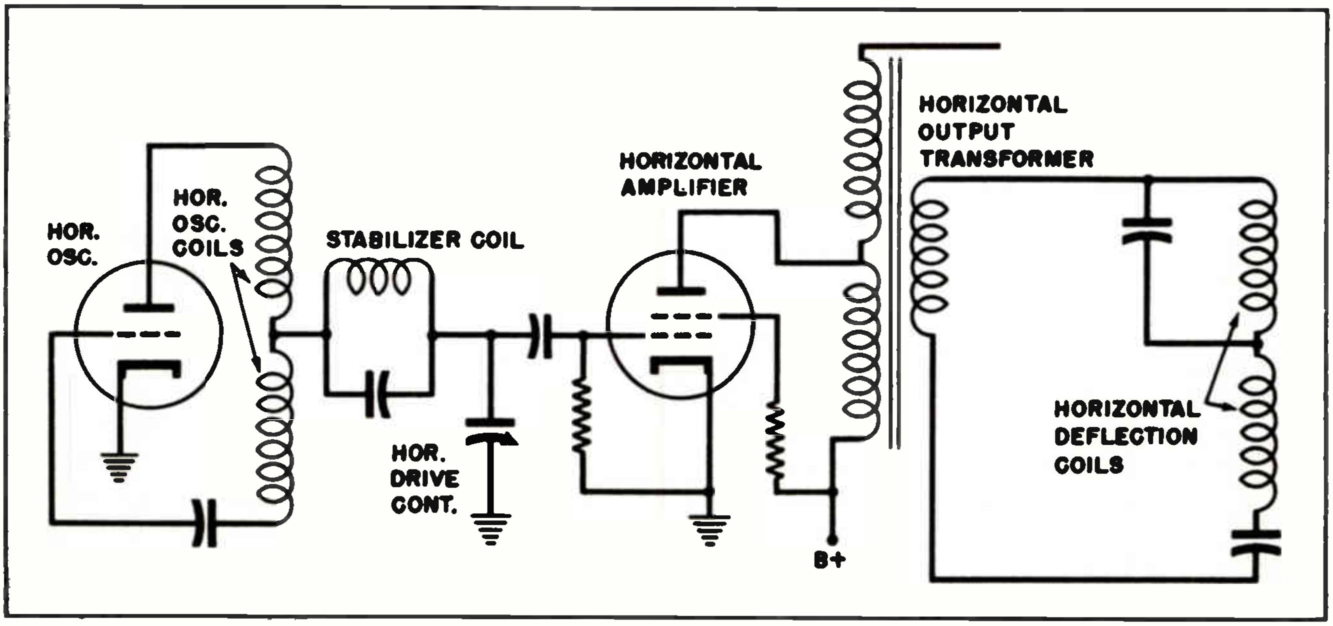

Fig. 4. Oscillator and coupling to horizontal amplifier showing horizontal drive control.

those manufacturers who follow the lead of RCA, and operate under RCA patents. The multivibrator is used more widely by companies who avoid using RCA patents. This is a rather broad statement, and must be limited by reservations and exceptions. Nevertheless, as a general statement, it is reasonably accurate.

Section 4. TYPES OF AUTOMATIC FREQUENCY CONTROL CIRCUITS

Several manufacturers have come up with differing types of automatic frequency control circuits which accomplish the purpose of causing the sync pulses to synchronize the horizontal sweep without permitting random noise pulses to affect the sweep. These are known under a variety of trade names, the more common of which are *Synchro-guide*, *Synchro-Lock*, *Franklin A-F-C*, *Modified Franklin*, and *Gruen A-F-C*.

When carefully examined it will be found that automatic frequency control circuits most commonly used in actual television receivers can be grouped into two general systems. One employs the principles of phase detection, and the other acts upon the width of a composite synchronizing pulse.

The automatic frequency control circuits which employ the principles of phase detection are used most frequently with multivibrators. This means that a TV receiver which uses a multivibrator as the horizontal oscillator will usually have some form of phase detection in the automatic frequency control circuit.

On the other hand, an automatic frequency control circuit which acts upon the width of a sync pulse is more commonly used in those receivers which have a blocking oscillator in the horizontal circuits. This latter type of frequency control is called pulse-width-modulation.

It should be understood that these are general statements, and are reasonably accurate. Actually, there is no technical reason why a phase detector AFC cannot be used with a blocking oscillator, nor a pulse-width-modulation AFC with a multivibrator. But that is not the general practice.

The *Synchro-guide* circuit, designed by RCA, is a form of pulse-width-modulation. The *Synchro-lock*, also designed by RCA, employs principles which differ little from a form of phase detection. The Gruen system is a modified form of phase detection.

Automatic frequency control circuits using the principles of pulse-width-modulation usually require an oscilloscope to properly align the circuits when they require servicing. Some manufacturers avoid using this type of control circuit on the theory that many servicemen do not have access to an oscilloscope.

The big advantage of using an AFC circuit employing the principles of pulse-width-modulation is that a single tube with two triode sections — such as 6SN7 — can act as both oscillator and control tube. This helps reduce the number of tubes in a receiver.

In most cases those automatic frequency control circuits which use the principles of phase detection can be serviced and adjusted without an oscilloscope. But they have the drawback that an extra tube is needed for the control tube. This results from the fact that a pair of diodes are needed to bring about the control action. A 6AL5 is most often used for this purpose, but a 6H6 can be used. It is even possible to use the pair of diodes in a tube like the 6SQ7 or the 6SR7, although, in practice, this is rarely done.

Section 5. SYNCHRO-LOCK SYSTEM OF AFC

The *Synchro-Lock* circuit was one of the first used in a TV receiver to stabilize the horizontal oscillator, and to prevent electrical noise pulses interfering with the sweep action. That circuit has since been discarded almost completely, and it is doubtful if any manufacturer is using it at this time.

The circuit was entirely effective, and did the job it was intended to do. The circuit fell into discard because it used three tubes, and was no more effective than any of several other circuits which have since been developed.

Since the Synchro-Lock circuit was designed by RCA, and has been usea in dozens of models built by many manufacturers, it is well that we devote some space to an explanation of how the circuit worked. Hundreds of thousands of receivers which have that circuit are still in use, and many will probably continue in use for many years.

The Synchro-Lock system included the action of the oscillator itself as well as of the control tubes. A typical Synchro-Lock circuit is shown in Fig. 5.

You will note the system contains three principal elements. One is an electron-coupled oscillator which generates an ordinary sine wave voltage output. Another is a reactance tube, and the third is a duodiode used as a discriminator, or phase detector. In truth, it is more a discriminator than phase detector.

Details of the operation of the circuit revolve around the action of linking together the output of the oscillator with that of the discriminator, and the manner in which they are controlled by the reactance tube.

The oscillator is designed to generate a sine wave voltage with a frequency as near 15,750 cycles per second as possible. Note that the inductor coil of the oscillator is closely coupled to the center-tapped coil of the discriminator. The action of the oscillator, then, is to apply equal voltages to each of the two plates of the discriminator circuit.

Note that the sync pulses are also applied directly to the two anodes of the discriminator tube.

Now, when the sync pulses are applied to the discriminator at the exact instant the sine wave voltage is at zero, the total output of the two halves of the diode tubes will be the same and the voltage across the voltage divider composed of resistors R_1 and R_2 in Fig. 5 will be zero, because both sides are balanced.

The reason why this is so can be better understood by studying the voltage graphs in Fig. 6 for a moment. The upper graph shows the voltage on the anode of the top diode in Fig. 5, while the center graph represents the voltage on the anode of the lower diode. If the voltages are equal, the voltage across the filter network at the bottom of Fig. 5 remains stable.

Now, if the voltage from the synchronizing pulses is superimposed upon the sine wave voltage so it strikes the anodes of the two diodes at the instant the sine wave voltage is crossing the zero line, the sync voltage will neither be adding nor subtracting from the instantaneous sine wave voltage. This means that exactly the same volt-

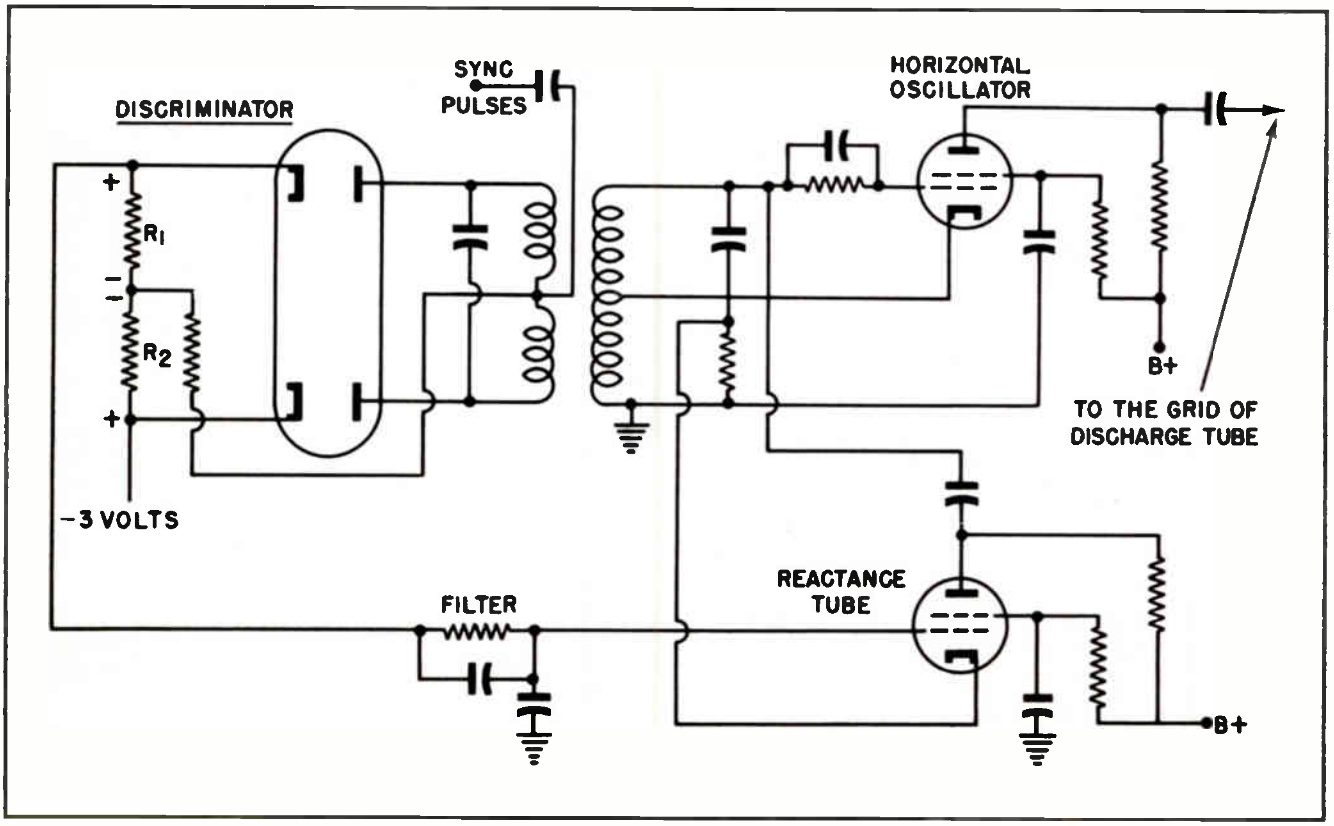

Fig. 5. Synchro-Lock System.

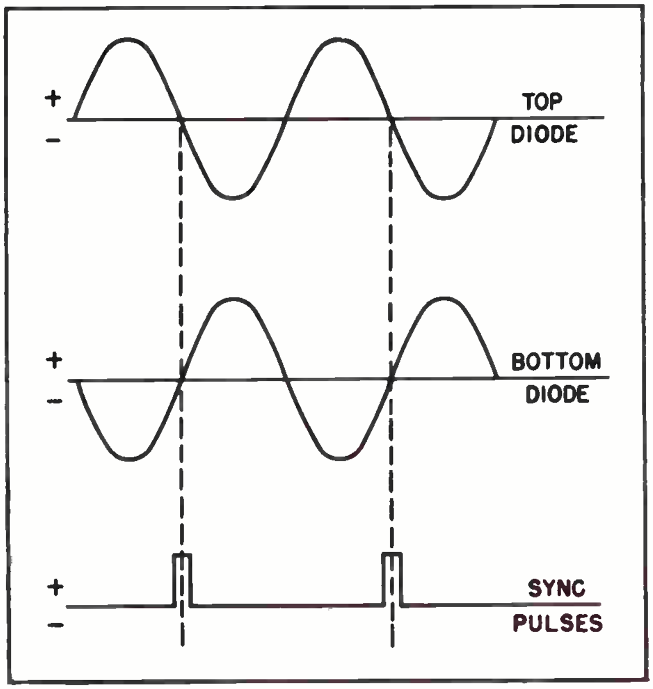

Fig. 6. Coincidence of sync pulses with zero voltage of sine wave.

age will be applied to both anodes at the same instant.

Suppose we go back and say this over again in another way. The sine wave voltage and the sync voltage are both being applied to the discriminator circuit in such manner that the output of the discriminator is balanced, or zero. The two halves of the sine wave tend to cancel each other at the output of the discriminator. The sync voltage is applied in equal measure to both diodes at the same time, and they also cancel out.

When the sync voltage is so applied to the discriminator circuit that it strikes at the instant the sine wave voltage is crossing the zero line, the output of the discriminator circuit is zero; it is balanced.

But this balanced condition is true *only* when the sync pulses strike the discriminator circuit at the instant the sine wave voltage is crossing the zero line. Suppose we see why this is true.

In Fig. 7 we have drawn additional graphs of the voltage as it is applied to the anodes of the diodes in the discriminator circuit. When the sync pulse strikes the discriminator circuit at any other time than when the sine wave is crossing the zero line, the sync voltage tends to aid one diode more than the other. The bottom two graphs show that the positive sync voltage added to both diodes tends to increase greatly the positive voltage on one tube, and makes less negative the normal negative voltage on the other.

The action in Fig. 7 occurs when the sync pulse is slightly slower than the frequency of the sine wave. The action is reversed when the sync pulse arrives earlier. It then arrives before the reversal of the sine wave voltage. When that occurs the other diode is favored.

This means that the sync voltage will aid the bottom diode more than the top one. This means one diode conducts more current than the other.

Any discrepancy in the synchronism between the sync pulse and the frequency of the sine wave throws the voltage divider across resistors R_1 and R_2 out of balance. When the voltage across the voltage divider is thrown out of balance, the voltage on the grid of the reactance tube is changed,

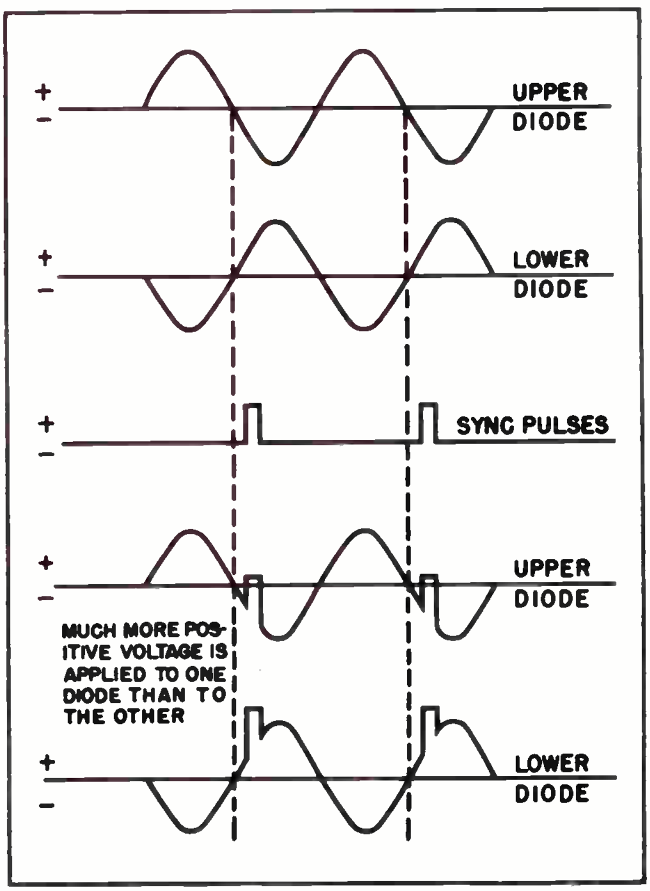

Fig. 7. Lack of coincidence between pulse voltage and sine wave voltage. One diode favored over other.

and that, in turn, affects the frequency of the oscillator.

The synchronizing pulses reach the discriminator circuit from the transmitter. They are regular, evenly spaced pulses, and are the things which control. If the sine wave oscillator tends to drift from the correct frequency it is brought back by the action of the discriminator and the reactance tube.

The point is, any tendency for the oscillator to drift would be at a relatively slow rate. The discriminator and reactance tube circuits would bring it back to correct frequency before it drifts far. On the other hand, random noise pulses, being of relatively short duration and not regularly spaced, will not affect the entire circuit, and this will not cause loss of synchronization.

The output of this circuit is used to trigger the action of a discharge tube. With decline in use of the discharge tube, the Synchro-Lock circuit fell into disfavor.

Section 6. PHASE DETECTOR CIRCUIT USED AS AFC

A modification of the Synchro-Lock circuit is the use of a phase detector as the frequency control element. A circuit using a phase detector to control the horizontal oscillator is shown in Fig. 8.

To understand the action of the phase detector we must first realize that two separate pulses are fed into the phase detector circuit. One is the sync pulse from the sync separator circuit. The other is a reference pulse fed back from the horizontal output transformer being driven by the horizontal output amplifier.

The reference voltage from the horizontal output transformer is in the form of what might be called a reverse saw-tooth waveform. Instead of the voltage rising in the positive direction gradually, as in normal saw-tooth waveform, it rises abruptly. This can be seen by studying the waveform adjacent to the line feeding the voltage back from the output transformer in Fig. 8.

That abruptly rising saw-tooth waveform voltage is applied simultaneously to two elements of the 6AL5 phase detector tube. It is applied to the anode of one of the diode sections and to the cathode of the other section. This can also be seen by studying Fig. 8. It can be seen that the feed-back reference voltage is applied to the diode anode at pin 7, and the other diode cathode at pin 5.

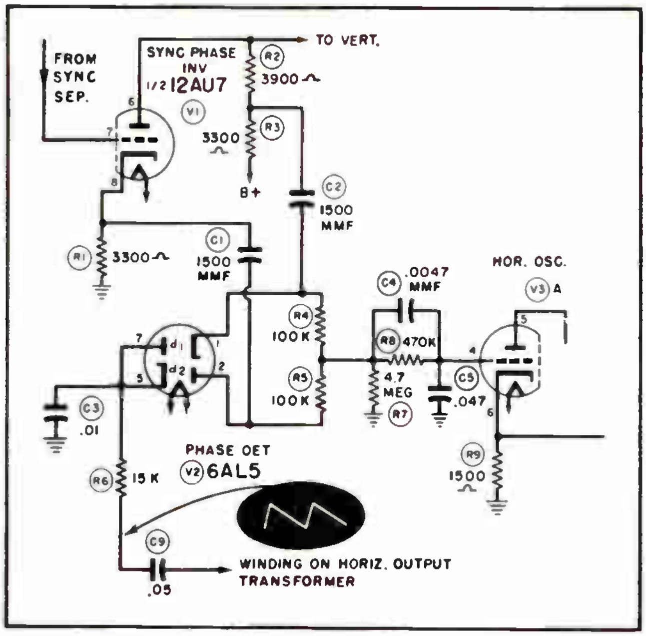

Fig. 8. Phase Detector Circuit.

The other diode anode—the one at pin 2—and the other diode cathode at pin 1 are connected together by two 100K resistors in series with each other. You can check this by examining the diagram in Fig. 8.

The grid of the horizontal oscillator is connected to the center tap between these two 100K resistors. The center tap is also connected to ground through a 4.7 megohm. All of which means that any voltage developed across either of the 100K resistors will be applied to the grid of the horizontal oscillator tube.

Earlier in this section we told you two separate pulses are applied to the phase detector. We have already told you about the reference pulses being applied to the anode at pin 7 and the cathode at pin 5. This pulse voltage is applied to the anode of one of the diode sections and the cathode of the other section.

Another voltage pulse is applied to the other anode and the other cathode. It is the sync pulse from the sync separator circuit.

It will be noted that the sync pulse from the sync separator is applied to the anode at pin 2 of the 6AL5 through a 1500 mmf capacitor from the cathode of the sync inverter. The sync pulse is applied simultaneously to the cathode at pin 1 through another 1500 mmf capacitor from the cathode of the sync inverter.

When the phase of the pulses which are applied to pins 1 and 2 from the sync inverter coincide with the reference voltage fed back from the horizontal transformer to pins 7 and 5 the voltages developed across the two 100K resistors between pins 1 and 2 cancel each other so no voltage is applied to the grid of the horizontal oscillator.

However, if the reference voltage pulses tend to arrive a trifle sooner or a trifle later the phase relationship is upset. The voltage across one or the other of the two 100K resistors becomes greater or less than that across the other. This immediately applies an increased or reduced bias voltage on the grid of the horizontal oscillator.

The voltage applied to the grid of the horizontal oscillator immediately changes the horizontal frequency just enough for the oscillator to pull back into step with the sync pulses from the sync separator circuit.

The net result is to synchronize the horizontal oscillator with the sync pulses from the sync separator circuit.

At the same time, random noise voltage pulses have relatively little effect on the phase detector unless they happen to coincide almost exactly with the normal sync pulses.

When working properly this circuit provides excellent horizontal stability, and there is little "tearing" of the picture as the result of electrical noise interference.

Failure of this circuit to function properly is almost always due to a defective component. The most frequent occurrence of trouble is traceable to a leaking coupling capacitor in the reference feed-back circuit—that is capacitor C-9. The reason it occasionally fails is traceable to the high voltage regularly impressed upon it.

Section 7. FREQUENCY CONTROL BY PULSE-WIDTH-MODULATION

It was mentioned earlier in this lesson that one of the principal drawbacks to the use of the phase detector as a frequency control ahead of the horizontal oscillator is that it requires an extra tube. In most cases this is a separate duo-diode tube, such as the 6AL5 shown in Fig. 8.

It is desirable to use as few tubes as possible in a TV receiver. Experience has shown that fully 80% of all the troubles in a receiver stem from a weak or defective tube. By reducing the number of tubes in a receiver the service problems are minimized.

Furthermore, reducing the number of tubes helps reduce the original manufacturing cost. This is a definite advantage.

In an effort to reduce the number of tubes in a receiver RCA came up with a modified AFC circuit. They call it their *Synchro-Guide* circuit to distinguish it from the original Synchro-Lock.

This newer circuit uses the principles of pulse-width-modulation. In essence, it measures the width of a composite pulse and compares it with that of a standard width.

Any tendency for the pulse to become *wider* acts to affect the frequency of the oscillator circuit in one direction. A tendency for the pulse to become *narrower* affects the oscillator frequency in the opposite direction.

A wider pulse causes the frequency of the oscillator to slow down. A narrower pulse causes the frequency to speed up.

By then applying the voltage which is developed at the cathode of a control tube by the action of the composite control pulse to the control grid of the horizontal oscillator it is possible to stabilize the frequency very precisely.

The basic circuit of a pulse-width-modulation frequency control, showing how it is incorporated into, and integrated with, the horizontal deflection system, is shown in Fig. 9. The circuit shown is one which is used in several RCA models, and the parts used in the circuit are identical to those actually used in RCA receivers.

RCA has licensed the use of this circuit to many other TV manufacturers. Some of the other manufacturers use the circuit exactly as shown in the schematic diagram of Fig. 9, others have made

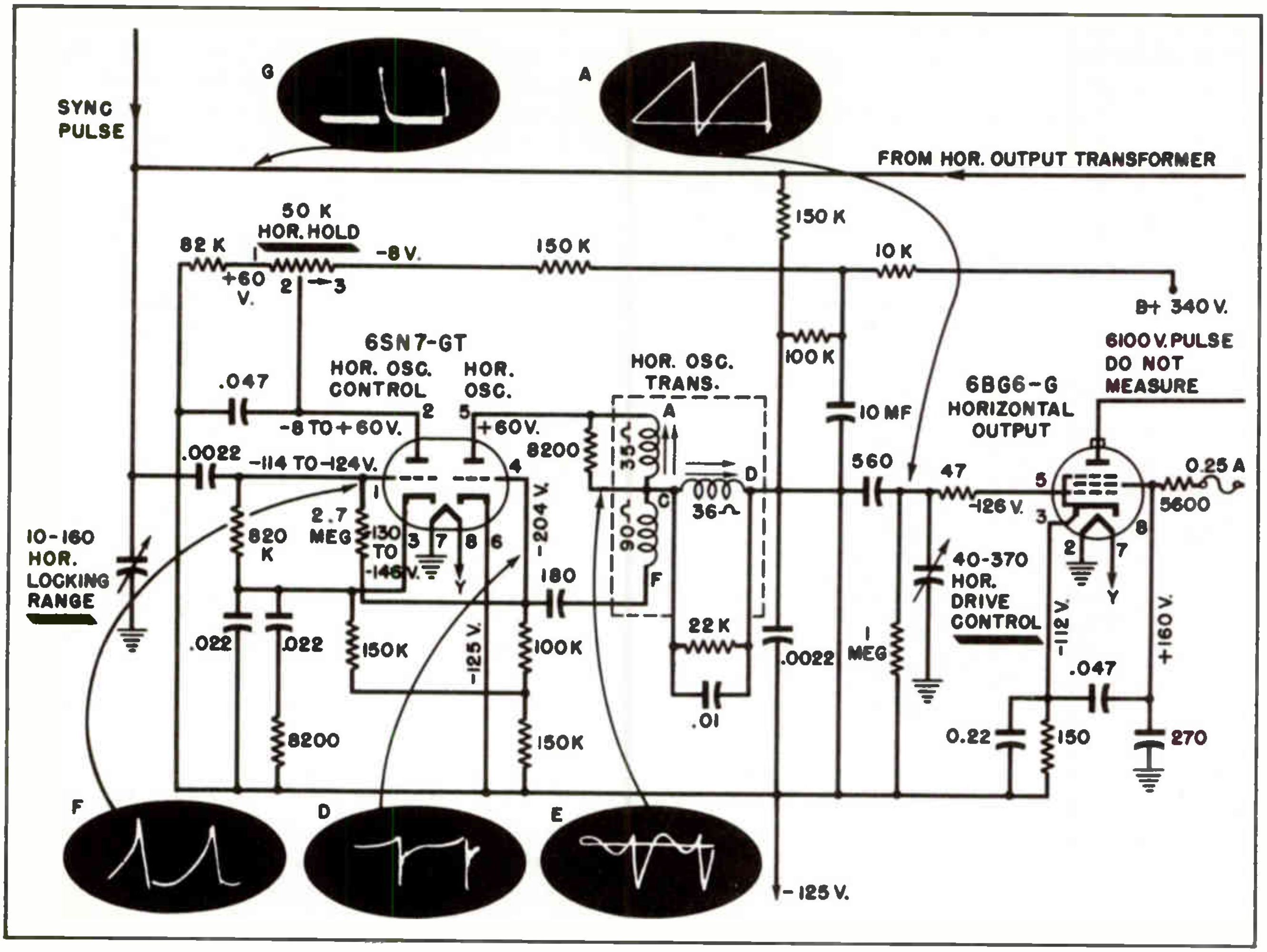

Fig. 9. Pulse-width-modulation frequency control circuit.

modifications in it. Admiral uses the circuit in many models with the component values unchanged from those shown in the diagram; in other models they make minor changes to meet the conditions created by other improvements in overall receiver design.

The whole purpose of the circuit is to develop a controllable bias which will, in turn, control the frequency of the horizontal oscillator. Any tendency for the oscillator to shift its frequency, so it would lose synchronism with the sync pulses, immediately sets up a change in the bias control voltage on the oscillator to instantly pull it back into synchronism.

The end result is to lock the horizontal oscillator into perfect synchronism with the sync pulses from the transmitter so a high degree of stability is achieved.

Much of the action of the oscillator — and its frequency control—centers around the horizontal oscillator transformer. This transformer is shown in Fig. 9.

The transformer is located in the anode circuit of the 6SN7 horizontal oscillator tube.

The second half of the 6SN7 tube and the horizontal oscillator transformer operate together to make a blocking oscillator.

These are the principal components of the blocking oscillator circuit, but other components also form a necessary part of the circuit.

The free-running, or natural, frequency of the blocking oscillator is approximately 15,750 cycles per second.

Each time the second half of the 6SN7 tube conducts during the oscillation cycle it acts to discharge the .0022 mfd capacitor shown to the right of the oscillator circuit. That is the discharge capacitor.

The capacitor charges during the major portion of the oscillation cycle. It charges through the 100K resistor which can be seen on the diagram in Fig. 9 a short distance above the capacitor.

The capacitor charges at a relatively slow rate through the resistor, but it is discharged very rapidly by the action of the oscillator tube 6SN7. Charging and discharging of that capacitor creates the saw-tooth waveform needed to drive the 6BG6 output amplifier tube.

While the action of the resistor and capacitor form the wave-shaping network to create the saw-tooth waveform needed to drive the 6BG6, it is the horizontal oscillator which determines the frequency of the saw-tooth waveform. The pulse-width-modulation circuit, in turn, controls the frequency of the horizontal oscillator.

It is a well known electronic principle that the frequency of an oscillator can be controlled — at least to some degree — by controlling the bias on the control grid or by controlling the magnitude of the B+ on the anode. A combination of the two conditions emphasizes the degree of control.

The pulse-width-modulation automatic-frequency control circuit depends upon changing the grid bias on the oscillator tube for its basic action. The principal components in the circuits surrounding the 6SN7 tube are shown in Fig. 10. Those components are the same as those in Fig. 9, but by confining our attention to the ones which are used only around the 6SN7 it is easier to understand the basic principles of the circuit.

Control of the grid bias on the oscillator section of the 6SN7 is exerted by varying the current through resistor R178, and by varying the voltage stored in capacitors C155 and C157.

Resistor R178 is one-half of the cathode biasing resistor in the cathode circuit of the first half of the 6SN7. The two capacitors are in parallel with each other, and also in parallel with the cathode biasing resistors. The voltage developed across the two cathode resistors is stored in the two capacitors.

Current through resistor R178 is controlled by the amount of current which flows through the first, or left-hand, section of the 6SN7. And that current, in turn, is controlled by a combination of pulses applied to the grid of the first section of the tube. The current is controlled by the width of the pulse on the grid, which is actually a composite pulse.

Increasing the current through the left-hand

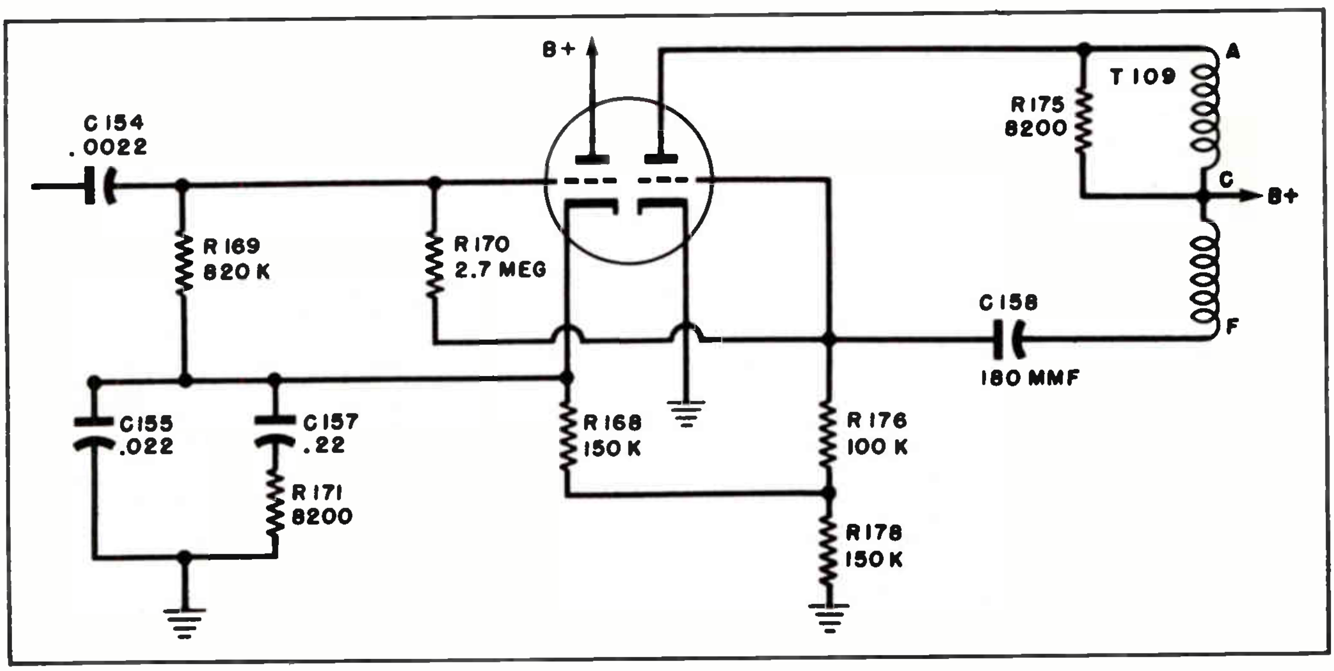

Fig. 10. Circuits around 6SN7 in pulse-width-modulation.

section of the tube increases the voltage drop across R178, and places a more positive voltage on the grid of the right-hand, or oscillator, section of the 6SN7. That, in turn, raises the frequency of the oscillator.

This explanation can be condensed somewhat by saying that an increase in the current through the left-hand section of the 6SN7 tends to place a more positive voltage on the grid of the right-hand section, and thus raises the frequency of the oscillator.

Now, the rather odd thing about all this is that no current at all flows through the left-hand section of the 6SN7 except during the interval a strong positive voltage pulse is placed on the grid of that section. The length of time during which current can pass through that section depends, then, upon the duration of the voltage pulse.

This can be said another way. The length of time during which current flows through the left-hand section of the 6SN7 depends on the *width* of the pulse which controls the action of that section of the tube.

Figure 11 shows the waveform of the voltage which is applied to the grid of the first section of the 6SN7. Note that all the voltage on that grid acts to maintain that section of the tube at cutoff, or beyond, most of the time. The only time that section can conduct is during the period when the voltage pulse raises the grid voltage above the cutoff level.

Equally important, the length of the period of time during which the first half of the tube can conduct is controlled by the *width* of that pulse. This was mentioned in an earlier paragraph, but is repeated here for emphasis.

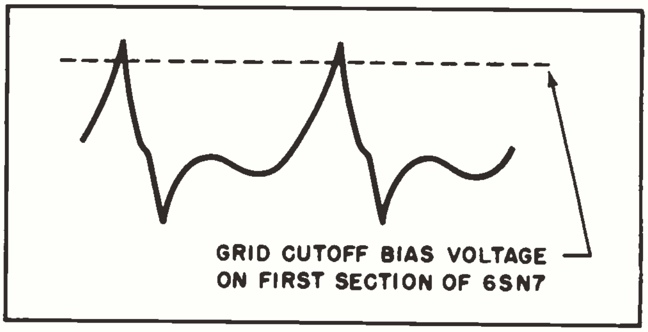

Fig. 11. Waveform of voltage on grid of control section of 6SN7.

The shape and width of the voltage pulse applied to the grid of the first half of the 6SN7 is derived from a combination of three electrical signals—or from three electrical pulses. One pulse comes from the oscillator transformer, one is a voltage pulse fed back from the output transformer, and the third is the sync pulse from the sync separator circuit.

The voltage pulse from the oscillator transformer is fed back through 150K resistor to combine with the incoming sync pulse.

The voltage pulse from the horizontal output transformer can be traced by examining Fig. 9. That pulse is also combined with the sync pulse.

The sync pulse from the separator circuit is also applied to capacitor C154, shown in Fig. 10.

In short, the three pulses — originating in three different places — are applied to C154, through which they reach the first grid of the 6SN7.

An examination of the waveform shown on the diagram in Fig. 9 shows the voltage pulse fed back from the output transformer has a negative polarity. The sync pulse and the one fed back from the oscillator transformer both have positive polarities.

The three pulses combine to form the waveform shown before the pulses are applied to the capacitor C154.

We can think of the pulse being fed back from the oscillator transformer as forming the basic pulse. That from the sync separator circuit tends to widen the basic pulse by adding to its front slope. That from the output transformer is a negative pulse which tends to chop off the back side of the basic pulse and makes it narrower and steeper.

The manner in which those three pulses combine together determines the thickness, or width, of the pulse which is actually applied to the capacitor C154.

As the pulse passes through C154 its shape undergoes a slight change, but the portion of the true pulse which applies the controlling voltage to the grid of the first half of the 6SN7 remains basically the same. Its width continues to be dependent upon the manner in which the three pulses reach the capacitor, and the manner in which they combine.

An examination of Figs. 9 and 12 discloses that the grids of two sections of the 6SN7 are tied together through resistor R170. The resistor has a resistance of 2.7 megohms.

This means the basic blocking voltage normally applied to the grid of the oscillator tube is also applied to the grid of the first section, or control section of the tube. That negative voltage is sufficient to keep the first half of the tube — the control section — biased beyond cutoff most of the time.

The only time the control section of the tube can conduct is when the peak voltage pulse of waveform F in Fig. 12 overcomes the negative bias and permits it to conduct.

During that short period the tube will conduct, and will charge capacitors C155 and C157 which are in parallel with the cathode resistors.

When the oscillator is operating at normal frequency of 15,750 cycles per second the control tube will conduct only long enough to charge capacitors C155 and C157 sufficiently to maintain the bias required to maintain that frequency. Any tendency for the oscillator to drift from that basic frequency sets up conditions which cause the control tube to conduct for a longer period — or a shorter period — and thus change the voltage of C155 and C157 sufficiently to bring the frequency back to normal.

It is now time to examine the voltage pulse applied to the grid of the control section of the tube to see just how its width can change.

Figure 13 shows three different waveforms of

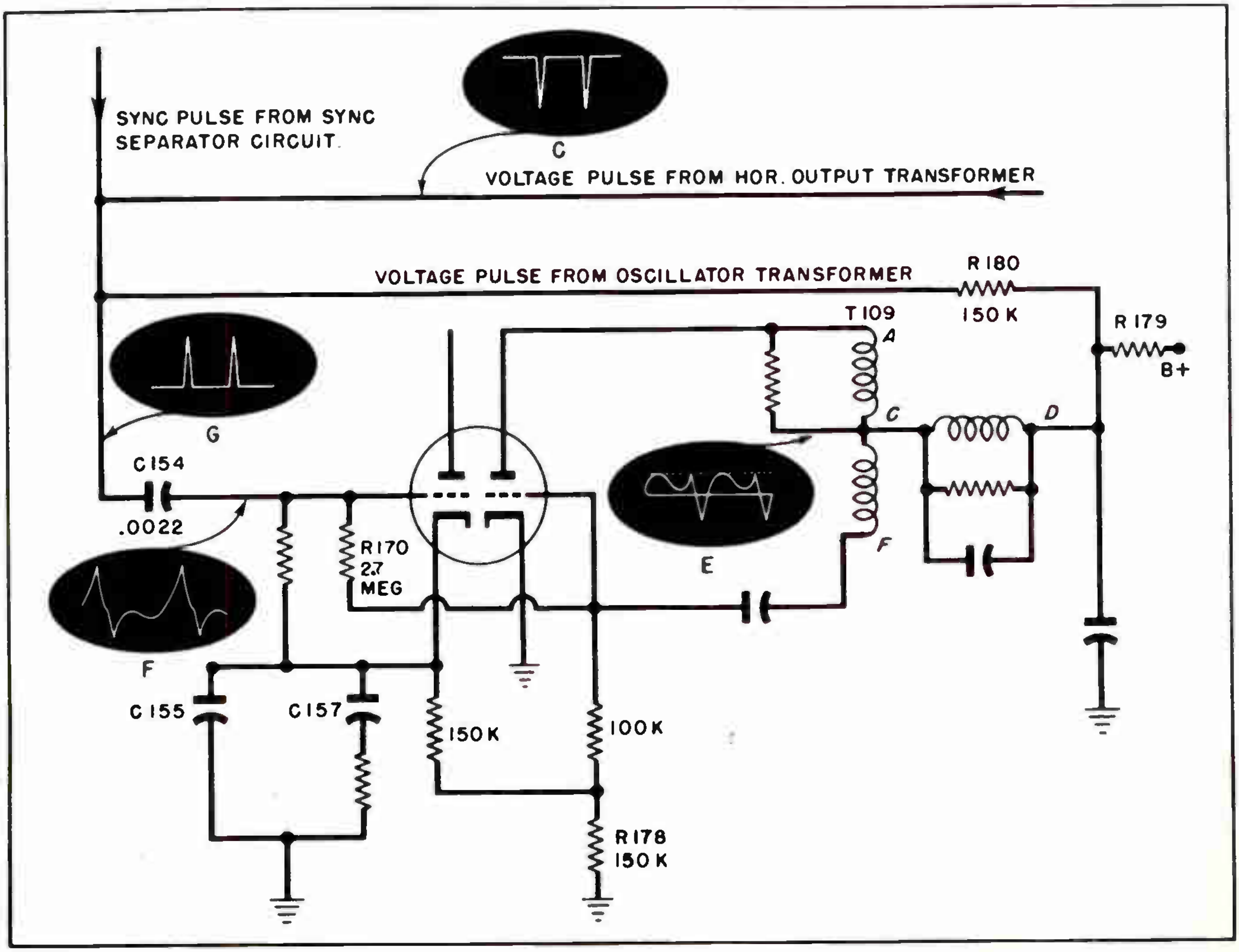

Fig. 12. Origin of three voltage pulses which combine into grid voltage on first half of 6SN7.

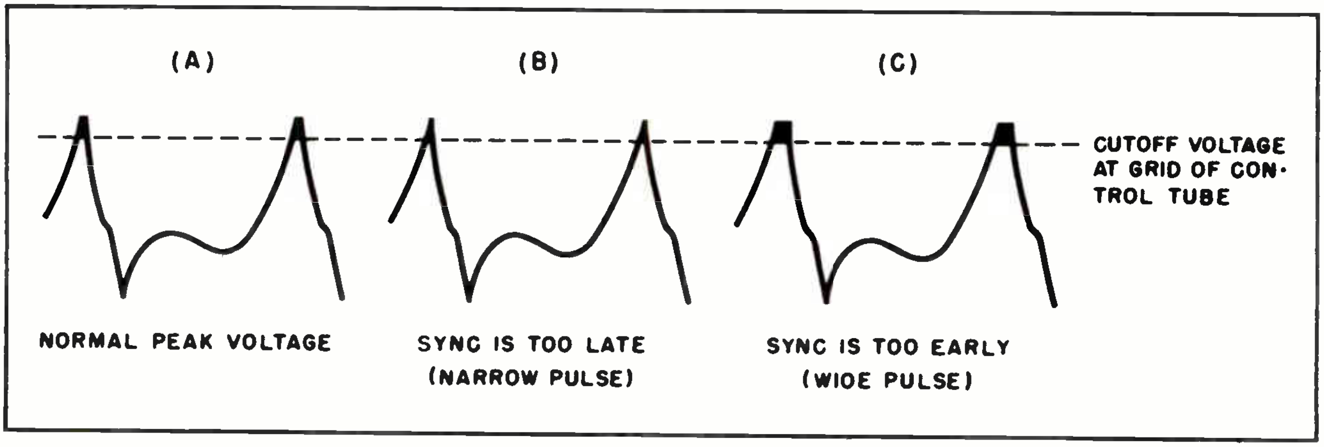

Fig. 13. Waveforms of composite pulse at grid of control tube under varying conditions.

the voltage pulse at the grid of the control tube.

These are the exact waveforms as they would appear on the screen of an oscilloscope.

The pulse at *A* of Fig. 13 is the normal appearance of the pulse. That is the way the pulse looks when the sync pulse is arriving just enough ahead of the reference pulse to maintain control. The sync pulse and the reference pulse combine to make the normal width of the pulse.

The waveform at *B* is one which shows the conditions as they exist when the sync pulse is arriving a little too late. This is the condition which would exist when the oscillator is tending to have a natural frequency a trifle higher than normal. The sync pulse and reference pulse are arriving almost together, thus making a very narrow control pulse.

Narrowing the pulse causes the control tube to conduct for a shorter period, and thus apply a slightly higher negative bias to the grid of the oscillator tube. This slows the frequency of the oscillator, and returns the circuit to normal operation.

The waveform at *C* is another abnormal one. There we see the peak of the waveform is wider. This causes the tube to conduct a trifle longer, applying a slightly less negative bias to the grid of the oscillator tube, thus causing it to oscillate a little faster; to increase the frequency.

It can be seen from these explanations that the magnitude of the pulse applied to the grid of the control section of the 6SN7 is a critically important feature of the operation of the circuit. It is desirable to maintain that magnitude at a constant level, one that is best suited to the most reliable operation of the circuit.

To effect that stability of operation a LOCKING RANGE CONTROL is inserted into the grid circuit of the control section of the 6SN7. That is the variable capacitor shown in Fig. 9. The circuit is shown in better detail in Fig. 14. It is also called the HORIZONTAL RANGE CONTROL, or the HORIZONTAL LOCK CONTROL.

Normally that capacitor is adjusted to provide maximum capacity which will permit the control circuit to work.

The effect of the capacitor, being located where it is, by-passes to ground a major portion of the combined sync pulse, permitting only that portion to pass through C154 to the grid of the control tube needed to maintain control. Reducing the capacity of C153A causes a stronger pulse to pass through C154 to the grid of the control tube. Increasing the capacity weakens the pulse through C154. The pulse through C154 should be just strong enough so only the portion above the dotted line in Fig. 13 permits the tube to conduct.

When the RANGE control is properly adjusted, only the peaks of the combined pulse are strong enough to drive the control tube into conduction.

The free-running frequency of the horizontal oscillator is tunable by adjusting the inductance of the oscillator transformer shown in Figs. 9 and 14. The inductance is adjustable in most cases by moving an iron slug further in or out of the transformer core. This adjustment is often called

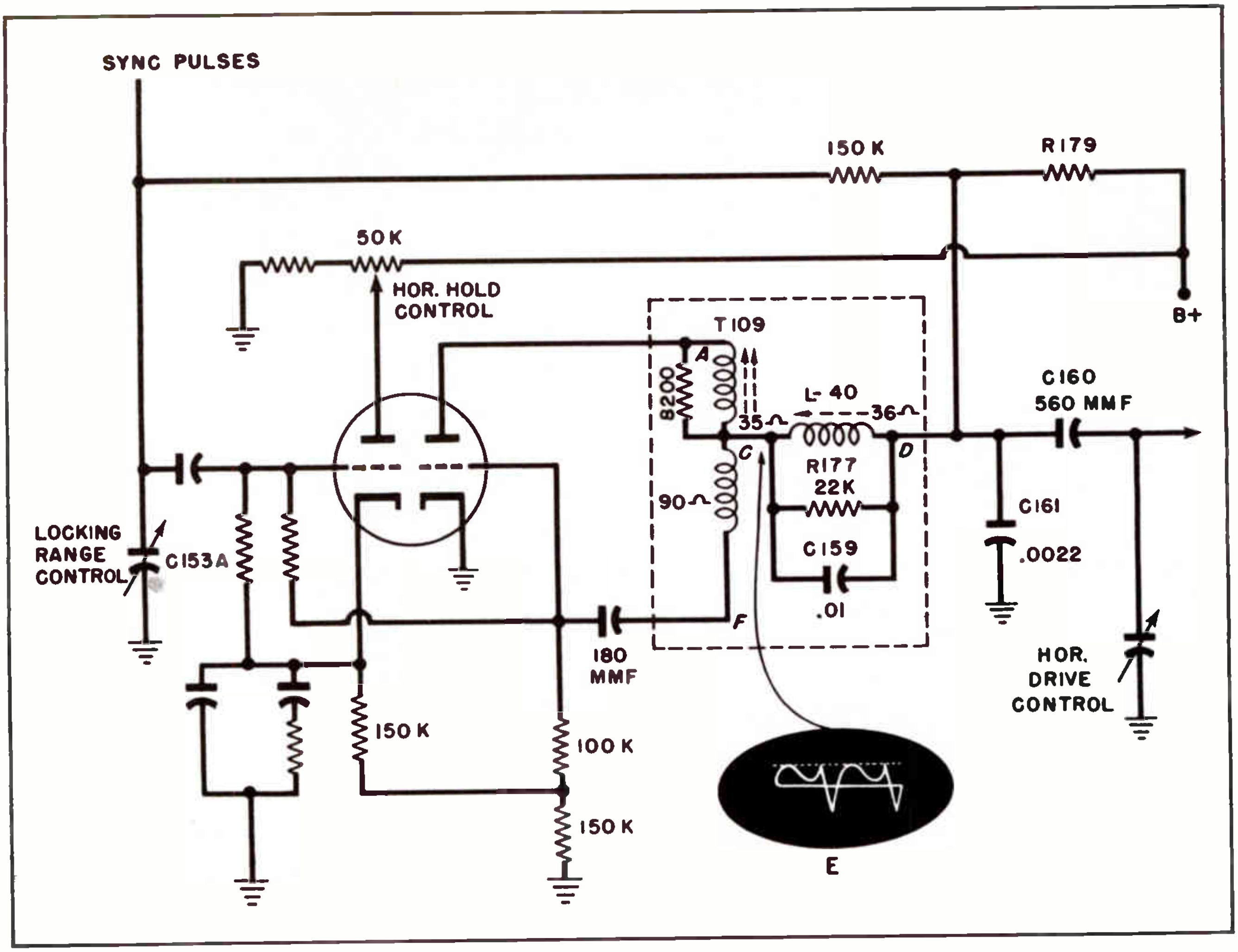

Fig. 14. Controls for adjusting AFC circuit.

HORIZONTAL FREQUENCY CONTROL. It is usually located on back panel of the chassis.

The HORIZONTAL HOLD control, which is so familiar to most users of television receivers, acts in this circuit to change the voltage applied to the anode of the control section of the 6SN7. It is shown as a 50K potentiometer. It provides a relatively narrow range of control over the action of the control section of the tube. It aids the user to maintain synchronization when the other controls are properly adjusted.

Section 8. THE SYNCHROGUIDE AFC CIRCUIT

The preceding section provides a good technical explanation of the action of pulse-width-modulation as it applies to AFC circuits in general. It would be useful to examine the evolution of this method of providing automatic frequency control as the various steps were taken by the RCA engineers. This should be useful despite the fact it is pretty much a duplication of the explanation given in the preceding section.

The pulse-width-modulation method of automatic frequency control was first utilized by RCA in their Synchroguide system. It has been copied by many other manufacturers so it is now used in hundreds of different models of TV receivers. It is well to learn just as much as possible about this peculiar circuit. It is used in so many receivers.

The Synchroguide AFC circuit is used almost exclusively with the blocking oscillator.

The blocking oscillator has the advantage over the multivibrator in that it uses one less tube than the multivibrator. On the other hand, it is more sensitive to noise pulses which normally cause

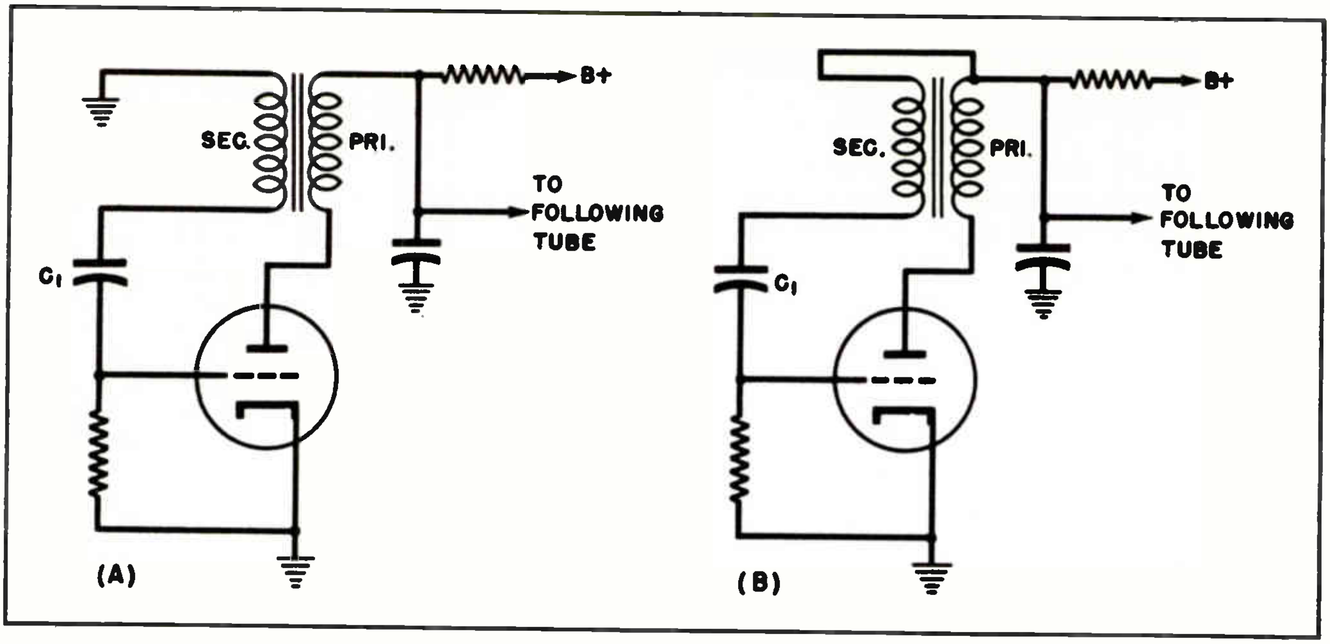

Fig. 15. Typical blocking oscillator circuits.

the picture to tear horizontally when electrical noise pulses trip the oscillator ahead of the normal sync pulse.

It was to take advantage of the favorable characteristics of the blocking oscillator that RCA came up with this AFC circuit to prevent interference from noise pulses.

To better understand the exact action of the synchroguide circuit, and the need for it, it seems advisable to review briefly the basic fundamentals of the oscillator action.

Typical blocking oscillator circuits are shown in Fig. 15. The one shown at *A* is somewhat easier to understand, but the one at *B* is the one most frequently used in actual circuits. The only difference is the manner in which the blocking transformer is wound and connected.

The transformer at *A* has one end of the secondary winding grounded. The one at *B* is not grounded; instead, the primary and secondary are connected together at a center tap, so they actually form an autotransformer. The connection to B+ is at the connecting center-tap. The signal to the following tube is tapped off at the same place.

The reason the blocking oscillator is unstable, and is susceptible to interference to random noise pulses, is shown by the graphs in Figs. 15 and 16. The graph in Fig. 16 shows the voltage on the grid of a tube as it would appear if viewed on the screen of an oscilloscope.

The reason the oscillator is susceptible to noise results from the fact that as the negative voltage leaks off the control grid at the end of each cycle there is a considerable period of time during which the negative voltage is only slightly below the value which would permit conduction.

The slightest variation in the grid voltage during that interval triggers the oscillator, thus starting it through another cycle before its normal time. This means that even a very small random electrical noise pulse will trigger the oscillator, and thus cause it to start through its cycle at the wrong time.

A more desirable voltage graph is shown in Fig. 17. While this latter graph is not necessarily

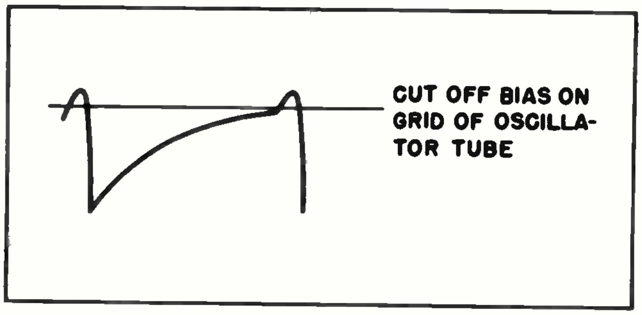

Fig. 16. Graph of grid voltage on blocking oscillator tube.

one that is always achieved in an actual circuit, it does provide the goal toward which engineers aim.

In this latter graph the negative voltage on the control grid is deliberately kept far beyond cut-off almost to the instant when the following sync pulse is due. This excessive negative bias voltage on the control grid prevents triggering by ordinary electrical noise pulses.

To isolate the blocking oscillator from direct contact with the incoming signal an additional tube has been placed between it and the sync pulses in Fig. 18. This represents a simplified version of the Synchroguide circuit, but contains the essential components of that circuit.

The action of the circuit can be understood somewhat better if we explain it step by step.

The blocking oscillator is composed of the second tube, the transformer, capacitors C1 and C2, and resistor R1.

Some of the voltage developed at the grid of the oscillator tube is fed back to the grid of the first tube through resistor R4. This maintains the grid of the first tube at about the same voltage level as that of the second tube.

Voltage developed across resistor R3 is applied to the control grids of both tubes.

Near the end of each cycle the first tube begins conducting, thus creating an additional voltage drop across resistor R3, which is common to the cathode circuits of both tubes. This sudden passage of current through R3 applies a sudden positive voltage to the control grid of the second tube — the oscillator tube — causing it to conduct.

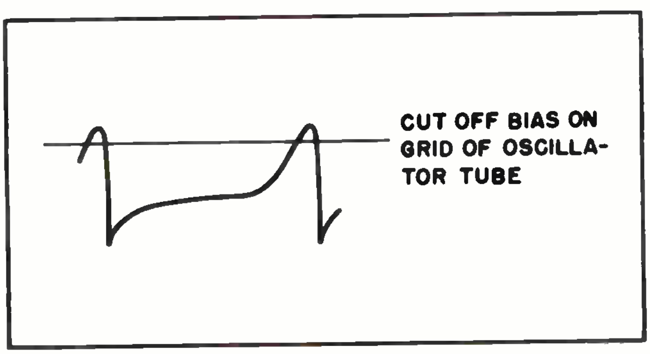

Fig. 17. Graph of desired grid bias.

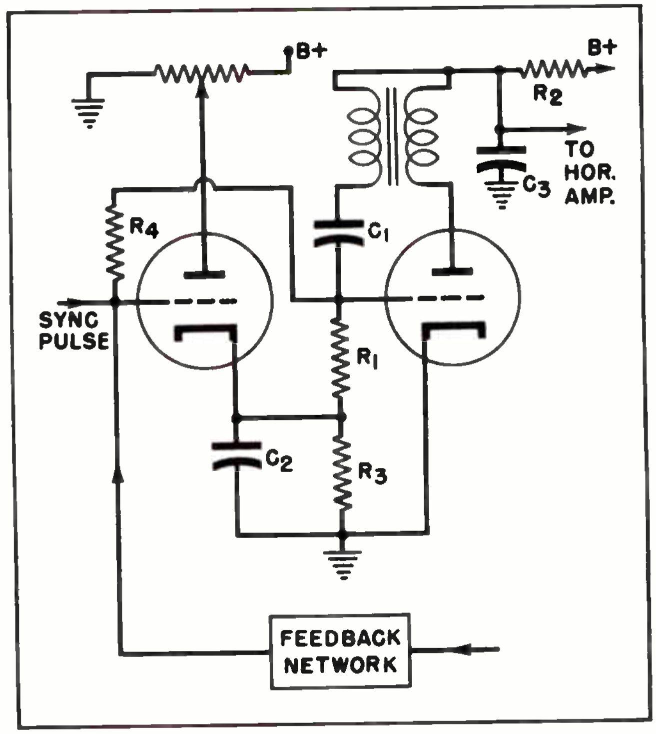

Fig. 18. Blocking oscillator with control tube.

By changing the values of the components in the circuits, acting to lengthen the time-constant somewhat, the oscillator tube can be caused to conduct by the sudden voltage deliberately developed across R3.

The circuit is deliberately arranged so this sudden rise in current through R3, and the voltage across it, comes near the normal end of the cycle. The net effect of all this is to keep the negative voltage on the control grid of the oscillator tube considerably beyond cut-off until the instant it is desirable for a new cycle to begin.

As was explained in preceding sections, the amount of current which flows through resistor R3 depends on the length of time the control tube is permitted to conduct. The period of conduction, in turn, is determined by the width of the voltage pulse momentarily placed on the control grid of that first tube.

Width of the voltage pulse is controlled by the sync pulse, and the frequency of the oscillator. If the sync pulse and the horizontal cycling coincide the oscillator is held rigidly on a synchronized frequency.

Whenever there is a tendency for the horizontal oscillator to speed up slightly, or slow down slightly, such changes in frequency instantly affects the period of conduction of the first tube. Any change in the voltage developed at the cathode of the first tube immediately reflects back onto the control grid of the oscillator, thus pulling the oscillator back into synchronism.

It is understandable that practical circuits involving this principle are modified slightly to meet specific needs. The exact circuits have been previously explained, so there seems little need to go into them again at this time.

Section 9. COMMON TROUBLES IN HORIZONTAL DEFLECTION SYSTEM

Certain symptoms appear on the screen of a television receiver, which, when observed by a technician, point straight to troubles in the horizontal deflection system. Other symptoms seem to indicate trouble in the horizontal system, but actually have their origin elsewhere.

A frequent complaint of customers is that the picture is too narrow. Normally this indicates trouble somewhere in the horizontal deflection system, since it is the horizontal system which determines just how far the electron beam is swept from side to side.

In many cases such a symptom indicates the horizontal output amplifier tube is weak and needs replacing. Almost as often it means the damper tube is approaching the end of its usefulness, and should be replaced.

The question is, what to do when faced by this kind of symptom.

Fortunately, in most cases, the remedy is quite simple. When a tube is weak, such as is indicated here, the only practical remedy is to replace it with a new one known to be good.

The horizontal output amplifier tube and the damper tube are enclosed within the high-voltage compartment on most modern receivers, regardless of the make. So, if one or both of those tubes are suspected of being weak, it is a good practice to replace them both while the high-voltage compartment is open.

If replacing the tubes widens out the sweep so the raster covers the entire screen it is a good sign the trouble has been found and corrected. If that does not correct the trouble it is then time to look for more serious defects.

There is always the possibility the owner is one of those persons who cannot resist the temptation to twiddle with the control knobs on the back of the chassis. If it can be done tactfully it is always in order to inquire if there is a possibility someone has attempted to adjust any of the controls. If there is reason to believe they are out of adjustment an effort to readjust them should be made.

The controls most likely to be out of adjustment are the horizontal width control and the horizontal linearity control. There is a possibility the horizontal drive control may be out of adjustment, but when it is out of adjustment there are usually other symptoms which are characteristic of such condition, and lead you to suspect it immediately.

If you have no reason to suspect someone has gotten the horizontal controls out of adjustment there is a strong possibility some of the other horizontal tubes may be weak and need replacement. There is also a good possibility the B+ power supply voltage is below normal. This means you should check the power supply voltage to see if it is lower than it should be.

A sub-normal voltage from the power supply may be a sign of a weak rectifier tube or a weak selenium rectifier. It can also mean the electrolytic filter capacitors have lost some of their capacity, and may even indicate they have high-resistance leakage.

They should be checked. If found to be weak or defective replace them. Nor should you overlook the possibility the boosted B+ is not working properly — thus, not supplying sufficient voltage back to the horizontal tubes.

Still another possibility which should not be overlooked is that the power line voltage may be sub-normal. If the power line voltage is lower than it should be it can cause some serious disturbances in the operation of the horizontal deflection circuits. There are cases on record where it has been impossible to make a receiver work in a given location. Investigation disclosed the only defect to be low line voltage.

If normal checks of the circuits surrounding the horizontal deflection system discloses no likely cause of trouble, it is time to suspect a partially defective component.

One such which occurs occasionally, although not often enough to be serious, is a broken slug in the width coil. If the slug breaks off, and falls out, the inductance of the width coil is reduced. When that happens it is difficult, or impossible, to adjust the width of the picture by adjusting the width control.

What happens is that when the slug is missing, and the inductance of the width coil is reduced, the reactance is also automatically reduced. Since this width coil is in parallel with the deflection coils, any radical reduction in its inductive reactance causes it to pass more than its normal amount of current. Since this current is shunted from the deflection coils it results in reducing the width of the picture.

Don't forget to investigate the screen grid circuit of the horizontal output amplifier.

If that resistor becomes overheated there is always the possibility it may change its resistance so it is much higher than normal. This acts to starve the screen grid of power, thus preventing the tube pouring power into the output transformer in its normal manner.

A defect which occasionally occurs in series-filament type receivers is for the filament resistance of one of the tubes to change slightly. Sometimes it is necessary for the filament resistance to change only a relatively small amount for the heating effect of the filaments in the other tubes to be seriously affected. If you find no evidence of ordinary types of trouble it is always well to check the filament resistances in the tubes in such a receiver.

NOTES FOR REFERENCE

Automatic frequency controls are used only in the horizontal circuits of the deflection system; they are not needed in the vertical circuits.

The horizontal oscillator is triggered by a short, sharp, voltage pulse.

Unless the horizontal oscillator is isolated from direct connection with the sync separator circuit it is possible for random noise pulses to trigger it.

Random electrical noise pulses can originate in many common electrical devices. Probably the most common are neon lights, electrical razors and food mixers, oil burners, and such.

Phase detection is used as a frequency control most often with multivibrators, while pulse-width-modulation is most often used with blocking oscillators.

There is no technical reason why phase detection cannot be used with a blocking oscillator, but it is rarely so used.

Circuits which are usually included in the horizontal deflection system are the AFC circuit, the horizontal oscillator, the horizontal amplifier, the damper tube and its circuits, and often the high-voltage power supply.

Since the high-voltage power supply is so closely connected with the horizontal deflection system it is usually included in such a grouping. In some of the older receivers, where the high-voltage supply has no connection with the horizontal deflection system, it would be omitted from such grouping.

The horizontal drive control is used to control the transfer point at which the horizontal sweep is transferred from the damper tube to the horizontal amplifier.

The horizontal drive control usually consists of a special type of variable capacitor.

The original RCA system of automatic frequency control was called the *Synchro-Lock* system.

The Synchro-Lock system of AFC differed little from an ordinary phase detection system.

The newer RCA AFC circuit is called the *Synchroguide* system of AFC.

The Synchroguide is essentially a pulse-width-modulation system.

Most other systems of automatic frequency control employ normal phase detection, or modifications of the basic phase detector circuit.

An advantage of the pulse-width-modulation system of AFC is that a single tube, such as the 6SN7, acts as the oscillator and the frequency control tube.

The multivibrator and phase detector circuits necessarily use a pair of tubes.

In most frequency control systems the control is exerted by controlling the bias voltage on the grid of the horizontal oscillator.

A serious disadvantage of the pulse-width-modulation system of automatic frequency control is that it requires an oscilloscope to adjust the circuit properly.

The *horizontal hold* control in a receiver using pulse-width-modulation in the AFC circuit is usually connected in the anode circuit of the control tube rather than directly to the oscillator tube.

The most common cause of trouble in the horizontal system of TV receivers is *weak tubes*. When weak tubes are suspected the best method to check them is to replace them with new ones known to be good.

Merely replacing tubes often clears up all symptoms of trouble in horizontal circuits.

Low voltage in the power supply circuits can easily lead to trouble in the horizontal deflection system. Both the horizontal oscillator and amplifier are sensitive to variations in the B+ voltage supply system.

When low voltage in the power supply circuit is suspected it is wise to replace the rectifier tube, or selenium rectifier, and check the condition of the electrolytic capacitors.

If the electrolytics are found to be weak they should be replaced.

One fairly common cause of a narrow picture is a partially defective resistor in the screen grid circuit of the output amplifier.

If there is no apparent cause of trouble in the horizontal deflection system, yet the picture is narrow, it is well to suspect low line voltage.

If the picture is narrow, yet all the voltages seem to be normal, check the width coil to make certain its slug is still in place. If the slug has fallen out the width coil will shunt too much current from the deflection yoke windings.

Never depend on a tube tester to check the condition of tubes used in horizontal circuits. Many tubes which check good on a tester will not work in an actual circuit.

The only satisfactory method of checking such tubes is through the process of substitution.

NOTES

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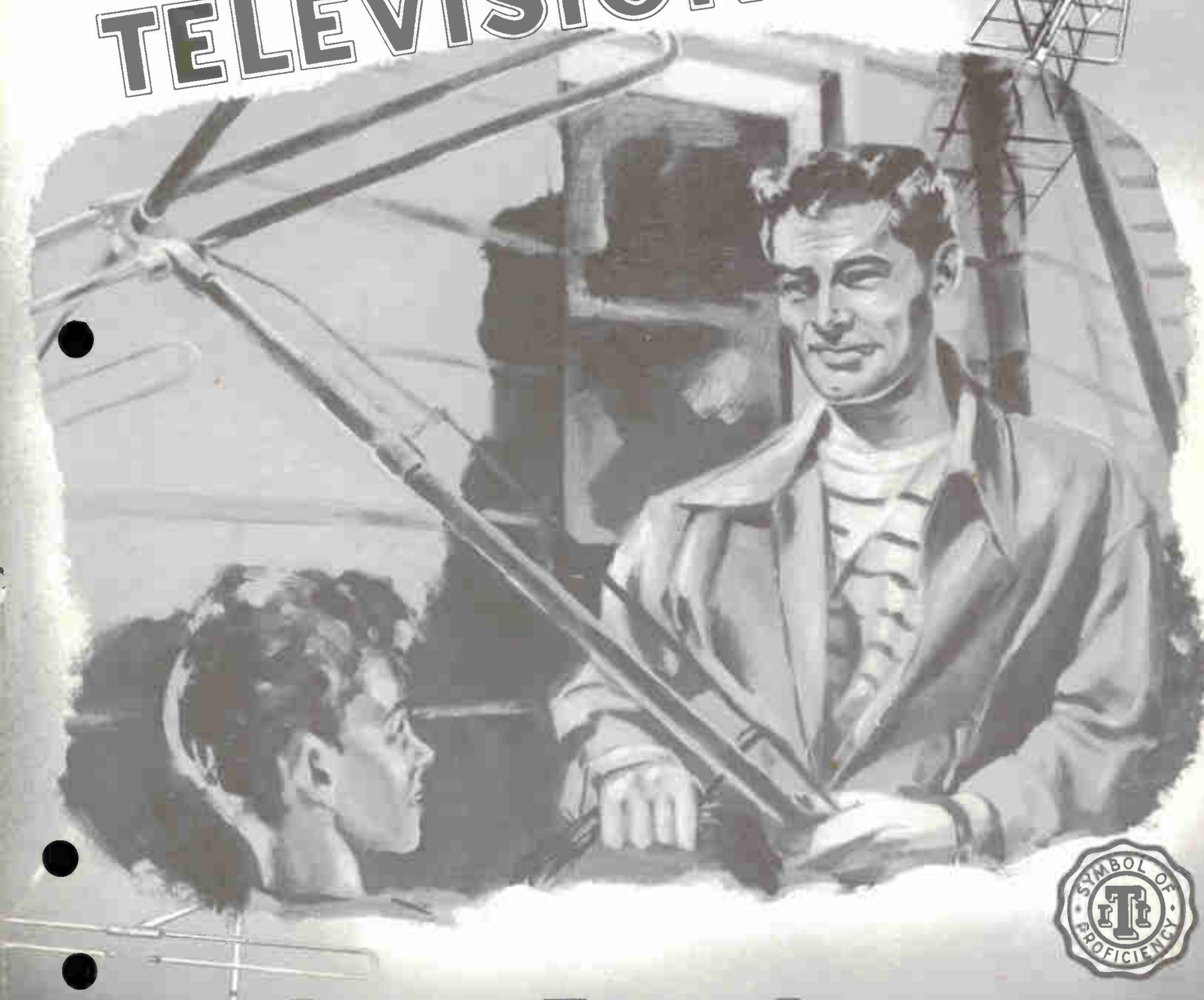

INDUSTRIAL TRAINING INSTITUTE

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RADIO TELEVISION

TELEVISION I-F AMPLIFIERS

Contents: Basic Requirements of an I-F Amplifier — Effect of Coupling on Frequency Response — How Proper I-F Response is Obtained by Using Several Types of Coupling — Disadvantages of Separate I-F Channels for Sound and Video — Types of I-F Transformers Used in TV Receivers — The Intercarrier System — Identifying the Type of I-F System Used in a Receiver — I-F Transformers for TV Receivers — The F-M Demodulator for Sound Signal — Aligning the I-F Circuits — Alignment for Fringe Areas — Common I-F Troubles — Signal Tracing Through the I-F Section — Signal Generator and Indicating Device — Alignment Hints — Notes for Reference.

Section 1. INTRODUCTION

I-F amplifiers in a television receiver perform the same general functions as those in radio receivers. Despite this basic resemblance, there are some very pronounced differences between those used in TV and those used in radio.

The I-F amplifier circuits in a *radio* receiver are normally tuned quite *sharply*. Few I-F circuits in AM radio receivers have a band-pass wider than 10 kc. Those in FM radio receivers have a band-pass somewhat wider, but not greatly wider.

I-F amplifiers in a *television* receiver are deliberately designed to have a far *wider* band-pass. Most have a band-pass exceeding two *megacycles*, and the better receivers have a band-pass of 4 megacycles.

Still other differences between the two kinds of I-F amplifiers exist. One of the most striking is the manner of tuning the individual stages of the I-F amplifier section.

In radio receivers it is the general practice to tune all the I-F transformers to the same frequency. This practice provides the greatest amount of amplification. In a few receivers the individual transformers may be tuned to frequencies which differ from each other by some 5 or 10 kilocycles, but usually they are tuned to the same frequency.

The aim of the designer of radio I-F amplifier sections is to achieve all the amplification of which the circuits are capable.

I-F transformers in a television receiver are tuned differently. They may be tuned to as many

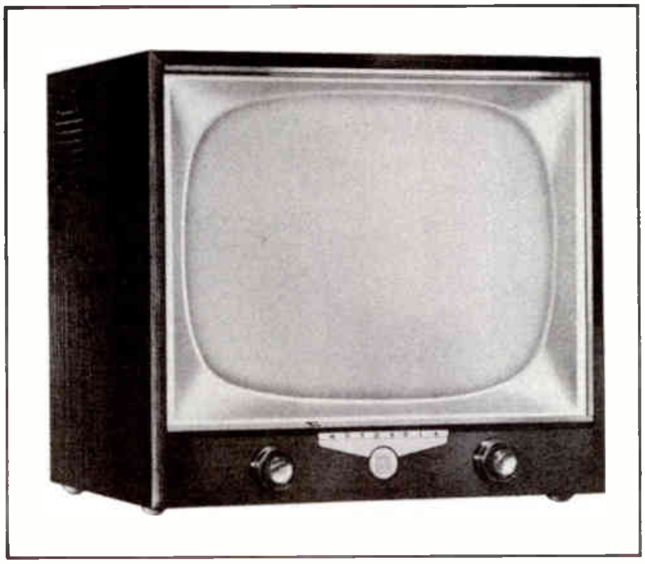

Fig. 1. Modern receiver which employs Intercarrier I-F Amplification (Courtesy Motorola).

as three, or even four, different frequencies. There may be as much as 3 or 4 megacycles difference in the frequency of the lowest I-F transformer and that of the highest. The aim in television I-F sections is to provide wide band-pass rather than maximum gain.

Television receivers rely on additional stages of amplification for their gain. They regularly use at least three stages of I-F amplification, and many use four stages. Radio receivers, on the other hand, rarely use more than two stages of I-F amplification, although a handful of the better radio receivers use as many as three stages.

While gain-per-stage is important in both radio and television receivers, it is not usually so important in television receivers as in radio receivers. Television engineers have reason to expect the TV antenna signal strength to be higher than ordinary radio signals.

Perhaps this last statement should be qualified to some extent, nevertheless the attitude of the designers is described fairly accurately.

In the earlier days of television most receivers used two separate I-F sections. One handled the I-F amplification of the video signal. The other section handled the I-F amplification of the sound signal.

The sound I-F section was commonly referred to as the *sound I-F channel.* The other I-F section was then referred to as the *video I-F channel.*

Millions of receivers were built using the two I-F sections. Then a more simple system of I-F amplification was introduced. It used only one I-F section which served to amplify both the video and sound I-F signals.

This newer system was called *intercarrier* I-F amplification.

When first introduced the intercarrier system was used only on the less expensive television receivers. The better quality receivers continued to use separate channels for the video and sound I-F signals.

With passage of time virtually all manufacturers have adopted the intercarrier system of I-F amplification so that nearly all modern television receivers use that system. Even so, it is not possible to ignore the two-channel I-F amplifiers because there are millions of receivers still in use which have that system, and many of those receivers will continue in use for many years.

Section 2. BASIC REQUIREMENTS OF AN I-F AMPLIFIER

It is desirable that an I-F amplifier be capable of providing as much gain as possible. But there are other things in connection with the amplifier which are equally important, and in some cases even more important.

Probably the most important feature of an I-F amplifier in a TV receiver is that it must be capable of amplifying *all* the frequencies contained in the composite video signal, and not just part of them.

From your previous studies of the composite video signal you understand the importance of amplifying all the frequencies embraced within that signal. Since the composite video signal rides —in the form of a modulation—on the video I-F signal, the I-F amplifiers must be capable of accepting and amplifying and passing all the frequencies in the composite video signal.

This means the band-pass of the I-F amplifier must be great enough to handle all the frequencies in the composite video signal, which range from as low as 60 cycles up to 4 megacycles. Strange as it may seem, the design of the I-F amplifiers for a two-channel I-F is often more difficult than for intercarrier amplification.

When two channels are used to amplify the I-F signals, one for the video and the other for the sound, much care must be exercised in the design and alignment of the I-F transformers. There must be little or no intermixing between the I-F *video* signal and the I-F *sound* signal—which means that the video I-F amplifiers must have their amplifying ability sharply attenuated at the lower edge of the band. Those are the frequencies which are adjacent to the sound I-F frequencies.

In plain words, the ability of I-F amplifiers to handle signals at frequencies near the sound I-F frequency should be sharply cut off.

Something of the requirements, with respect to

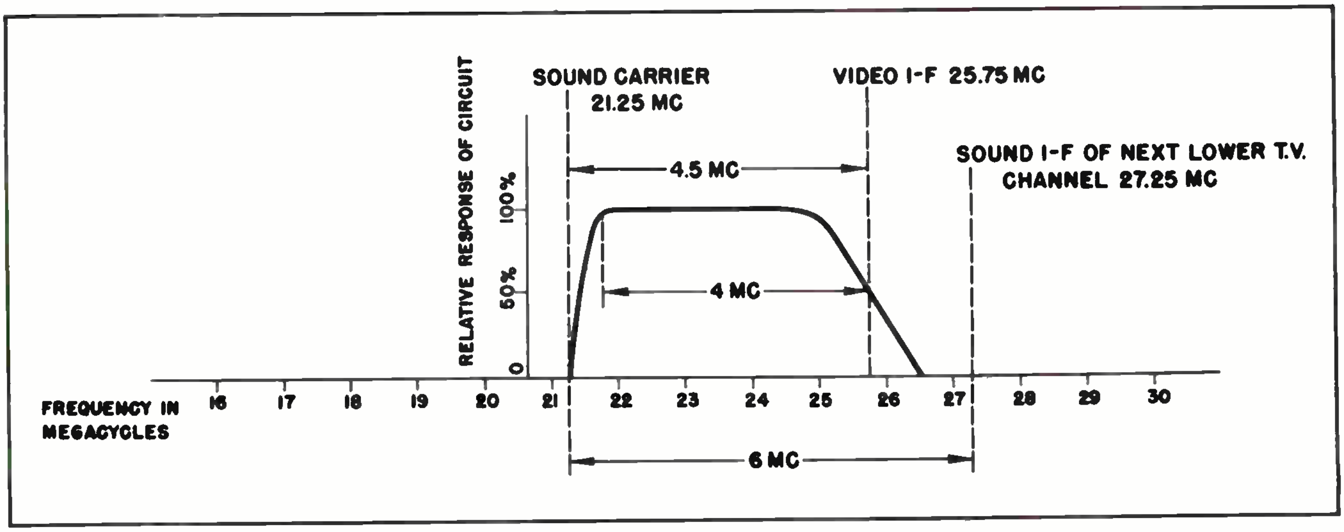

Fig. 2. Frequency response of Video I-F channel in Two-Channel receiver.

frequency response, can be better understood by studying Fig. 2.

It should be kept clearly in mind that the frequency response curve in Fig. 2 refers to the *video* I-F channel of a two-channel receiver. The *sound* channel response is not included, although the relationship of the sound channel frequency to the video I-F response curve is indicated. You will note that the frequency of the sound I-F signal for the *same* TV channel is lower than the video I-F frequency, but the sound I-F channel for the *adjacent* TV channel is at higher frequency.

The frequency response curve for an intercarrier I-F amplifier is somewhat different. It resembles more closely the response curve for a radio receiver. However, the response curve is not nearly so sharp as that for a radio.

Fig. 3 shows the frequency response of the I-F amplifier section used in a typical intercarrier receiver.

Note the differences between the response curves for the two types of I-F amplifiers. The response curve for the two-channel receiver shows the amplification response of the I-F section to various signal frequencies. It is specially designed to accept and amplify those frequencies which pertain to the video signal of a given TV channel. But it is also carefully designed to reject those frequencies immediately outside that band. It carefully rejects all signals associated with the sound I-F carrier.

Much less attention is paid to the edges of the response curve in the case of the intercarrier receiver. In this case it resembles the I-F circuits in a radio receiver somewhat more closely than those in a two-channel television receiver.

To effect the extremely sharp cut-off in frequency response at the low end of the frequency band special wave-traps are employed in the I-F circuits. These wave-traps act to reject signals whose frequencies are near the sound I-F frequency. This is especially true in the case of video I-F circuits in those receivers which use split-sound I-F amplification. The term *split-sound* I-F amplification is merely another way to describe two-channel I-F amplification.

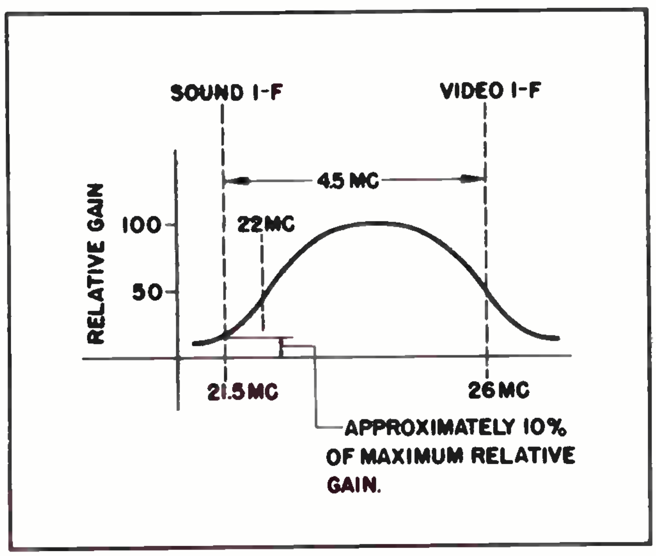

Fig. 3. Frequency response of intercarrier I-F amplifier.

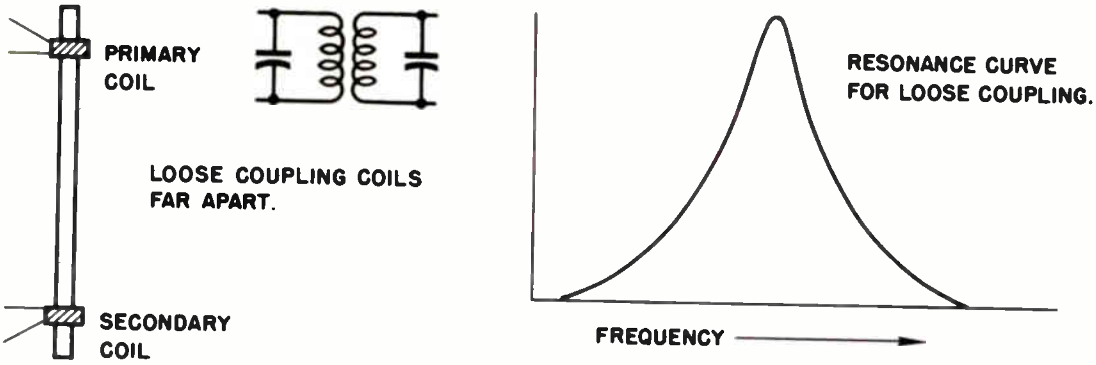

Fig. 4. Loose Coupling between two tuned circuits.

The manner in which the windings on the I-F transformers are coupled together also affects the response of the transformers to various frequencies. Varying methods of coupling the several transformers in the same I-F section has a very pronounced effect on the over-all frequency response of the section.

Since, in an intercarrier receiver, both the video I-F signal and the sound I-F signal are amplified in the same circuits it is desirable that the I-F amplifiers have a somewhat broader frequency response. In fact a wider response is necessary. This means there is less need for the sharp cut-off in frequency response at each end of the frequency response curve.

Section 3. EFFECT OF COUPLING ON FREQUENCY RESPONSE

Many television I-F transformers, like the I-F transformers used in radio receivers, use a primary winding and a secondary winding. The manner in which the two windings are coupled together have a considerable influence on the way the signal is affected while it is passing through the transformer.

Radio men have experimented with several methods of coupling the two windings together. They have found that when the two coils of the transformer are separated quite widely, as in Fig. 4, the frequency response of the transformer circuit follows one pattern, but when the spacing of the windings is different they bring about a different frequency response.

These remarks apply specifically to *tuned* transformers — those which use resonant circuits in the primary or secondary or both.

When the two windings are widely spaced on the coil form, as in Fig. 4, the coupling is said to be "loose." The two coils are not tightly, or closely, coupled together.

When *loose* coupling between the two windings is employed the greatest response of the circuit is to the exact frequency to which the two windings are tuned. In this connection it should be kept in mind that it is a regular practice to have both the primary and the secondary windings of I-F transformers tuned to the frequency they are expected to pass.

Furthermore, the slope of the two sides of the response curve rise rather gradually to the peak. There is not the sharp and abrupt rise that is found in some of the other methods of coupling.

For other conditions of operations the two windings can be brought a little more closely together on the coil form. Such positioning is shown in Fig. 5. The position of the two windings on the coil form in Fig. 5 can be compared with the positioning of the windings in Fig. 4.

The manner in which the windings are positioned on the coil form in Fig. 5 is known as "critical coupling." This is the type of coupling most often employed in the I-F transformers used in radio receivers.

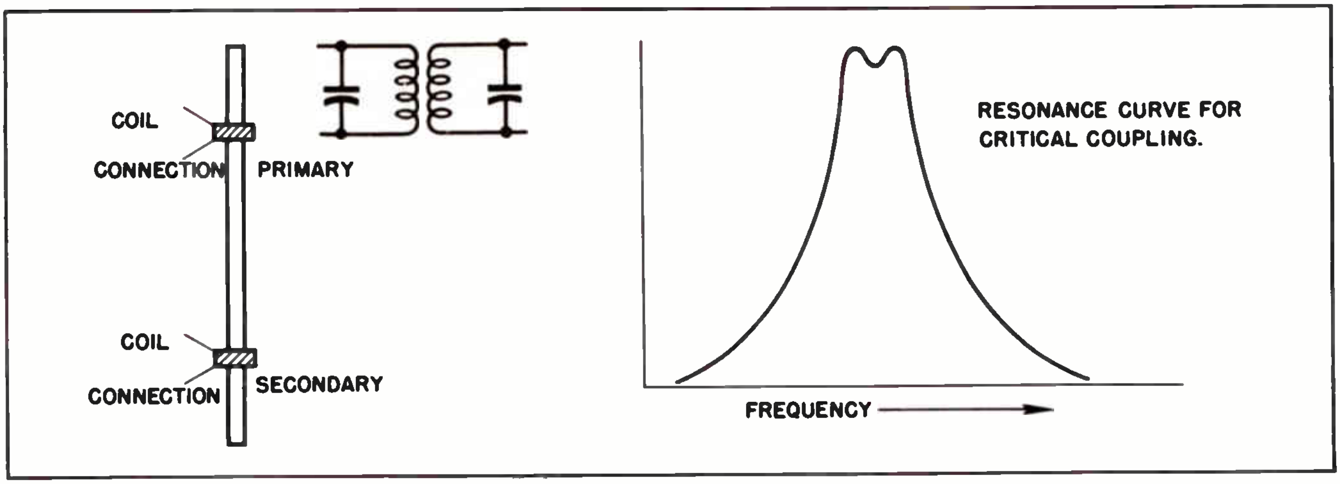

Fig. 5. Critical Coupling between two tuned circuits.

Note the difference in the response curve in Fig. 5 as compared with the one in Fig. 4. The sides of the curve are steeper, which provides the transformer with the ability to reject those frequencies immediately outside the band it is desired to pass. In radio work this is a desirable characteristic.

Note also that the width of the peak of the response curve is considerably greater than that in Fig. 4. This provides what is called a *wider band-pass*. In the case of a radio the width of the band of frequencies which can be passed by such a transformer is about 10 kilocycles, possibly a little more or a little less. A critically coupled transformer has greater gain than a loosely coupled transformer.

You have probably noticed the slight dip in the center of the top of the response curve. This is characteristic of the frequency-passing ability of a tuned transformer when the coupling is critical. So long as the dip is no greater than the amount shown in Fig. 5 there is no serious effect on the output of the radio.

But the dip becomes more pronounced as the coupling between the two tuned windings is made closer. Closer coupling is accomplished by bringing the two windings closer together. The closeness of coupling is referred to by engineers as the *coefficient of coupling*. It is a numerical factor, and is always less than unity (1).

The positioning of the two windings on the coil form, and the shape of the frequency response curve, when close coupling is employed is shown in Fig. 6. The physical positioning of the two windings is such that they are quite close together. The added magnetic coupling between the windings changes the response of the transformer to the various frequencies applied to it.

When the coupling is as close as that of the two windings in Fig. 6 the transformer tends to respond best to two different frequencies, one of which is slightly above and the other slightly below the resonant frequency, rather than to the resonant frequency itself. In fact, there is a very pronounced dip in the response of the transformer to the resonant frequency.

It is an odd characteristic of a tuned transformer that it does not respond to the exact resonant frequency quite so well as it does to two other frequencies. As mentioned earlier, it responds better to one slightly above the resonant frequency, and another slightly below, than to the resonant frequency itself.

When the frequency response curve for a closely coupled tuned transformer is drawn it will be shaped very much as the one in Fig. 6. The curve shows two peaks, with a pronounced dip between them.

It must be kept clearly in mind that the peculiar condition described here is present in a transformer where the *primary and secondary are tuned*. We are not discussing an ordinary *untuned* transformer.

Facts and figures regarding the action of a tuned transformer have been acquired through a

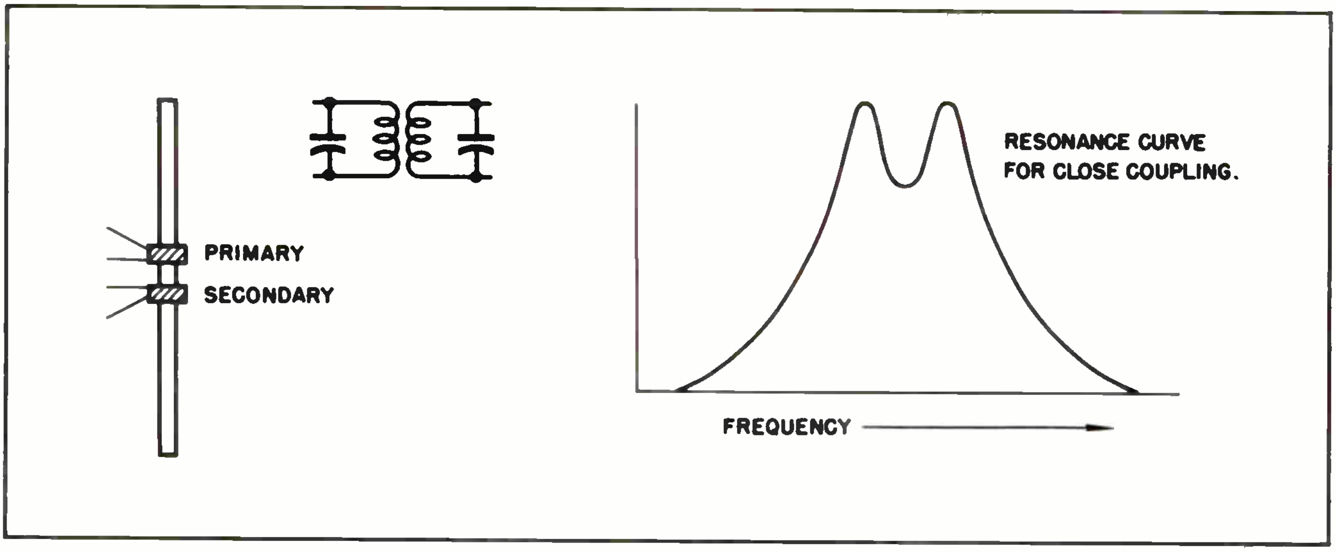

Fig. 6. Close Coupling between two tuned circuits.

long series of experiences and experiments. The action can be explained mathematically, but for our purpose there is little need to inquire into it so closely. Practical radio and television service men are interested in the actions which take place, and what is necessary to bring about any given type of condition.

It is seldom necessary to inquire into the precise nature of the causes any more than it is necessary for us to inquire into what causes an apple to fall from a tree when its stem is broken. Ordinary experiences of life teach us the apple will fall when the stem is broken, and we accept that fact without inquiring into the reasons as to what causes the fall. We attribute the fall to force of gravity and let it go with that, without questioning the nature of gravity itself.

So it is with the peculiar action of a tuned transformer, such as those used in I-F circuits. We can accept the fact that certain actions will occur when certain conditions are present. We can do that even though we do not fully understand the underlying physical conditions and activity which causes the action to occur.

Section 4. HOW PROPER I-F RESPONSE IS OBTAINED BY USING SEVERAL TYPES OF COUPLING

In the early days of television it was the practice to use an I-F frequency between 21 mc and 26 mc. Since I-F transformers used in the I-F section had to pass a band of frequencies approximately 4 mc wide the problem of designing circuits capable of performing their duties was a rather tough one. (Mc means megacycles.)

The width of the band of frequencies which had to be passed was quite large compared with the resonant frequency of the circuits themselves.

This condition can be better understood when it is contrasted with those present in an ordinary radio I-F transformer. By way of explanation we will point out an example.

The I-F frequency most widely used in radio work is approximately 455 kc. The width of the band pass is approximately 10 kc. This means the resonant frequency of the tuned I-F circuit is approximately 45 times as great as the narrow band of frequencies it is expected to pass.

To put this in other words we can say the band of frequencies to be passed is only a small percent of the actual resonant frequency of the circuits through which they pass. It is on the order of 1 to 45.

In the case of television I-F circuits the width of the band to be passed comes much closer to the resonant frequency. Using 4 mc as the width of the band to be passed, we find a ratio of 4 to 24, or approximately 1 to 6.

Thus we find that instead of the ratio of 1 to 45, which has been used for so many years in radio work, we have 1 to 6 in the early television

I-F circuits. Making the frequency response of the circuits so wide, with respect to the resonant frequency of the circuit, tended to reduce the gain radically.

Several measures have been employed to help boost the gain while retaining a broad frequency response. One is to have one or more stages of the I-F section use closely coupled transformers while one or more others use loosely coupled transformers.

Another method is to tune the successive I-F transformers to slightly different frequencies.

A combination of both methods usually proves most successful. Such systems have two I-F transformers tuned to the center frequency of the band to be passed, one loosely coupled and the other tightly coupled. A third transformer using critical coupling is tuned to a frequency slightly above the center frequency, and a fourth transformer is critically coupled and tuned to a frequency slightly below the center frequency.

The result of such a combination can be better understood by referring to Fig. 7.

Fig. 7 shows two I-F transformers which are tuned to 23.25 mc. One is loosely coupled. Its frequency response curve has a single peak, and the maximum gain is not so high as some of the other stages. The other transformer is closely coupled. It has more gain, but its frequency response curve has a deep dip in the center.

Both of these transformers are tuned to a frequency near the center of the band of frequencies the circuits are expected to pass.

There are two other I-F transformers in this I-F section. Both are critically coupled. One is tuned to a frequency higher than the center frequency — in this case it is 25.25 mc. The other is tuned to a frequency lower than the center frequency; it is tuned to 21.50 mc.

Combining the responses of all these stages of I-F amplification results in an over-all frequency response which can handle the full range of 4 megacycles which a television I-F section is expected to handle.

Section 5. DISADVANTAGES OF SEPARATE I-F CHANNELS FOR SOUND AND VIDEO

Probably the most obvious disadvantage of

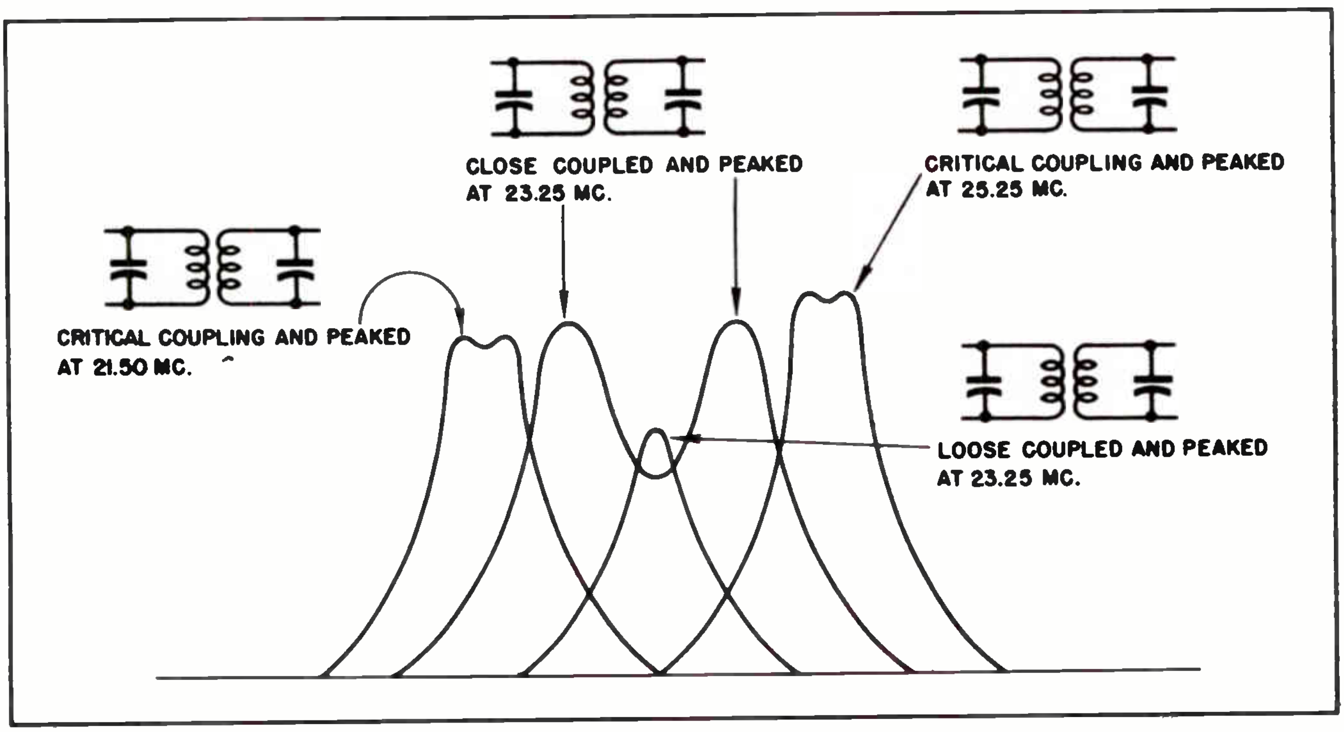

Fig. 7. Combined frequency responses of four I-F stages employing different types of coupling or frequencies.

using two separate channels in the I-F section to amplify the sound signals and the video signals is the fact that such practice employs more tubes, more I-F transformers, more space, and is more costly. There are still other disadvantages which are not so obvious, yet are equally important.

When separate I-F channels are used for the sound and video it is necessary to provide relatively wide response for those video frequencies which must be passed, yet the response must be cut off quite sharply at each end of the band to prevent interference. From a practical point of view this means that carefully tuned wave-traps must be provided at each of the I-F transformers.

A wave-trap, as you already well know, is a tuned circuit capable of accepting or rejecting a given frequency. A series tuned circuit can be installed between the I-F circuit and ground, in which case the wave-trap circuit is tuned to the frequency to be trapped out. The series resonant circuit provides a path of low impedance to ground for the undesired frequency. This is shown in Fig. 8.

Another method is to connect a parallel tuned wave-trap in series with the coupling between the I-F stages. The parallel resonant circuit is tuned to the frequency which is not to pass. See Fig. 9.

Sometimes there is a wave-trap tuned to a frequency just below the edge of the band which is to be passed. In other cases the wave-trap is tuned to the frequency just above the band to be passed.

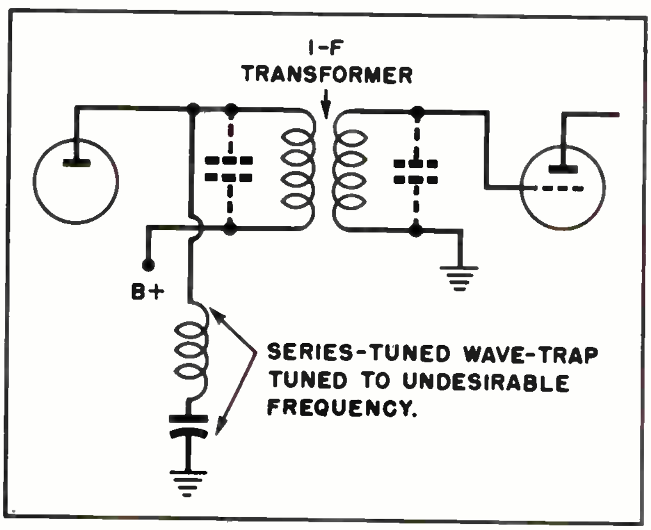

Fig. 8. One method of trapping out unwanted signal by using series-tuned wave-trap.

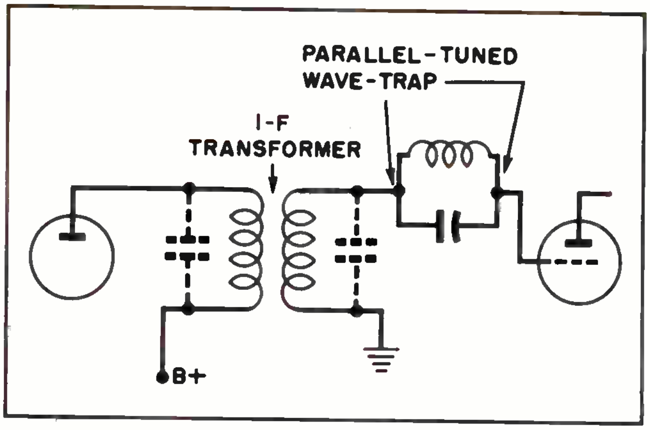

Fig. 9. Rejecting unwanted signal by using parallel-tuned wave-trap.

In some cases there are wave-traps tuned to frequencies both above and below those which are to be passed.

Including wave-traps in the I-F section makes it technically possible to control those frequencies which are to be passed and those which are to be rejected. But their inclusion adds much to the cost of the receiver.

Furthermore, they must all be carefully adjusted, and must be maintained in careful adjustment. Permitting the resonant frequency of any of these wave-traps to shift can cause serious interference with the quality of the picture. That is most undesirable.

It must be kept in mind there is a strong I-F carrier operating on a frequency just below the video I-F signal. That is the sound I-F carrier.

It is undesirable that the sound I-F be permitted to get into the video amplifiers since that would cause interference. Wave-traps must be arranged to trap out the I-F sound carrier to keep it from the video amplifier circuits.

One other disadvantage to using separate channels for the sound and the video is the action which occurs when the oscillator in the tuner section tends to drift.

The electrical constants of the tuned resonant circuit connected with the high-frequency oscillator in the tuner have a tendency to change slightly during the warm-up period just after the television receiver is first turned on. Part of these changes result from mechanical expansion from the heat which builds up as the tubes warm up. Other changes occur in the oscillator tube itself.

This oscillator generates a sine-wave signal at high frequency which is mixed with both the sound RF carrier and the video RF carrier. The result of that mixing is to create the I-F frequencies for the sound and video. This action is much like that which occurs in a radio receiver, and is one to which we devote a separate lesson.

The difference frequency, which results from mixing the oscillator signal with RF video carrier, is fed to the I-F section. The other difference frequency, which results from mixing the oscillator signal with the RF sound carrier, is also fed to the I-F section.

When separate I-F channels are employed for sound and video the video I-F signal is fed to the video I-F section and the sound I-F signal is fed to the sound I-F section. When intercarrier I-F amplification is employed both I-F signals are fed to the same I-F amplifier section.

If the frequency of the oscillator signal tends to shift slightly, so as to favor the video I-F signal, the sound I-F signal is weakened and the sound tends to fade away. On the other hand, if the oscillator shifts slightly, so as to favor the sound I-F signal, the sound at the speaker may become quite strong while the picture is weakened. The effect of this favoring of one I-F signal, while discriminating against the other, is most noticeable when separate I-F channels are used.

Because of this action it is often necessary to stabilize the frequency of the oscillator by using some type of automatic frequency control. This can be done, but it calls for at least one extra tube, and that runs into money.

The alternative is for the viewer to continually adjust the "fine tuning" control until the oscillator settles down and stabilizes itself. For some persons this tends to become annoying.

Due to the different manner in which amplification takes place in an intercarrier system, and the manner in which the signals are separated, there is less effect on the two signals when the oscillator in the tuner tends to shift its frequency. This will become more apparent to you after we have explained the amplifying action of an intercarrier system.

Section 6. TYPES OF I-F TRANSFORMERS USED IN TV RECEIVERS

I-F transformers used in radio receivers normally consist of an actual coil in the primary circuit and another actual coil in the secondary. Across each of these two coils is connected an actual capacitor, quite frequently a mica capacitor.

It must be recognized that the construction of a coil for an I-F transformer causes some capacitance to exist between the windings. This matter of *distributed* capacitance has been mentioned before, and it will be mentioned in other later lessons.

Such distributed capacitance occurs whenever metal conductors are separated from each other by an insulating material which can form the dielectric.

The I-F transformers for some radio receivers are so designed that the *distributed* capacitance combines with the inductance of the coils to form the tuned circuit. This means the inductance of the coil is combined with its own distributed capacitance so the circuit will resonate at the regular I-F frequency.

Examination of such a transformer fails to disclose the presence of the *capacitor* needed for tuning purposes, but the *capacitance* is present nevertheless. It is present as the *distributed capacitance* between the windings of the coil.

Such a transformer is tuned, or adjusted, by varying the inductance of the coil. That can be done by moving a powdered iron core inside the coil form. Usually the powdered iron core is moved into, or out of, the coil form by rotating a screw in the end of the iron core. These are the types of I-F transformers which are "inductance tuned."

Fig. 10 is a circuit diagram of an I-F transformer using inductance tuning in both the primary and secondary circuits. It is what is called a "double tuned" transformer because both the primary and secondary circuits are tuned. Most radio receivers use double-tuned transformers,

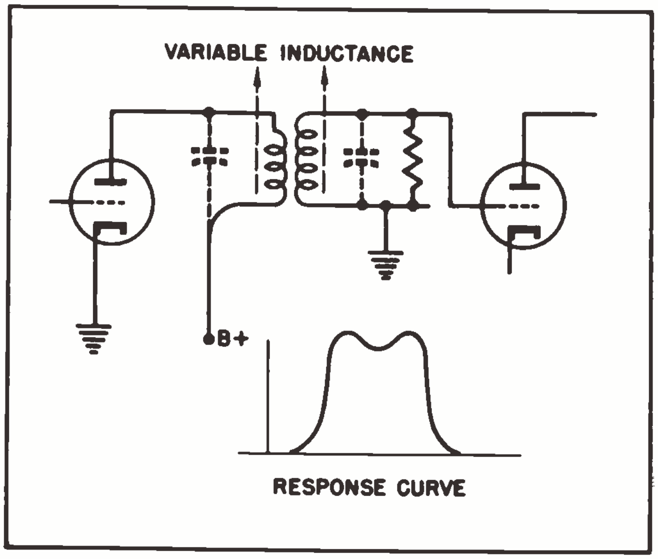

Fig. 10. Inductance tuned I-F transformer.

and many television receivers also use them.

When you study the diagram in Fig. 10 you will see the capacitor across the primary winding represented by the dotted lines. The use of the dotted lines to represent the capacitor is intended to convey the idea that *capacitance* exists at that point, and such capacitance is taken into consideration in the design of the circuit, but that no actual *physical capacitor* is employed.

The same condition exists in the secondary circuit. The dotted lines used to indicate the presence of the capacitance shows the capacitance is present without actually using a capacitor.

The I-F sections of television receivers use far higher frequencies than those used in radio work. I-F coils have far fewer turns than those used in radio. This means that less capacitance is needed to tune the coil to the I-F resonant frequency.

Thus, it becomes possible to tune I-F transformer windings for television work without using actual capacitors, just as is true of some radio I-F transformers. In fact, such practice is easier in the case of television I-F circuits.

Few, if any, I-F transformers used in television work employ actual, physical capacitors for tuning purposes. But the necessary tuning capacitance is present, nevertheless. It is present in the form of distributed capacitance between the windings of the transformer coils.

The response curve shown in connection with the I-F transformer circuit in Fig. 10 is the typical "flat-topped" curve of a critically coupled I-F transformer. The curve can be shaped differently by employing some other degree of coupling between the two windings. The peak will be much broader, and have a much deeper dip, if the coupling is closer. On the other hand it can be peaked more sharply by employing looser coupling.

All the conditions of coupling described in connection with Figs. 4 and 5 and 6 apply with equal force to the transformer shown in Fig. 10.

Because of the high frequencies employed in television I-F circuits it is possible to employ single coil tuning and obtain excellent results. Fig. 11 shows an I-F circuit which uses single-coil tuning.

The capacitance across the coil consists of the output capacitance of the preceding tube plus the distributed capacitance of the coil. That combined capacitance is used to tune the inductance of the coil to form a resonant circuit.

The inductance of the coil resonates with the distributed capacitance to form a parallel resonant circuit. That circuit is adjusted to resonate at the I-F frequency. Such a load in the anode circuit of the tube provides a relatively high load impedance at the I-F frequency, and thus obtains excellent gain. The high L/C ratio is conducive to high gain.

The frequency responsive curve of such a coupling transformer tends to be peaked. This is shown by the graph in Fig. 11.

It is not practical to broaden the response of a single-coil circuit, therefore a stage using this type of coupling is usually combined with at least one other stage which is broadly tuned.

The problem of designing coupling circuits for television receivers has been simplified somewhat by the increasing tendency to use a higher frequency in the I-F circuits. Most television receivers now being built use an I-F frequency on the order of 41 mc to 45 mc. This makes the I-F frequency about 10 or 11 times as high as the bandwidth of the signals to be passed by it. This

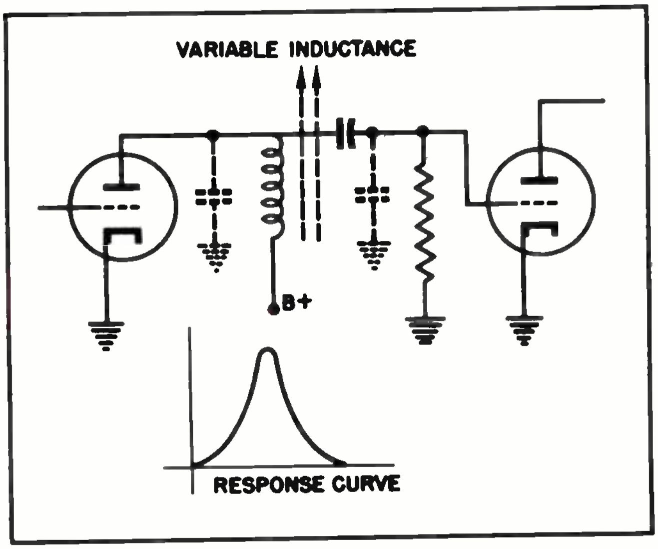

Fig. 11. Single coil I-F circuit.

brings the operating conditions somewhat closer to the ideal ones found in radio work.

Under most circumstances the act of increasing the frequency of the I-F stages from approximately 21 mc to approximately 41 mc would result in the I-F section having a lower gain. This would normally result from the well-known fact that the lower the I-F frequency the greater the amount of gain which can be attained in the I-F section.

But raising the I-F frequency has another effect — a beneficial effect — which goes far toward overcoming the normal loss of gain. This is the fact that increasing the I-F frequency without increasing the band-width improves the ratio between the band-pass and the resonant frequency of the circuit.

This makes it possible to sharpen the I-F response of the I-F stages, and thus actually increase the gain.

Experiments have shown that a well-designed TV I-F section which resonates between 41 mc and 45 mc can actually have more gain than one of the older models which is peaked between 21 mc and 25 mc. The additional gain is obtained by sharpening the response curve.

The response curve can be sharpened more satisfactorily by using the newer intercarrier system of I-F amplification than the older method of dual I-F sections. This is because the response curve of the intercarrier I-F section can be made sharper than the response curve for the older types of I-F amplifiers, and less of the signal is attenuated by use of the wave-traps and other modifying circuits.

Section 7 THE INTERCARRIER SYSTEM

The intercarrier system of I-F amplification employs a single channel for the amplification of all I-F signals. This means both the video I-F signals and the sound I-F signals are amplified in the same circuits.

The maximum width of the composite video signal is 4 megacycles. This means the widest band of frequencies which must be amplified for video purposes is 4 megacycles.

Furthermore, there is a difference of 4.5 megacycles between the video carrier signal and the sound carrier signal. This same 4.5 megacycle difference holds true in the I-F section after the original signals have been converted in the mixer section.

For all practical purposes, then, we have three signals present in the I-F section when intercarrier amplification is used. We have the video I-F, with its *amplitude* modulation of the composite video signal, with side-bands not exceeding 4 megacycles in width. We have the *frequency* modulated sound I-F; and, we have the 4.5 megacycle *difference* signal which represents the difference between the two I-F carriers.

The I-F amplifier circuits are so designed that they favor the amplification of the video carrier. The sound carrier is also accepted, passed and amplified, but its degree of amplification is far less than the video I-F signal.

Nevertheless, both I-F carriers are amplified. And since both are amplified, the 4.5-megacycle difference between them is maintained. Since both I-F carriers are stronger at the output of the I-F amplifier section than at the input it follows, as a natural result, that the strength of the difference signal will also be greater.

The relationship among the several frequencies present in the I-F section can be better visualized by studying the response curve in Fig. 12. That response curve is drawn to show the I-F response

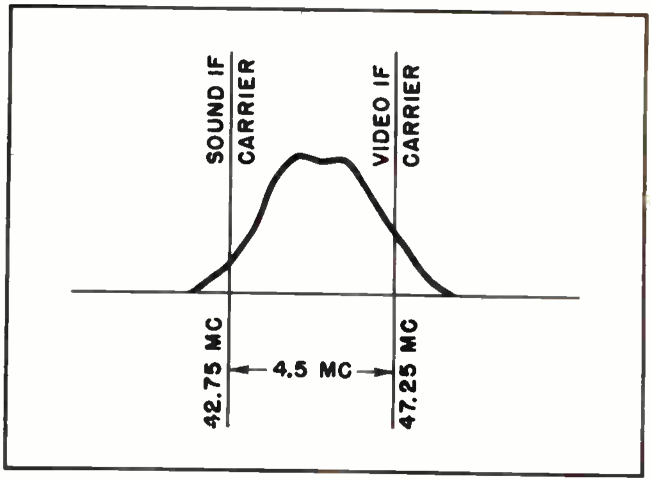

Fig. 12. Intercarrier I-F frequency response in the 40-mc range.

in an intercarrier system operating at the higher frequencies in the band just above 40 megacycles. Note that the curve is somewhat sharper than the one shown in Fig. 3, which was drawn for the 20-megacycle I-F band.

A study of the curve in Fig. 12 shows the maximum response of the I-F amplifier is for the middle and lower composite video frequencies. The principal emphasis is on the middle range frequencies.

There is some attenuation of the extremely low video frequencies, and some of the extremely high video frequencies. Nevertheless, the overall response is good.

Note also that the amplification of the sound I-F carrier is much less than for the video I-F frequencies. This fact can be better understood when it is remembered that the side-bands for the sound I-F do not extend very far from the exact carrier frequency itself. Therefore, the overall amplification of the sound I-F is restricted to that level shown by the response curve.

The lower side-bands of the video I-F, the side-bands which carry the intelligence of the composite video signal, extend from the video I-F carrier frequency down almost to the frequency of the sound I-F carrier. The bulk of the I-F intelligence is carried in those frequencies which are most strongly affected by the action of the I-F circuits — which receive the greatest amplification. In plain words, those frequencies which fall within the range of greatest I-F amplification are the ones which carry the bulk of the video intelligence. Thus, the effectiveness of the I-F circuits is such as to provide the greatest amplification for those frequencies which do the most to recreate the picture.

The output of the intercarrier I-F amplifier section feeds directly into the video detector. That detector is primarily sensitive to *amplitude* modulation, and acts to demodulate the video information carried by the video I-F signal.

The video detector also responds, to some extent, to the sound I-F signal, and tries to demodulate it also. However, the strength of the signal is deliberately kept low, so anything demodulated from it and fed into the following video amplifiers is very weak and ineffective. Furthermore, most of the information which is carried on the sound I-F signal is carried in the form of *frequency* modulation — not amplitude modulation. This further reduces the possibility of any signals from it reaching the video amplifiers.

But it should be kept clearly in mind that two I-F carriers reach the video detector. For all intents and purposes these carriers are operating at RF frequencies.

Furthermore, these two carriers, separated from each other by 4.5 megacycles, feed into a non-linear device when they feed into the video detector. As always happens when two RF carriers feed into a non-linear circuit, the output will contain a frequency corresponding to the difference between the two carriers. In this case, a difference frequency amounting to 4.5 megacycles appears at the output of the video detector. See Fig. 13.

The demodulation of the sound I-F carrier at the video detector — if any occurs — is very slight, and causes very little signal to enter the video amplifier circuit. The demodulation of the video carrier results in the composite video signal leaving the video detector so it can enter the video amplifier.

The 4.5-megacycle difference signal is also present at the output of the video detector. The video amplifier circuits are so designed that they discriminate against the 4.5-megacycle difference signal, but some of that signal would enter those circuits if it were not trapped out.

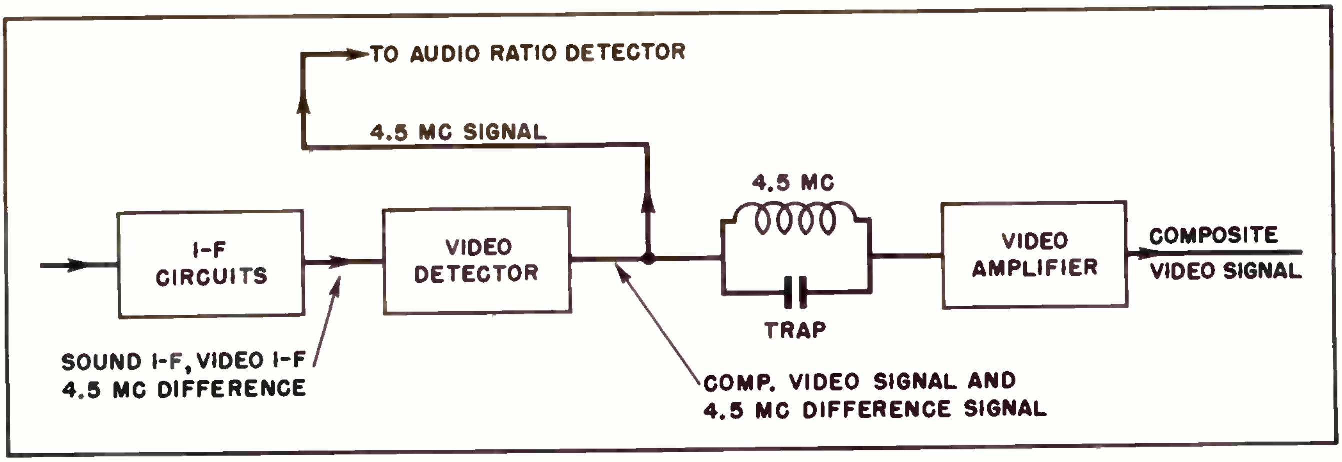

Fig. 13. Separation of signals at video detector.

Since the presence of the 4.5-megacycle difference signal is definitely not wanted in the video amplifier section a trap is inserted between the output of the video detector and the input to the video amplifier. That trap can take any of several forms, but usually consists of a high-Q parallel resonant circuit tuned to 4.5 mc. They have been pretty well standardized in design. Replacements are readily available. They are often called *4.5 mc sound take-off coils.*

Presence of the trap prevents passage of the 4.5 mc signal into the video amplifier circuit, but the signal is free to follow another path provided for it. It can follow that path to the ratio detector of the audio system. Because it separates the sound signal from the video is the reason it is often called a *sound take-off coil.*

That 4.5 mc signal contains two kinds of modulation. It contains *amplitude* modulation from the video carrier and *frequency* modulation from the sound carrier.

That signal is then fed into a ratio detector circuit which is not sensitive to amplitude modulations, or to a limiter-discriminator circuit which responds only to the frequency modulations on the 4.5-megacycle signal. In either case, the amplitude modulations have no effect, but the frequency modulations pass on into the audio amplifier stages where they act to reproduce the sound.

The 4.5 mc signal is usually coupled from the output of the video detector to the input of the ratio detector by passing through a low-capacity coupling capacitor. The capacity of that capacitor is normally on the order of about 2 mmfd.

The use of such a low-capacity capacitor tends to restrict, or reject, video frequencies so they cannot enter the audio section. However, the 4.5 mc signal can pass through the capacitor to the audio circuits.

Section 8. IDENTIFYING THE TYPE OF I-F SYSTEM USED IN A RECEIVER

When servicing a television receiver it is often important to recognize as quickly as possible the type of I-F amplifying system being used. This is particularly important when symptoms point to some sort of trouble in the RF or I-F amplifying circuits.

Those receivers which use a separate sound I-F amplifying system usually tap off the sound I-F signal at the output of the mixer stage. If it can be clearly established that the sound I-F signal it tapped off at that location it is clearly evident the receiver uses a separate I-F channel for the sound.

However, all receivers which use a separate I-F amplifying system for the sound do not tap off the sound I-F signal at the mixer circuit. Some tap off the signal at the output of the first video I-F stage, or the second video I-F stage. Such practice sometimes tends to confuse practical servicemen, even experienced ones.

Receivers using intercarrier I-F systems always have the sound signal tapped off following the video detector. The reason for this, of course, is that it is necessary to recover the *difference* signal which has a frequency of 4.5 megacycles, when this type of amplifying system is used. That difference signal must be tapped off following the video detector.

All of which is merely a prelude to the establishment of a rule which clearly indicates the type of I-F amplifying system being used in any given receiver. If the sound I-F signal is tapped off and fed into the sound amplifying circuits at any point *ahead* of the video detector the receiver uses a *separate* sound I-F amplification system. If the sound signal is tapped off *following* the video detector the receiver uses *intercarrier* amplification.

There is one exception to this rule. That is in the case of color receivers. Because of a peculiar necessity, which we need not to go into at this time, the sound signal in a color receiver is tapped off immediately ahead of the video detector rather than immediately following it. In most cases, however, color receivers employ intercarrier amplification, but they use a slightly different procedure when separating the sound signals from the video signals. This fact will be taken up when color is discussed.

In B/W receivers using intercarrier amplification the sound signal is always tapped off following the video detector.

Section 9. I-F TRANSFORMERS FOR TV RECEIVERS

Very often the I-F transformers used in TV receivers are enclosed within a metal can in much the same manner we have become accustomed to finding I-F transformers in radio work. Other manufacturers mount their I-F transformers directly on the chassis without enclosing them within shielding cans.

When the transformer is enclosed within a metal can it is common practice to mount the can on top of the main chassis. In some receivers the metal can is mounted on a smaller sub-chassis. It is the usual custom, however, to mount such transformers on the top of the chassis.

The transformer is nearly always mounted very close to the amplifier tubes with which it is immediately identified. In most cases the transformer is mounted between the two tubes it couples together. This practice makes the problem of identifying the I-F amplifier tubes much easier.

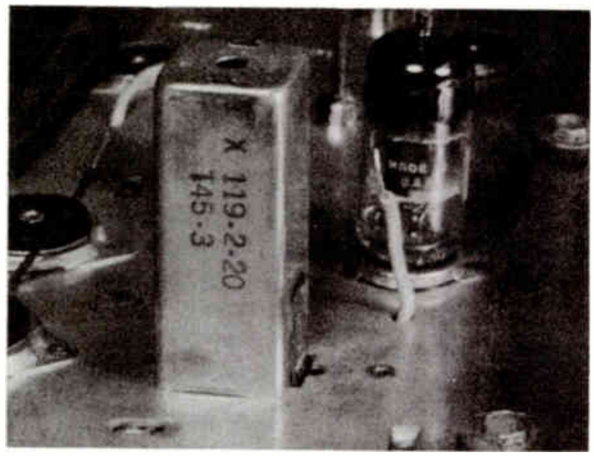

Fig. 14. Can-enclosed I-F transformer mounted on top of chassis.

Fig. 14 shows a can-enclosed I-F transformer mounted on top of a chassis.

When transformers are used without being enclosed in metal cans the more common practice is to mount them under the chassis. Here, again, the practice is to mount them between the tube sockets of the two amplifier tubes they couple together. Fig. 15 shows an unshielded I-F transformer mounted underneath the chassis of a TV receiver.

Section 10. THE F-M DEMODULATOR FOR SOUND SIGNAL

The transformer used in connection with the demodulator of the sound I-F signal is almost invariably mounted in a metal can. This is true

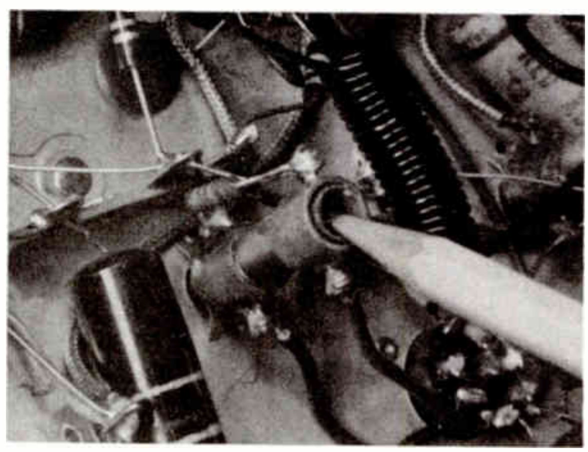

Fig. 15. Unshielded I-F transformer.

whether a ratio detector is used, or the demodulation is by means of a limiter-discriminator.

It is always well to definitely identify the transformer for the sound demodulation circuit so it is not confused with the I-F transformers. An error in identification may result in the demodulator being accidentally thrown out of adjustment when the intention is to adjust the I-F transformers. Should that happen you may wind up with both the sound and the video out of adjustment, whereas previously you had trouble only in the video I-F section.

The sound demodulator transformer is usually adjustable, whether it is for a ratio detector or for a limiter-discriminator. This makes it possible to adjust the tuning of the circuit if it gets out of adjustment through aging or through accident.

Fig. 16 shows what one *ratio detector transformer* looks like when mounted on a chassis. It will be noted there is little difference between its appearance and that of an *I-F transformer* mounted in a can. In most cases the ratio detector transformer is mounted on the chassis at a distance from the I-F transformers. But this is not an invariable rule.

In general, the physical size of the metal can which encloses a ratio detector is slightly larger than those which enclose I-F transformers. But this is not a positive method of identification. A better method is to trace the circuits under the chassis, or study the chart of the location of the various parts. Such chart is normally included as a part of the technical information furnished in the technical manual covering each receiver.

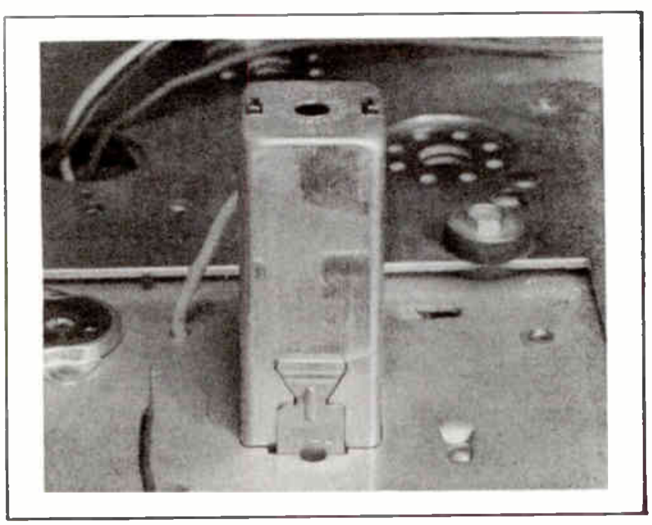

Fig. 16. Ratio Detector transformer.

If such a chart is available it provides the quickest, and most certain, method of identification.

Section 11. ALIGNING THE I-F CIRCUITS

Whenever it becomes necessary to replace an I-F transformer it is sometimes necessary to check the alignment of the I-F circuits. A re-alignment is also sometimes necessary if some of the other parts used in the circuit are changed, or other radical changes have been made in the arrangement of the I-F section.

In addition, the physical and electrical constants of the parts used in the I-F circuits of a television receiver have some tendency to change during the process of aging. The coils change inductance slightly, some of the other parts are physically shifted, or changed, so they affect the inductance or capacitance of the circuit.

When these things occur it is sometimes necessary to realign the I-F circuits.

There are also those cases, always unfortunate and lamentable, which involve the "screwdriver happy" owner who delights in tightening every loose screw he can find. Since adjustment screws in a television receiver, like those in a radio receiver, are rarely supposed to be tight any attempt to tighten them is almost certain to result in the I-F circuits being thrown out of adjustment.

After the tuned circuits of a television receiver have been exposed to such an experience the only possible way to get the receiver back into operation again is to realign it.

In some ways the procedure for realigning the tuned circuits of a TV I-F section is easier than in the case of realigning, or "phasing," the tuned circuits in a radio receiver. In other ways the procedure is more difficult and more tricky.

Before entering on any discussion of I-F alignment procedures we want to inject a few words of caution. Do not attempt indiscriminate aligning actions without first making certain the receiver's tuned circuits actually need realignment. You may do more harm than good.

We would also like to emphasize that under normal operating conditions the I-F circuits in television receivers rarely need realignment unless new parts have been added, or the circuits have been deliberately detuned through accident or design. All of which means that you should be very slow to begin alignment procedures unless you have installed some new parts, or know that the circuits have been deliberately detuned.

Old age, and other natural occurrences, will cause some degree of misalignment of the I-F tuned circuits, but such things are not usually serious enough to require realignment except on rare occasions.

We also want to warn you against attempting to realign the tuned circuits of a television receiver unless you have a technical manual available so you know exactly what you are doing.

Such manual provides you with the technical information you need for realignment. It tells you the kind of frequency to inject into the tuned circuits, the frequency to which each I-F transformer is tuned, and the manner of coupling your signal generator to the circuit so you will not overload the circuits and bring about errors.

Failure to observe the explicit directions provided in the technical manuals may cause you to get the circuits *out of alignment* instead of *into alignment*, and you may get them so badly out of alignment you cannot restore them to their original condition.

We are not trying to frighten you into thinking that alignment of TV I-F circuits is a difficult matter. It is not hard to realign them. But you must follow the procedures recommended by the engineers who designed the receivers. If you fail to follow those instructions you are merely asking for trouble.

Because the band-pass of television I-F circuits are much wider than those used in radio work it is easier to send a signal through them, even when they are partially misaligned. From that point of view it is easier to realign a TV circuit than a radio circuit.

If a sweep generator and oscilloscope are available most technicians prefer to use them for realignment purposes. Yet, a good alignment job can be accomplished by using nothing but an ordinary RF signal generator, capable of generating signals in the I-F frequency range, and some kind of output meter. An ordinary VOM or VTVM is usually satisfactory for use as an output meter.

Your first step is to secure a technical manual covering the receiver you intend to align. In the case of an authorized serviceman such manuals are usually available directly from the manufacturer. Other service technicians depend on Howard W. Sams' Photofacts manuals, or on John F. Rider's technical manuals.

In any case some technical information covering that particular model must be available. Without such a technical manual you might be unable to locate the I-F tubes, the I-F transformers, the detector stage or other critical parts of the receiver. Furthermore, you could do little more than guess at the I-F frequency, the setting of each stage, or the frequency to which each stage is tuned. You must know those things if you are to do a good job.

Sometimes the alignment instructions tell you to connect your signal generator directly to the input of the stage you intend to check. On other occasions the instructions instruct you to use a "dummy antenna."

The reason for connecting a dummy antenna between the signal generator and the tuned circuit of the receiver is to prevent the capacity of the generator leads "loading" the tuned circuits of the receiver, and thus affecting their resonant frequencies.

A dummy antenna is a simple thing, and may be constructed in any of several ways. In most cases the technical manuals give you precise instructions as to what components you must use for a dummy antenna. Sometimes the dummy antenna consists of a capacitor, and sometimes it consists of a resistor. In other cases it may be both a resistor and a capacitor, connected in series.

Fig. 17 provides a rough, but general, idea of the manner in which a dummy antenna is in-

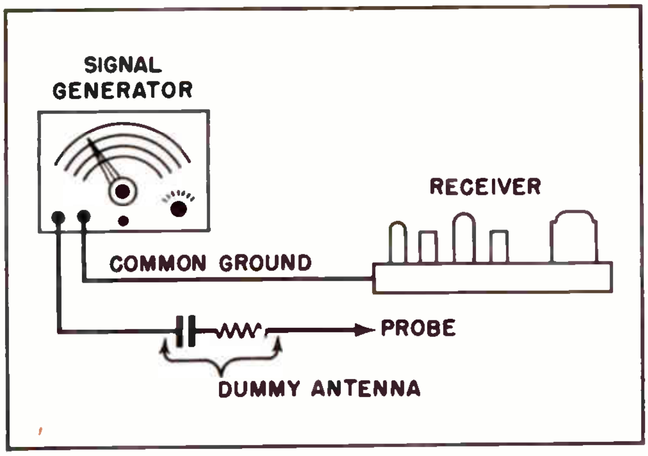

Fig. 17. How dummy antenna is inserted in "hot lead" from signal generator.

serted in the "hot lead" from the signal generator. It is inserted in the lead which is used as the probe for injecting the signal into the tuned circuits of the I-F section.

Once the dummy antenna has been properly prepared and inserted in the "hot lead" from the signal generator the next step is to set the signal generator to the correct frequency. The technical manual gives the exact frequency to which the generator is to be set for each adjustment, and the exact point at which the adjustment is to be made. Furthermore, the manual tells you what to read on the meter; whether it is for maximum deflection, or minimum deflection, or for something else.

The technical manual provides 'scope patterns with which you can compare those on your own 'scope — provided you are using a scope. With all that information available there is little left for you to do but go through the motions.

Instructions in the technical manual provide you with information relating to the manner of setting the 4.5-mc sound trap, for adjusting your ratio detector in the sound circuit, and other specific bits of information concerning other parts of the tuned circuits.

Section 12. ALIGNMENT FOR FRINGE AREAS

Alignment procedures in technical manuals are intended to provide the correct adjustment which will bring in the best picture. Such alignment is intended to provide a band-width of the correct proportions so all frequencies are properly handled.

This is all well and good so long as the signal at the antenna is sufficiently strong. But there are some localities where it is more desirable to obtain a good *basic* picture rather than one containing *all the fine details* desired by those living near the transmitter. This is particularly true of those who live in remote fringe areas.

Viewers in fringe areas are less concerned with performance which provides fine detail than they are in the basic fact of getting some kind of a viewable picture. They are willing to sacrifice some of the fine details in their pictures if such sacrifice makes it possible for them to obtain a stronger and better basic picture.

The more gain one can obtain in the I-F amplifier section of a television receiver the more it is possible to build a weak antenna signal into one strong enough to properly affect the picture tube. This is just as true in the case of a TV receiver as it is with a radio receiver.

But increasing the gain in the I-F circuits means sharpening the response curve, and this, in turn, means narrowing its response. Such narrowed response means reducing the band-width, with the resultant loss of some fine detail.

Nevertheless, a practice has grown up among some technicians in fringe areas of readjusting the I-F circuits. Such readjustment is not always approved by the manufacturer, but it often makes the customer better satisfied.

The practice is to slightly reduce the top edge of the I-F frequency response so those frequencies closest to the carrier receive less amplification. The extreme side-band frequencies are also attenuated.

Such changes in the I-F tuned circuits make the receiver much more sensitive, and capable of bringing in video signals from much greater distances. The pictures received on such a receiver lack the fine details which are present in the signals picked up closer to the station by a more broadly tuned receiver. But the practice often makes it possible to pick up pictures which were previously unobtainable.

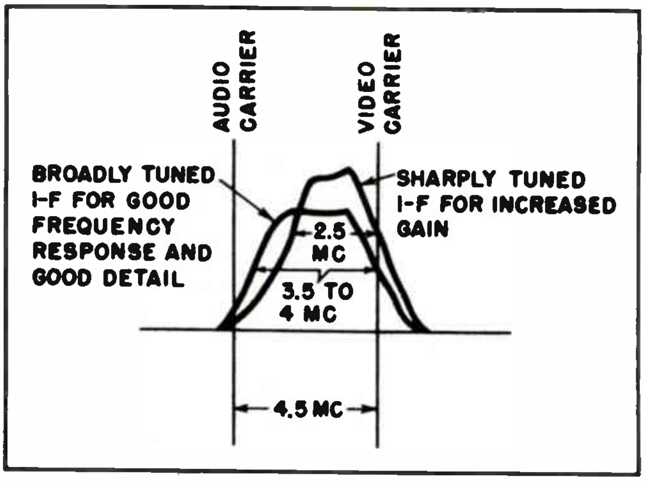

Fig. 18. Comparison of Frequency Response Curves for Sharply Tuned I-F and Normally Tuned I-F.

Fig. 18 shows a frequency response curve for a sharply tuned I-F section compared with a response curve for a normal I-F section tuned broadly for a good frequency response and good picture detail. Where the antenna signal is strong the picture is better when the I-F circuits are broadly tuned. In remote fringe areas, where the signal is normally very weak, it is possible to improve the quality of the picture by sharpening the tuning.

The manufacturer does not normally recommend this practice. Neither do we except in special cases. But we mention it to you so you will know what can be accomplished when conditions are extremely bad.

Section 13. COMMON I-F TROUBLES

The most common kind of trouble in a television receiver is that connected with failing tubes. If all indications and symptoms point to trouble of some kind in the I-F circuits the first step in servicing is to make certain the tubes are all right.

This does not mean merely checking the tubes with a tube checker. That method of checking tubes for television work is far from reliable. Many tubes which check "good" on a tube checker fail to work when placed in an actual I-F circuit.

The most reliable method of checking the tubes in the I-F circuits of a television receiver is the same as that recommended for most other TV circuits. Remove the tube which is suspected of being bad and replace it with another known to be good. That is the method followed by practical servicemen, and is the one we recommend.

The symptoms which result from I-F tube failure depend to some degree on the type of circuits being used, and the degree of failure.

In an intercarrier receiver the failure of an I-F tube usually results in failure to receive both picture or sound on any station. If the failure is partial the sound may come through at reduced volume, but the picture will be missing.

Failure of an I-F tube does not affect the raster. The raster will be bright, and probably fill the screen, but there will be no picture and no sound. At least the sound will not be up to normal volume. Usually, it will be completely missing. Much depends on the exact degree of failure.

The failure of a tube in a receiver which uses separate I-F sound applification will show different results. If the tube is in the video I-F channel there will be no picture, but the sound will not be affected. Neither will the raster be affected. The reason for this is that the sound has a separate channel of its own through which to pass. Furthermore, the presence or lack of a raster has nothing to do with the presence of a signal, at least on many receivers.

If the tube which fails is in the sound I-F section the picture will not be affected. However, the sound will be lost.

One advantage of using a separate sound I-F section is that it is easier to find the trouble in a case of this kind. If the sound is gone, but the picture is present it is a sign that the tuner circuits, the video I-F circuits and all the sync and deflection circuits are working all right. This leaves only the sound I-F and the audio amplifier circuits where the trouble can be.

On the other hand, if the sound is good and the raster is good, but there is no picture, one can look for the trouble in the video I-F circuits or the video amplifier circuits.

In the case of an intercarrier receiver, failure to receive a picture when the sound and raster are both good points straight to trouble in the video amplifier. That is about the only place a defect in the picture signal can occur without also affecting the sound or the raster in addition to the picture.

If the sound fails in an intercarrier receiver, while the picture remains good, the source of the trouble is automatically narrowed down to the ratio detector or the audio circuits. Such narrowing of the possibility of the source of trouble is very helpful when troubleshooting a receiver.

Next to bad tubes the most common source of trouble in the I-F section is defective capacitors. These can be open, short-circuits, "leaky," or have changed values. A partially short-circuited capacitor is usually termed "leaky," and can cause a lot of trouble.

Check the value of each capacitor carefully. If it differs by more than 10% from those values given in the technical manual, or schematic, it should be changed.

One type of tube defect which does not always show up on a tube checker, and which may not actually seem to be caused by a defect in the I-F circuit is that involving leakage between the cathode and filament of a tube. Such leakage shows up on the screen of the picture tube as a dark area on the upper or lower part of the picture tube screen and a light area in the other part. The disturbance may be severe, or so slight as to be scarcely noticeable.

A similar defect in one of the tuner tubes will produce the same symptoms. Which means, when such symptoms are present it is well to check all the RF and I-F tubes carefully.

If trouble is suspected in the I-F section of a TV receiver, and the possibility of the trouble being in the tubes or capacitors has been eliminated, the screen and anode voltages should be checked. If the voltages at either the screen or anode of any I-F amplifier tube differ by more than 10% with the voltages shown in the technical manual chart the reason should be sought. It may be that a resistor has changed value in that immediate circuit, or some change has taken place in some remote circuit which affects the I-F circuit.

Bending or pulling of the picture on the screen, especially if it bends or pulls toward the right, suggests the possibility the I-F circuits may not be properly aligned. Such symptoms can also be caused by clipping of the sync pulses until they are below normal amplitude, but the possibility of the I-F circuits being out of alignment must be taken into consideration.

Such bending can also be caused by maintaining the contrast control at too high a setting, and by a change in amplifier tube characteristics.

Therefore, if there is a tendency toward such bending keep in mind those things which are most likely to cause it — change in tube characteristics in one of the sync circuit tubes, too high contrast, or improperly adjusted I-F circuits.

Perhaps a few words of explanation are needed to show how improper adjustment of the I-F circuits can cause poor synchronization, and thus bending or pulling of the picture.

The vertical sync pulse has a frequency of 60 cycles per second. This is true despite the fact it is *serrated*, or composed of several pulses.

Compared with most of the other video frequencies this is very low frequency — one of the lowest frequencies carried by the composite video signals.

The horizontal sync pulse has a frequency of 15,750 cycles per second. This is much higher than the frequency of the vertical sync pulse; nevertheless, when compared with more common video frequencies it is a pretty low frequency.

The lower frequencies in the composite video signal are in those parts of the side-bands which cluster around the carrier frequency. In Fig. 19 the low video frequencies are quite close to the carrier frequency because they do not differ from it very much.

When the carrier signal is so positioned on the frequency response curve that the carrier and the adjacent side-bands are amplified fairly well the sync pulses have a normal amplitude. That would be the case when the carrier frequency is about midway up the slope of the frequency response curve. This is shown by the dotted line in Fig. 19.

If the I-F circuits are not properly aligned, so

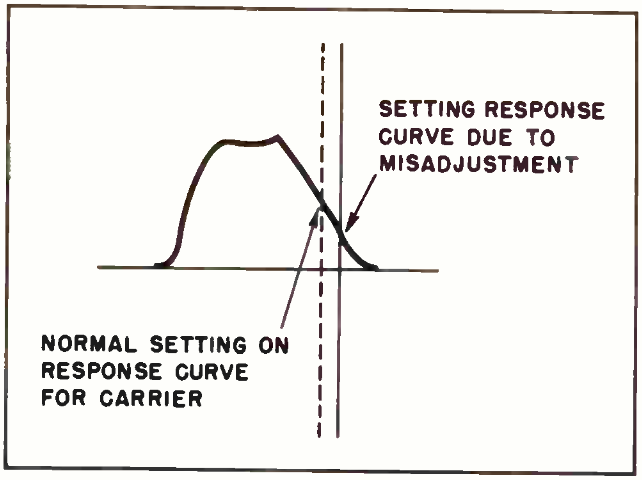

Fig. 19. Misadjustment of I-F circuits which results in poor Low-frequency Response.

the carrier frequency and the low-frequencies which lie close to the carrier are not amplified sufficiently, we have a situation shown by the heavy vertical line in Fig. 19. The low-frequency sync pulses are not amplified sufficiently in the I-F circuits so they can be tapped off in the normal manner in the sync separating circuits. Therefore, they do not reach deflection circuits, or they reach the deflection circuits at such low amplitude they have little effect.

If the misalignment is so bad that the sync pulses are completely lost there is no synchronization at all.

But if the sync pulses are only *partially* lost they become ineffective only under certain picture conditions. One of these conditions occurs when large black picture elements are present. That is the reason the picture tends to bend or kink whenever the black level of the picture changes radically. Especially when the black picture elements are on the right side of the screen —close to the horizontal sync pulse.

One fairly common trouble, encountered in I-F sections of TV receivers, especially in intercarrier receivers, is what is known as "buzz." This buzz is even better known as *intercarrier buzz.*

Intercarrier buzz occurs whenever there is cross-modulation between the vertical sync pulses and the audio I-F signal. Cross-modulation results from the two signals passing through a non-linear amplifier in the I-F section. So they become mixed together.

It is important to keep the I-F amplifiers operating as linear class A amplifiers, since any non-linear operation will cause some degree of cross-modulation, and thus the annoying intercarrier buzz.

Buzz is clearly distinguishable from ordinary hum. Ordinary 60-cycle hum is audible as a low-pitched, smooth humming noise. Buzz, however, due to its peaked waveform, is raspy and harsh. In some cases it sounds much like a vibrating rasping noise.

Practically all television receivers have some degree of cross-modulation, and thus some amount of intercarrier buzz. But in most cases the level is kept so low it is below the threshold of sound for the human ear, thus is not annoying.

If conditions change so the buzz becomes pronounced it is usually necessary to take steps to remove it, otherwise the receiver cannot be used.

Some tubes undergo changes in their tube constants and operating characteristics as they become older. Bias voltage requirements change positions. Bias voltages, which keep the tube operating on the linear portion of its characteristic curve when new, may cause it to operate into one of the "knees" when old. This upsets the operation of the circuits in which the tube is used.

Very often the only correction needed to end intercarrier buzz is to replace one or more of the I-F amplifier tubes. Replacing an old tube with a new one restores the original operating conditions, and puts an end to the "buzz."

In this connection a word of caution is worth consideration. The I-F circuits of television receivers operate at high frequencies. Those in the newer receivers are commonly above 40 megacycles. These are high frequencies regardless of how you look at them.

Very slight changes in the dimensions of a tube can easily change its operating characteristics to an extent which definitely affects the circuits in which the tube is used. This must be kept in mind when changing I-F amplifier tubes in a TV receiver.

Frequently there are slight differences in two *apparently identical* replacement tubes. Both may fall well within the limits of tolerances prescribed for that particular tube; but, one may work better in a specific I-F section than the other, which appears to be identical.

Practical service technicians have learned through experience that all tubes of a given type do not have exactly the same characteristics. They know this is true despite all the efforts of manufacturers to turn out tubes of a given type which are identical in all respects.

Experienced servicemen have learned that when a replacement tube fails to work in the expected manner to try another of the same type. Some service technicians have learned they may have to try two or three tubes of a given type before they find one which works properly.

This is no reflection on those tubes which did not work properly, nor an indication they are defective. Tubes which do not work in one receiver may work perfectly well in another. It merely means when working with circuits where such high frequencies are found it is seldom wise to take anything for granted. Tiny variations in the structural construction of vacuum tubes can assume major importance when the tube is used at the extremely high frequencies in television receivers.

These comments are not intended to give you the impression the parts which you use in service work are inadequate for the purpose for which they are intended, nor that such inadequacies are likely to make your work uncertain and lacking in satisfaction. As a matter of fact vacuum tubes, and other components used in television service work, are manufactured to a surprisingly high degree of accuracy and uniformity. But the fact still remains that standards are so very high they are sometimes difficult to attain, and occasionally you will run into situations where you may have to try several different tubes, or other components, before you find one which works in a particular circuit.

Section 14. SIGNAL TRACING THROUGH THE I-F SECTION

When visible and audible symptoms point to a defect of some sort in the I-F section the first logical suspect is a defective tube. That fact has been previously emphasized and discussed.

But there are occasions where all attempts to correct the conditions by substituting new tubes still fail to bring in a signal. The antenna signal simply fails to get through the I-F section. Such a condition calls for a checking procedure which reveals the stage where the signal is lost—the stage it fails to get through.

In many respects such a checking procedure is similar to signal tracing methods employed in I-F circuits of a radio receiver. It is little more than a case of injecting an AC signal of some kind into the input of the first I-F stage, then checking to see where the signal is lost.

It is possible to inject the signal into the first I-F stage, then check the output at each of the I-F stages to see if the signal is present there. This method is indicated in Fig. 20.

In Fig. 20 the signal from a signal generator of some kind is injected into the input of the first I-F stage. The signal may be injected in any of various ways. It may be injected directly on the grid of the first I-F stage. Or, can be inductively coupled to the coupling circuit between the mixer circuit and the first I-F stage. It can even be injected into the mixer circuit, from which it will feed into the I-F stages in the normal manner.

Some sort of indicating device can then be used to see if the signal is passing through the first stage of the I-F section. If the signal can be detected at the output of the first I-F stage it is good evidence the first stage is operating properly.

At this time we are not discussing the type of signal generator which should be used. Nor are we emphasizing any specific type of indicating device. These will be discussed later. At this moment we are concerned only with the checking procedures.

If the first I-F stage is found to be working satisfactorily the probe from the indicating device is then moved to the output of the second stage. If the signal is not present there, it is a sign the second stage circuit has some type of defect, and should be checked further with an ohmmeter and voltmeter in the same way the circuits around any vacuum tube circuit are checked.

If the signal comes through to the output of

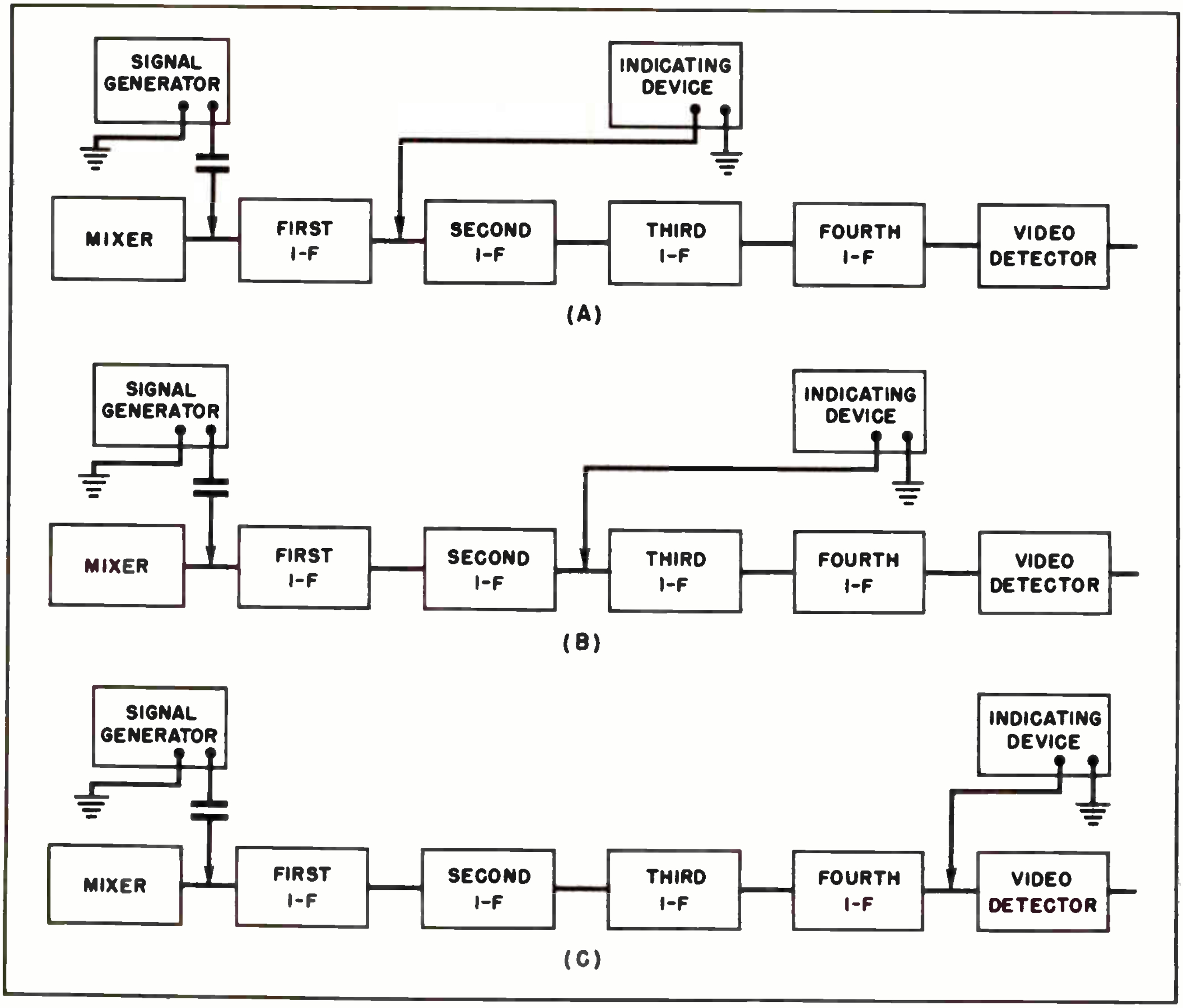

Fig. 20. Injecting signal at first I-F then checking other stages to see where it is lost.

the second stage it is an indication the second stage is working satisfactorily, and the search for a defect should then be moved on to the next stage.

The output of the third stage is then checked for the presence of the signal, and also the output of the fourth I-F stage. If the signal is present at the output it is reasonable to assume the stage is operating properly; if the signal is absent at the output it is a sign the stage has some sort of defect. When the defective stage is located it should be checked carefully with an ohmmeter and voltmeter, as previously mentioned.

It is possible to use a signal from a transmitter instead of one from a signal generator when following this method of tracing a signal through the I-F stages. However, such method is not usually so satisfactory. It is not possible to control the frequency and volume level of the transmitter signal, and such types of control are often very useful.

This method of tracing a signal through the I-F stages has the further defect that it is necessary to move the probe of the indicating device every time a new stage is to be checked. This often takes time because some types of indicating devices have to be reset each time a different stage is checked.

A somewhat more satisfactory method, and one followed more widely by experienced service technicians, is to connect the indicating device to the output of the detector circuit, or to the output of the final I-F. Then inject the signal into first one, then another of the several I-F stages.

Of course, this means moving the probe of the signal generator from the input of one stage to another, but as a practical matter this is a much more simple procedure than moving the connections to some types of indicating devices.

Fig. 21 shows the procedure which is followed in this method of checking. The indicating device is connected to the output of the video detector, or to the output of the final I-F stage. Then the signal from the signal generator is injected successively to one I-F stage after another.

If the indicating device shows the presence of the signal at the output of the final stage, when the signal is being injected to the input of that stage, it is pretty good proof the stage is operating properly. If that stage is found working all right the signal is next injected into the preceding stage.

If the signal comes through from the input of the third stage to the output of the final stage it shows the third stage, as well as the fourth stage, is working. But if the signal does not come through it shows the third stage is defective. Then the ohmmeter and voltmeter are put to work to learn exactly what is causing the trouble.

If the third stage is found to be working, the next step is to check the two preceding stages. They are checked in the same manner. When the exact stage is located that is blocking the pas-

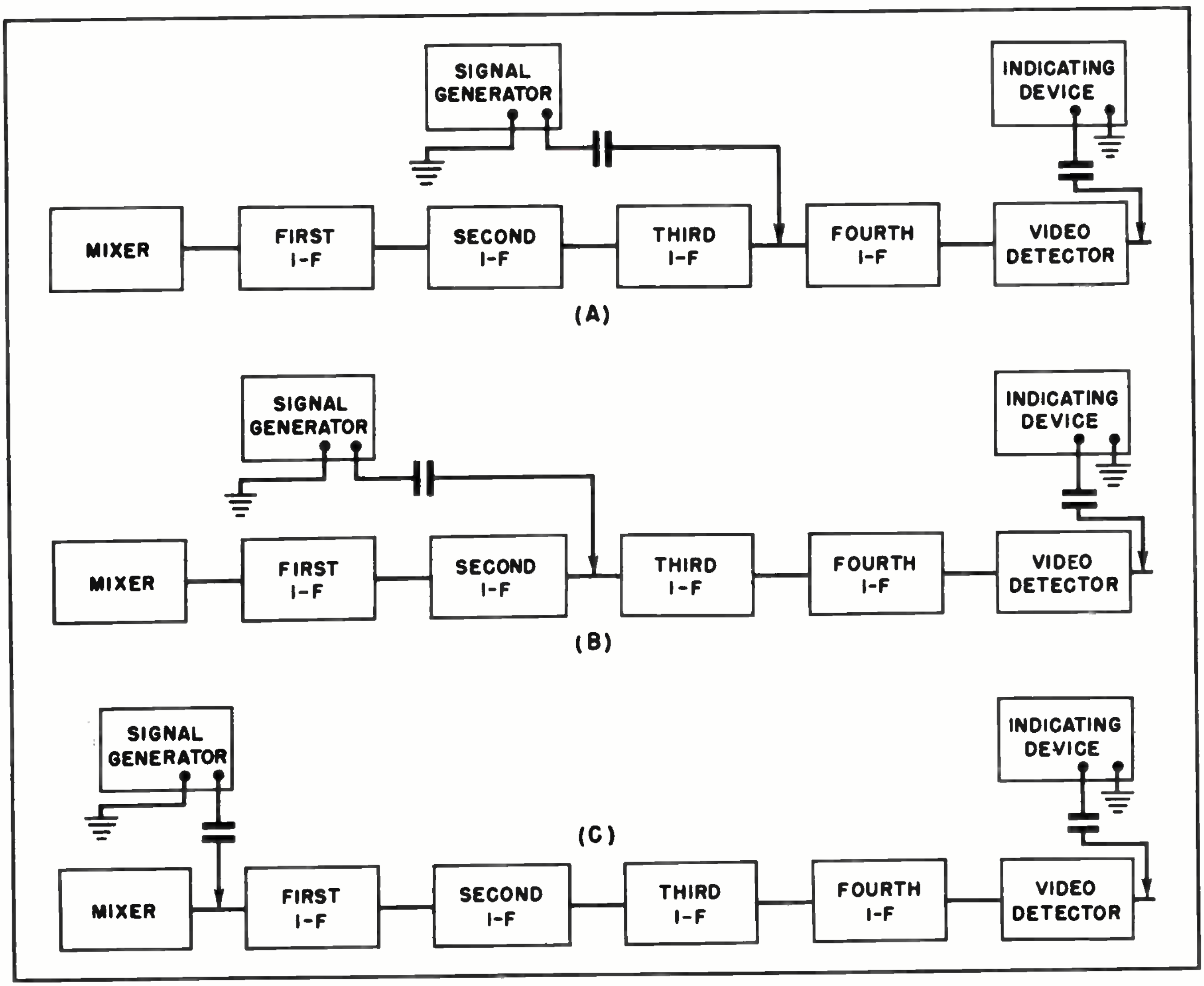

Fig. 21. Reading Output at only one stage while injecting signal at different stages.

sage of the signal, it is then checked component by component until the defective part ls located.

Once the cause of the trouble is definitely located it is usually a simple matter to correct it. If a capacitor is found to be defective it is removed and a new one used to replace it. If a resistor has burned out, or become otherwise defective, it is also removed and replaced. If a wire is found broken it is repaired.

In plain words, once the cause of the trouble is found the trouble is then repaired. In most cases it is easier to repair the defect than it is to find it. Television service work, like radio service work, usually requires more time to locate the trouble than is needed to correct it once the defect is found.

Section 15. SIGNAL GENERATOR AND INDICATING DEVICE

A person expecting to enter the television service business is naturally curious as to the type of instruments needed to check the various parts of a television receiver. In the case at hand it is important to know just what is needed to check I-F circuits.

Probably the first thing which enters one's mind in this connection is what kinds of instruments are necessary to trouble shoot an I-F section, as mentioned in the preceding section. In that section we were deliberately vague concerning the instruments because we were more interested in explaining the *manner* in which they were *used*, than we were in the instruments themselves.

If trouble symptoms point to a defective I-F section, and it seems reasonable to assume the trouble is clearly located in that section, the first thing a service technician must do is locate the exact stage causing the trouble. In such a case one is not particularly interested in the frequency response of the I-F section, nor the manner in which the various frequencies pass through it. All that is needed is to locate the one single stage which is preventing the passage of any signal.

Almost any AM signal generator, such as those used in ordinary radio work, can be used as the signal source. Provided, of course, it is capable of generating a signal with a sufficiently high frequency. Most modern AM signal generators are capable of generating such a signal. An FM signal generator can also be used if a 'scope is the indicating device.

A sweep generator can be used, of course, but such a generator is definitely not essential. Many shops do not have a sweep generator, although such an instrument is quite useful for other purposes.

A signal from the signal generator can be injected in exactly the same manner as is injected into a radio receiver.

For simple signal tracing purposes it is possible to use any of several types of instruments as the indicating device.

Probably the most simple of these is a low-scale AC voltmeter, or the AC scale of a volt-ohm-milliammeter. If such instrument is used it should be connected to the output of the detector stage so it can measure the magnitude of the demodulated audio signal with which the RF signal of the signal generator is modulated. Such a meter will not work between the final I-F stage and the detector; at least it will not work in many situations.

When the voltmeter scale of a V-O-M is used as the indicating device it is connected across the output of the detector so it can read the output audio voltage. The exact manner in which the meter is connected must necessarily depend on the type of circuits used around the detector, but in most cases it can be connected in parallel with the contrast control if no other place is readily available.

A modulated AM RF signal is then fed into the I-F stages of the receiver. The modulated signal passes through the I-F stage, carrying the AF modulating component. After demodulation in the detector circuits the audio signal indicates its presence on the meter.

The other stages are checked in the same manner.

For best results the signal from the generator should be set at a frequency about 1.5 to 2 megacycles lower than the I-F video carrier frequency. This will put it in the region of best video I-F response.

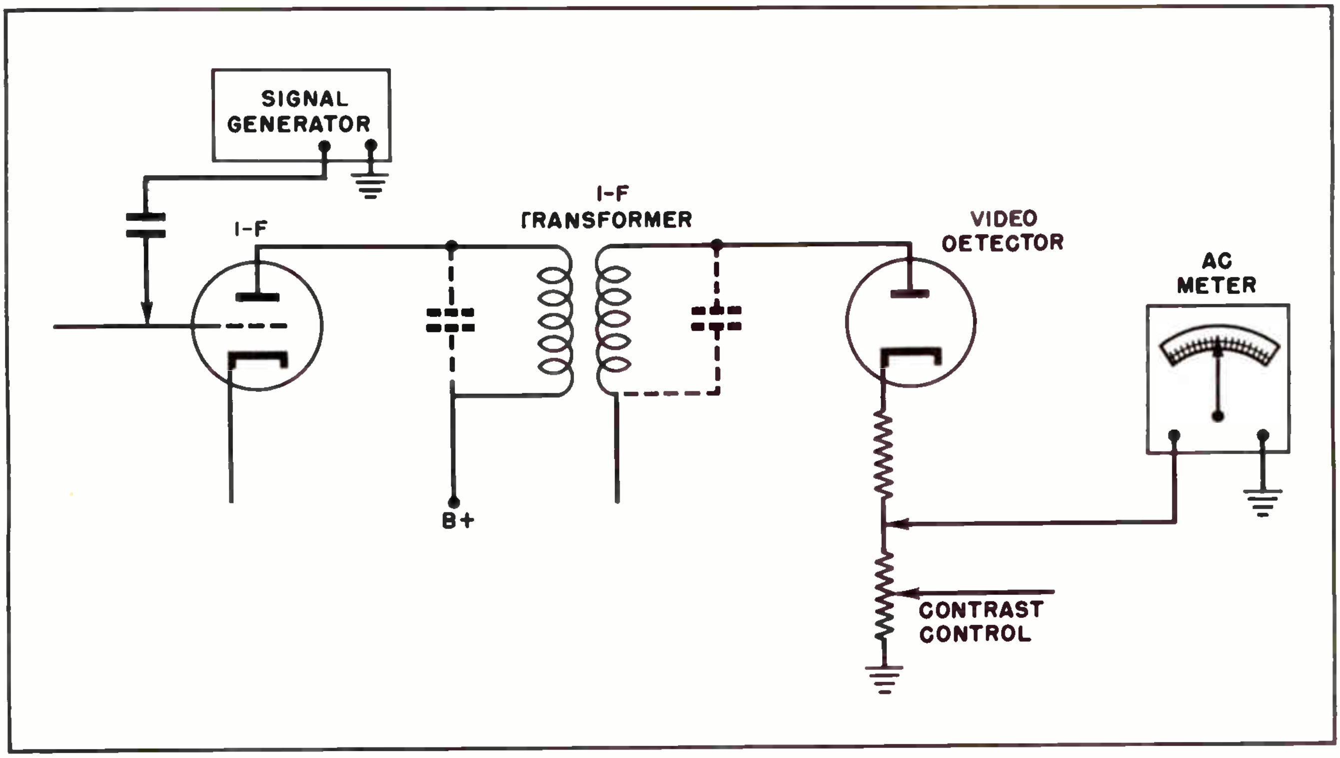

Fig. 22. Injecting signal from generator and measuring it at output of Video Detector.

Keep in mind the procedure we have outlined is merely for the purpose of checking the condition of an I-F circuit to determine whether or not it is passing I-F frequencies. It is *not the procedure for aligning* the tuned circuits of the I-F stages.

An oscilloscope can be substituted for the AC voltmeter as the indicating device. In that case the scope can be connected across the output of the final I-F stage or across the output of the detector. The exact manner in which it is connected will depend to some extent on the exact type of circuits employed in the receiver undergoing test, and the type of scope being employed.

Any oscilloscope can be used at the output of the detector, but only those which are capable of handling high frequencies can be used between the final I-F stage and the detector.

When a signal is getting through from the I-F stages the pattern of the signal can be observed on the screen.

When an oscilloscope is being used as the indicating device it is possible to use either an ordinary AM signal generator, such as those used in ordinary radio work, or a sweep generator to generate the signal injected into the I-F tuned circuits, or an FM signal generator.

If an ordinary AM signal generator is used, and the RF signal is modulated with a 400-cycle sine wave, the oscilloscope should be connected across the output of the detector. The sweep circuits of the oscilloscope are then adjusted for 400-cycle horizontal sweep. When that is done the pattern of the sine wave of the modulating signal should be visible on the screen of the scope.

If a sweep generator is used as the signal source the pattern on the screen of the scope will be the same as the response curve of the I-F circuits. An FM signal generator is used in the same way.

Regardless of whether an oscilloscope or an AC meter is being used as the indicating device, it is good practice to first check the operation of the final I-F stage, then move stage-by-stage toward the tuner. Experience has shown practical service technicians that is the best practice.

Section 16. ALIGNMENT HINTS

Alignment procedures involving the I-F circuits of television receivers have been explained in earlier parts of this lesson. Additional practical hints should prove valuable.

It is possible to do a good job of aligning the I-F tuned circuits of a television receiver by using an ordinary AM signal generator, such as is used in radio work, and an AC voltmeter. A better practice, and one most generally recommended, is to use an oscilloscope and sweep generator.

No alignment of any television receiver should be attempted unless a technical manual covering the specific receiver is immediately available. Otherwise you may do more harm than good.

When an oscilloscope and sweep generator are available the scope vertical input is connected across the output of the video detector. The output of the sweep generator is then injected into the input of the first I-F stage. In most cases it is better to connect the sweep generator to the anode lug of the mixer tube, so the signal must pass through all tuned circuits.

An even better way, if the designs of the circuits will permit it, is to inject the signal from the sweep generator into the control grid of the mixer tube.

In any case it is advisable to remove the oscillator from the socket, or render it inoperative in some other manner. In AC-DC receivers it may be necessary to ground the grid of the oscillator tube, or render it inoperative in some other manner. This is because it is not usually possible to remove any tube in an AC-DC receiver without affecting the operation of the others.

When the signal from the sweep generator is feeding into the first stages of the I-F section, and the trace of the response curve is visible on the screen of the oscilloscope, you are ready to begin your alignment procedures.

During each step of the alignment you should consult your technical manual. Follow the instructions point-by-point, as to what you are to do next. And most important of all — *follow those* instructions.

Make each adjustment slowly, deliberately and carefully. If the results are not what you expect, reverse the adjustment.

When you are finished, the trace pattern on the screen of the scope should be the same as the pattern provided for your guidance in the technical manual. Each technical manual provides you with a pattern which engineers have determined is best for that particular receiver.

The reason the oscillator tube is removed during such alignment procedure is to remove the possibility the sweep signal may be affected or influenced by the oscillator signal. There is a distinct possibility the two signals may mix, or heterdyne, together, and thus bring about spurious or false patterns.

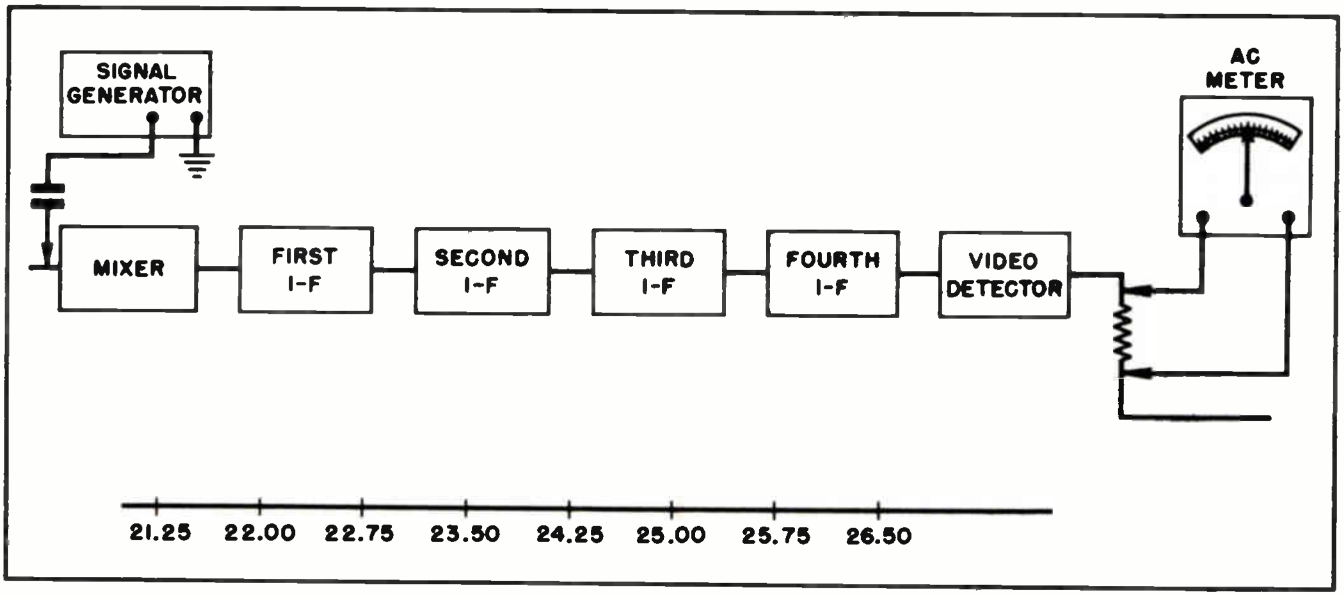

Fig. 23. Set-up for Aligning I-F Section with AM Signal Generator and AC Voltmeter.

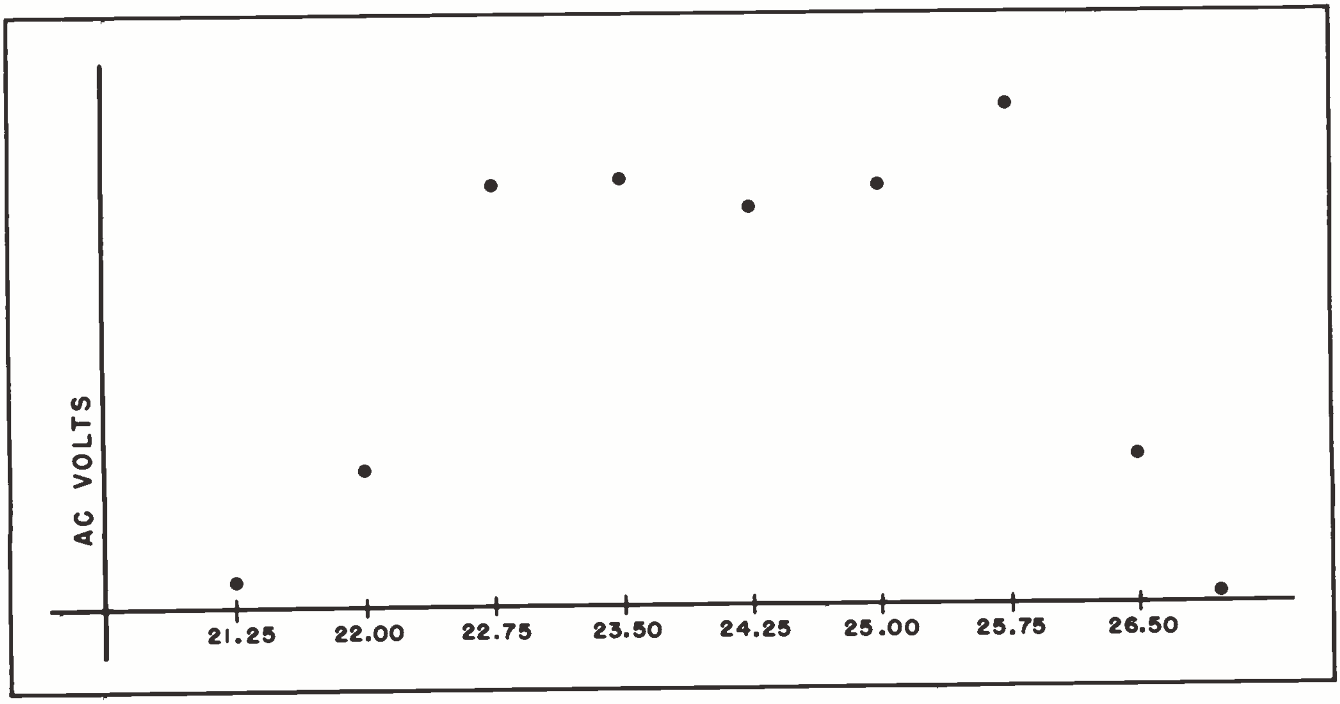

Fig. 24. Manner of recording AC voltmeter readings.

If a sweep generator or oscilloscope is not available it is possible to do a reasonably good job of aligning the I-F circuits with an ordinary AM signal generator and an AC meter. It is necessary to take a variety of readings at differing frequencies, then draw your own response curve; but, that is not especially difficult.

The signal generator feeds its signal into the mixer tube of the first I-F stage. Fig. 23 shows how this is done. The AC voltmeter, or other type of output meter, is connected across the video detector load wherever practical.

The signal generator is then adjusted to generate the lowest signal the I-F section circuits are expected to pass. The amount of voltage the AC meter registers for that I-F frequency is then noted. A dot should then be placed on a chart similar to the one under Fig. 23. The dot should show the magnitude of the voltage registered by the meter for that particular frequency.

The signal generator is then adjusted to generate a somewhat higher RF frequency. This should cause the AC meter to register a somewhat higher voltage. Such information should also be indicated on the chart in a manner similar to that shown in the lower part of Fig. 23.

We have drawn the graph in Fig. 23 with frequency multiples of 0.75 megacycles. You can draw your own chart for those frequency ranges, or you can use others, just as you find convenient. Sufficient measurements should be made so the response curve can be drawn with a reasonable degree of accuracy.

You should continue to inject, step-by-step, increasingly higher RF frequencies into the first I-F stage. Each different frequency should result in a different voltage reading on the voltmeter. Each voltage should be indicated on the chart according to the voltage amplitude and the frequency at which the measurement is taken.

When you have read the various voltages at steps over a range of approximately 6 megacycles you should have a series of dots on your chart similar to those shown in Fig. 24. Provided, of course, the I-F circuits are aligned accurately.

Here, again, we want to remind you that the I-F circuits of all television receivers are not adjusted to give exactly the same response curve. You must always be guided by the technical manual covering the specific receiver.

Furthermore, in our discussions here we have referred specifically to I-F frequencies in the range immediately above 21 megacycles. You must keep in mind that other frequencies are used

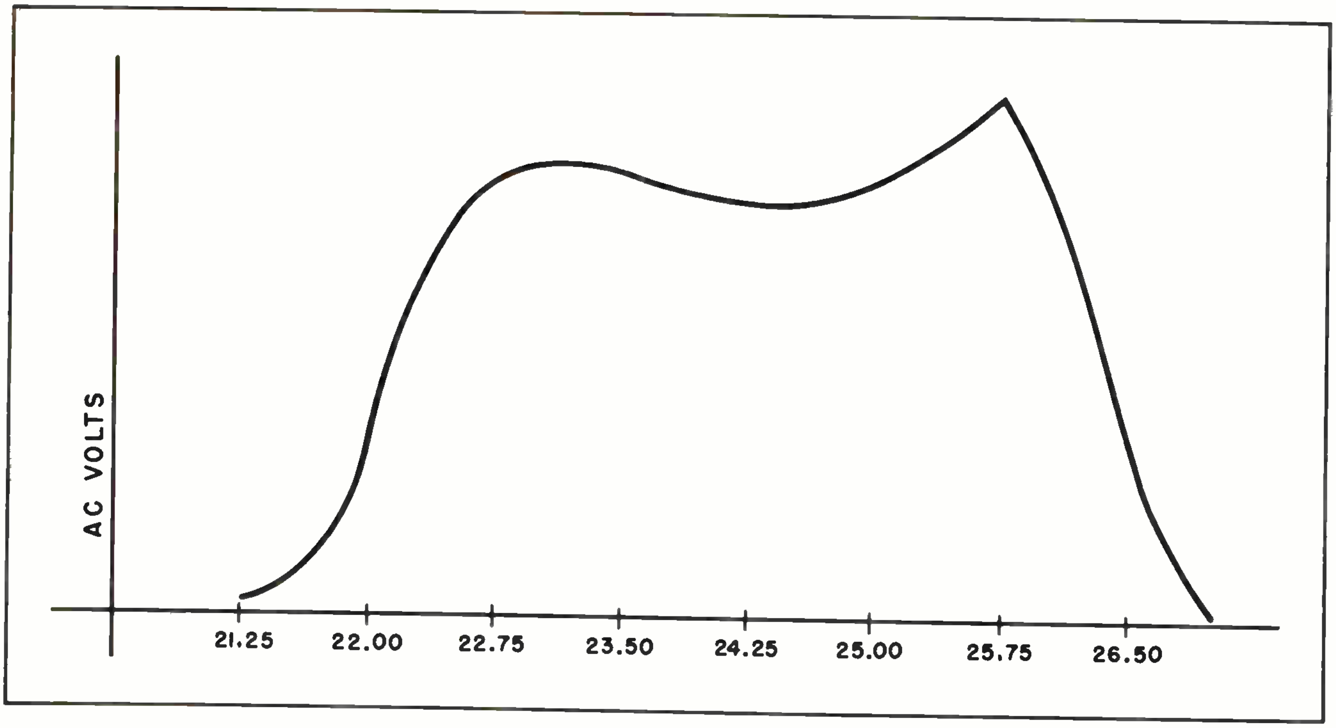

Fig. 25. Response Curve Created by joining dots in Fig. 24.

in the I-F sections of some TV receivers, and you must guide yourself accordingly.

It is rather obvious that the job of aligning the tuned circuits of a TV I-F section by using an ordinary signal generator and AC meter is somewhat more complicated and time consuming than is true when a sweep generator and oscilloscope are available. Nevertheless, the information which can be obtained in this manner is just as good, and the over-all results just as accurate.

To the average radio service technician this method has certain definite advantages. Most radio servicemen have a signal generator, and V-O-M or electronic multimeter. These are relatively inexpensive instruments. But many do not have a sweep generator or oscilloscope.

All of which means that a service technician is not entirely dependent upon possessing expensive testing instruments in order to align the tuned circuits of a television I-F section.

In closing we want to repeat the warning we gave you earlier: Do not attempt to align the I-F circuits unless you *know* they really need aligning. You may do more harm than good.

NOTES FOR REFERENCE

There are two general types of I-F circuits in television receivers, the intercarrier system and the split-sound system.

The intercarrier system of I-F amplification uses the same I-F circuits for both the sound and video I-F signals.

The split-sound system employs one channel for amplifying the I-F video signal and a second separate channel for amplifying the I-F sound signal.

Television I-F circuits are tuned much more broadly than radio I-F circuits because the composite video signal embraces a much wider band of frequencies than a radio audio signal.

Because of the higher frequencies involved, and the broader band-pass, television I-F stages do not produce nearly so much gain-per-stage as equivalent radio I-F stages.

Frequency band-pass characteristics of a television I-F section have a strongly determining influence on the quality of the picture reproduced on the screen.

A broad band-pass improves the quality of the picture but reduces the gain-per-stage.

It is possible to improve the gain of a TV receiver in a fringe area, and thus make it more sensitive, by sharpening the band-pass of the I-F circuits.

A receiver which uses split-sound I-F amplification usually must have wave-traps installed between stages to prevent the sound I-F reaching the detector.

Early models of television receivers employed I-F frequencies in the range around 21 megacycles, but later designs favor using a frequency somewhat above 40 megacycles.

There is less tendency for sound to disappear when the tuner oscillator drifts in frequency when intercarrier amplification is used.

Intercarrier buzz is sometimes troublesome, but can usually be eliminated by changing I-F amplifier tubes, or improving the alignment of the I-F circuits.

Tendency for the picture to bend is often caused by improper alignment of the I-F circuits or a partially defective I-F amplifier tube. This symptom is also caused by the contrast control being adjusted too high.

When the sound I-F signal heterodynes with the video I-F signal in the final detector they produce a difference signal of 4.5 megacycles.

The 4.5 megacycle signal at the output of the video detector carries two types of modulation — amplitude and frequency.

The 4.5 megacycle difference signal from the video detector is fed to a ratio detector or limiter-discriminator circuit. Such circuit is not affected by amplitude modulation, but the audio signal is demodulated because it is carried in the form of frequency modulation.

A "dead" I-F stage can be located by feeding a signal into it and trying to recover it at the output. The stage where the signal disappears is where the trouble is.

A simple AM signal generator, regularly used in radio work, can be used as the signal generating device.

An oscilloscope or AC voltmeter can be used to detect the presence of a signal at the output of the I-F section.

A sweep generator and an oscilloscope are the preferred instruments for aligning the tuned I-F circuits of a TV receiver. But an ordinary AM signal generator and AC voltmeter can be used for that purpose if necessary.

A signal generator should be coupled to the tuned circuits of an I-F section through a "dummy" antenna. Components of the dummy are specified in technical manuals.

NOTES

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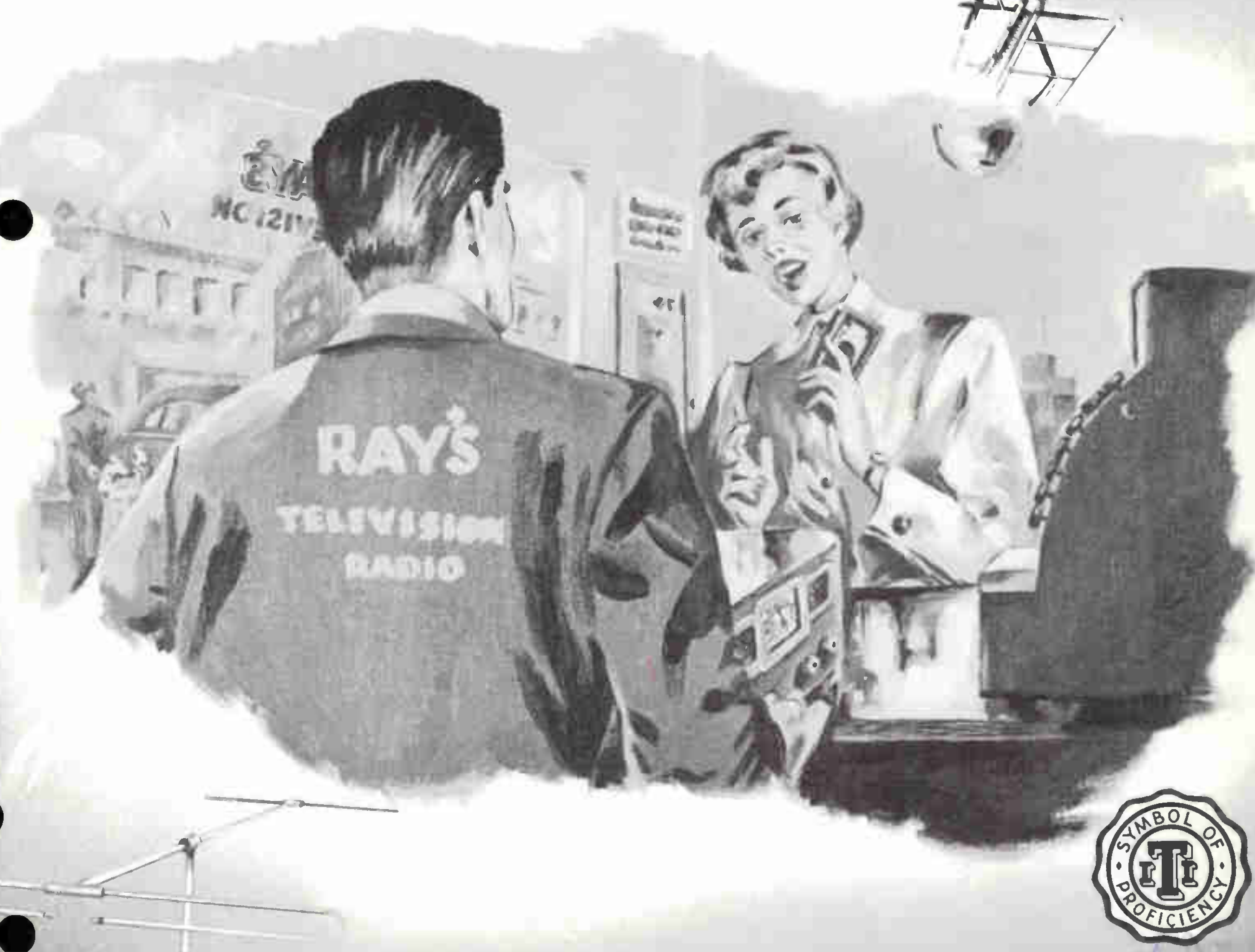

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RADIO TELEVISION

TV TUNERS

Contents: What the RF Stage Does — Matching Tuner to the Antenna Transmission Line — The RF Transformer — Signal-to-Noise Ratio — Grounded-Grid Triode Amplifier — Cascode RF Amplifier Circuit — The Mixer Stage — The Oscillator — Tapped Coil Tuners — Continuous Tuners — RF Interference from Another Receiver — Trapping Out Interference — Radiation from Receiver Chassis — Tuner Input Filter Circuit — Usable Signal Strength Levels — Trouble in the Tuner — Notes for Reference.

Section 1. INTRODUCTION

Television tuners include those circuits which are directly involved with accepting carrier signals from the antenna transmission line. These RF carrier signals radiate from the transmitter antenna; they are modulated with the electrical intelligence needed to reproduce video and sound conditions present at the program source.

In modern receivers the tuner is built as a compact and separate component. In most respects it is isolated from the other receiver circuits except for the necessary wiring to supply the tuner with B plus and filament power, and to handle the signal between the tuner and the I-F section, and a wire to connect with the AGC (Automatic Gain Control).

Tuners used in most receivers include the circuits shown in Fig. 2, or modifications of them. These are the RF amplifier, the mixer tube and the high-frequency oscillator.

The oscillator generates a high-frequency signal against which the incoming RF carrier signals are heterodyned. This action is closely similar to that which takes place in the mixer of a superheterodyne radio.

Considering the various types of mixer tubes which have been used in radio receivers it may come as a surprise that the mixer in a TV tuner is a triode more often than any other type of tube. This is not to say that a triode is the unanimous choice for a TV mixer tube, but a triode is used

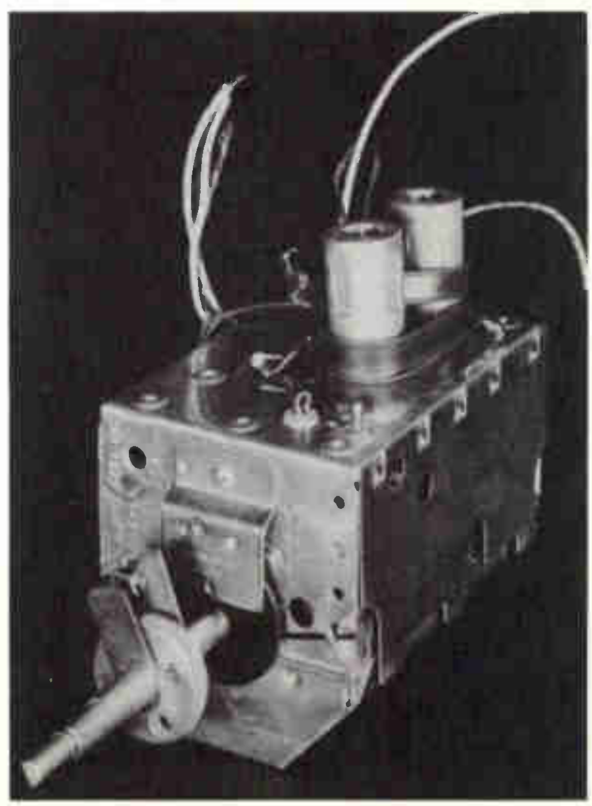

Fig. 1. Standard Coil Products Tuner.

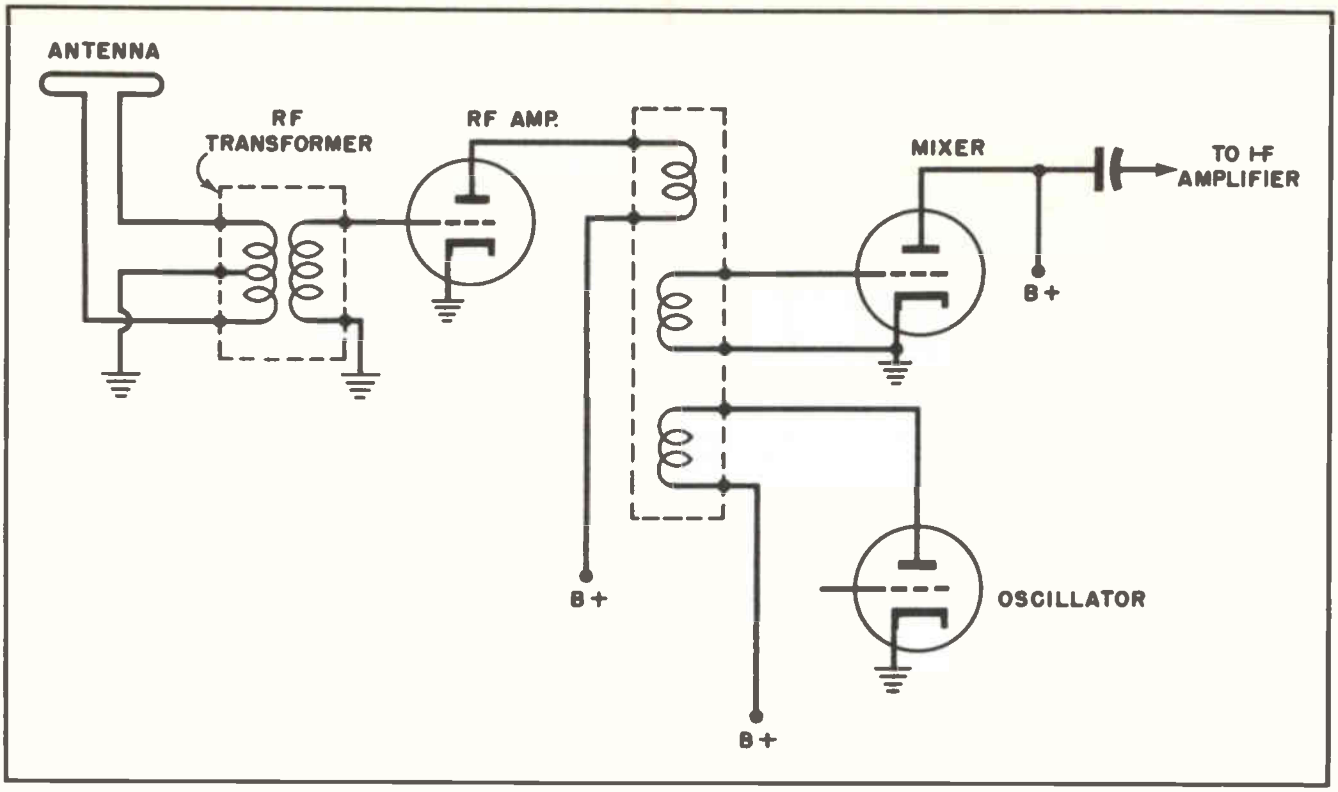

Fig. 2. Basic circuit used in TV tuner.

as a mixer in more television receivers than any other type.

The diagram in Fig. 2 shows one method which is commonly used to couple the RF and oscillator signals into the triode mixer circuit. This is not the only type of circuit used, but it is probably the most common of all TV mixer circuits.

The diagram in Fig. 2 does not contain all the circuit refinements which must be necessarily included in practical tuner circuits. Biasing methods, for example, have not been shown, nor has the complete oscillator been shown. But Fig. 2 does outline the general principles which are employed in a large percentage of modern TV receivers.

In the early days of television most of the receiver manufacturers built the tuner into the main chassis so it became part of the general receiver circuits. With the passage of time that practice has fallen into disuse, so that relatively few receiver manufacturers follow that practice.

It has become the regular and general practice among receiver manufacturers to purchase the tuner for their receiver as a complete unit from a component manufacturer who specializes in the manufacture of tuners. The result of this practice is that dozens of TV receivers on the market, which otherwise use widely differing circuits, all use exactly the same type tuner.

Undoubtedly, the best example of this practice is the case of the TV tuners built by Standard Coil Products. Standard Coil tuners are used in more than half of all the TV receivers now being offered to the American public.

Among the receiver manufacturers which use Standard Coil tuners are such large and well-known companies as Admiral, Sentinel, Hoffman, Crosley, Emerson and Sparton. Many of the smaller receiver manufacturers also use the Standard Coil tuner.

Large numbers of TV receivers built under private brands, such as Silvertone for Sears, Roebuck, and Airline for Montgomery Ward, use Standard Coil tuners.

Standard Coil Products Company is not the only manufacturer of TV tuners. Sarkes-Tarzian Company of Bloomington, Indiana is another tuner manufacturer, and the Mallory Company of Indianapolis also builds tuners.

Several receiver manufacturers build tuners for their own receivers. Among these are Motorola, Hallicrafters, RCA, Philco, Zenith and Raytheon. Some receiver manufacturers who build their own tuners also use Standard Coil tuners in some models. Other receiver manufacturers who have built their own tuners in the past are gradually turning to Standard Coil, or to Sarkes-Tarzian, as a source for their tuners.

Some manufacturers use one type of tuner in some models and another type in other models. Crosley, for example, has built some models which used tuners they built themselves. They have built models which used the Mallory tuner. They have built other models which used the Standard Coil tuner.

One tremendous advantage of building the tuner as a completely separate unit, which is easily detached from the other receiver circuits, is the flexibility such practice provides. If a manufacturer experiences difficulty building enough tuners to maintain his production schedules, or is unable to purchase enough tuners of a given type, he can readily switch to another type of tuner without interrupting his production schedules. Building tuners is a delicate and precise type of manufacture, and in many ways is a highly specialized one.

Another advantage is on the side of the serviceman. If trouble-shooting procedures clearly indicate trouble is present in the tuner circuits it is much easier to remove the old tuner and install a new one than to search through the tuner circuits to locate and repair the trouble. There are rarely more than five wiring connections between the tuner and the main chassis. In many cases there are even fewer connections. Mechanical connections between the tuner and the main chassis usually consist of two to four screws.

All of which makes the job of removing an old tuner from a TV chassis, then installing a new one, a relatively simple job.

Section 2. WHAT THE RF STAGE DOES

It was explained in the previous section, which introduced this subject, that the tuner normally consists of three stages; or at least three types of electrical circuit activity. The first of these is the RF amplifier stage, the second is the mixer stage, and the third is the oscillator.

All of these circuits work together to pick the RF carrier signals from the air, strengthen them, and convert them to a lower frequency which can be applied to the I-F amplifier section.

Let us first turn our attention to the RF amplifier stage. We will examine the duties imposed on that stage, note the difficulties and problems it faces, then see just what the engineers have done to solve these problems.

When RF amplification is needed in a *radio* receiver it has become a standardized practice to use a pentode tube. A pentode has much higher amplifying ability than other types of tubes. It has the necessary low inter-electrode capacitance to prevent undesirable feedback at high frequencies, and thus is able to do a better job at RF frequencies than triodes.

Because pentodes have been used so long in RF stages of radio receivers it was natural that engineers turned to them when they began designing RF amplifiers for television receivers. Most earlier television receivers used pentodes in the RF stage, and a very large percentage now being built continue to use pentode tubes. Where the signal level is fairly high, as in primary signal strength areas, pentodes do an acceptable job.

The job of the RF stage in a TV tuner is to partially separate the desired TV carrier signals from all others on the air, provide it with some degree of amplification, then pass the amplified signal along to the mixer stage.

The full job of selecting one carrier signal, and separating it from all others, does not fall entirely on the RF stage. Much of the process of separating the desired signal from the others falls on the I-F stage, which is even more selective than the RF stage. But the RF stage is the one which begins that process of selecting.

Due to the frequencies involved, and the bandwidths involved, the RF stage does not provide nearly so much gain as comparable stages in radio receivers. But a well designed RF stage is capable of providing a gain of 10 to 20.

Boosting the strength of the desired RF carrier signal by as much as 10 to 20 times before the carrier reaches the mixer aids very materially in raising the level of the carrier to a point where it mixes well with the oscillator signal. It aids in the process of discriminating in favor of the desired carrier signal, and against all others.

Section 3. MATCHING TUNER TO THE ANTENNA TRANSMISSION LINE

There are various ways through which the antenna signal is brought to the control grid of the RF amplifier. But the design of the circuits which handle that signal before it reaches the RF amplifier grid has much to do with the ability of the tuner to do the job expected.

It has become commercial practice to match the characteristic impedance of the transmission line to the characteristic impedance of the antenna. We have not yet discussed the subject of antennas nor transmission lines, and have not touched upon the matter of *characteristic impedance* at all. These are strictly technical subjects which must wait until later. They must wait until we can give you additional preparatory instruction so you can understand the basic theory behind the action which takes place in an antenna and the transmission line.

However, without getting unnecessarily involved in the subject, we can tell you that most commercial TV antennas are so constructed that their *characteristic impedance* is either 75 ohms or 300 ohms.

Because of certain technical necessities, it has become almost imperative that the *characteristic impedance* of the transmission line be matched to the *characteristic impedance* of the antenna. All of which has resulted in the manufacturers of transmission lines coming up with lines which have characteristic impedances of 75 ohms and 300 ohms to match the impedance of the most frequently used antennas.

This makes it possible for a TV serviceman, or TV antenna installer, to install a 300-ohm antenna, then match its impedance by using a 300-ohm line to connect the antenna to the input of the receiver tuner.

Which brings us to the point of this qualifying explanation. Because 75-ohm and 300-ohm antennas and transmission lines are those most widely used for television work it has been necessary for tuner engineers to design the tuner in such a way that the impedance of its input will match the characteristic impedance of the transmission line.

One very common method of coupling the transmission line to the tuner is to terminate the line in the primary of an RF transformer as shown in Fig. 3. The primary winding is designed to have an impedance of 300 ohms at the frequencv to be received.

The impedance of the primary winding is 300 ohms at some specific frequency, and the impedance is measured from one end of the coil to the other. The two conductors of the transmission line are connected to the two extreme ends of the primary winding as shown in Fig. 3. (It must be kept in mind that we are discussing impedances. The characteristic impedance of an antenna or line cannot be measured by using an ohmmeter — it depends upon the physical construction of the line, and not on the resistance in the conductors.)

One advantage of using this type of input coupling is the fact it can be easily re-connected so it can be used to terminate either a 300-ohm line or a 75-ohm line.

A study of Figs. 2 and 3 discloses the fact there are three connections to the primary winding of the RF transformer. There is a connection at each end, and a center tap. In Figs. 2 and 3 the center tap is connected to ground. Usually this "ground" connection will be to the ground of the chassis, but in many receivers it is entirely possible to make a connection directly to the ground of the earth if such a thing should be desirable. It is

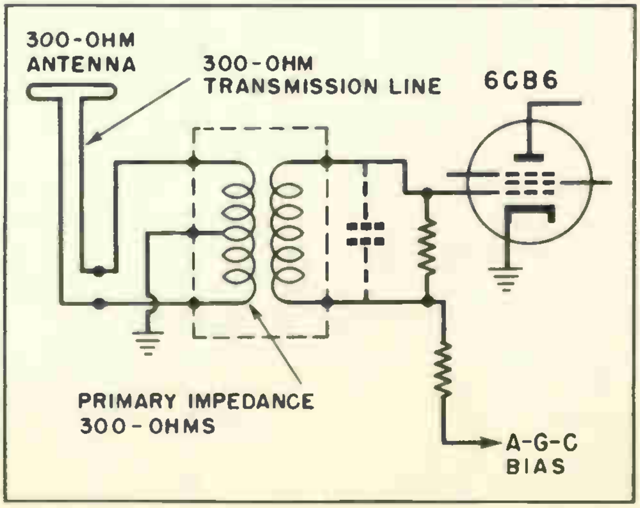

Fig. 3. Matching transmission line input of tuner.

rare that a connection directly to the earth would be considered desirable or necessary, but such connection is possible if it is needed.

The presence of that center-tap makes it possible to match the primary winding to a 75-ohm line, should that become necessary. It is fairly common knowledge that 300-ohm antennas, and 300-ohm transmission lines are used most in TV work; but 75-ohm antennas and 75-ohm lines are used for some purposes.

A simple di-pole antenna, such as the one shown in Fig. 4, has a characteristic impedance of 75 ohms. When such an antenna is used it would be matched to a 75-ohm line, then it would be necessary to match the line to the input of the tuner.

A simple method of connecting the 75-ohm line to the input of the tuner so the impedances match is shown in Fig. 4. One side of the line is connected to one end of the transformer winding while the other side of the line is connected to the center tap of the primary winding. You will recall from your previous electrical theory that reducing the number of turns on a transformer winding by half automatically reduces the impedance of the winding to one-fourth its previous impedance.

The actual physical appearance of the terminal strip on the receiver, to which the transmission line is connected, is shown in Fig. 4.

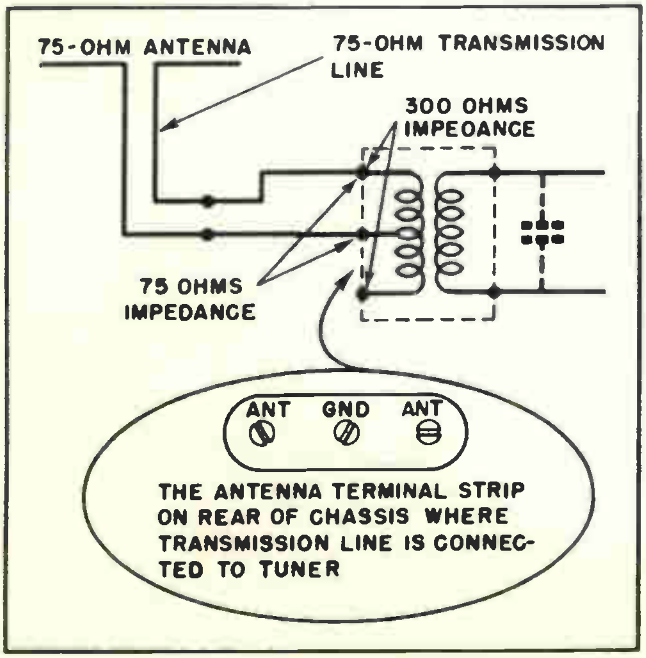

Fig. 4. Matching 75-ohm line to tuner.

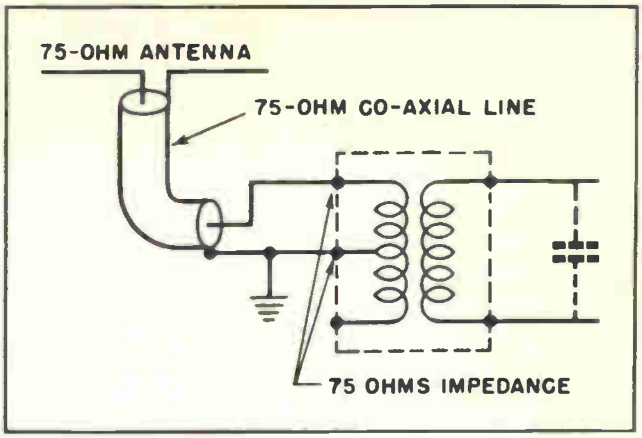

Fig. 5. Matching 75-ohm co-axial line to tuner.

Where outside electrical noise levels are high, and there is danger of the transmission line picking up so much noise as to interfere with the signal, it is fairly common practice to use a co-axial line. A co-axial line is one in which the active conductor is completely surrounded by, and shielded by, the second conductor. Presence of the shielding prevents electrical noise reaching the inner, or shielded, conductor.

The characteristic impedance of a co-axial line varies somewhat from one general type to another. Those used in TV work usually have a nominal impedance of approximately 75 ohms. The manner in which a co-axial line is connected to a TV tuner is shown in Fig. 5.

Section 4. THE RF TRANSFORMER

The RF transformer in Figs. 2, 3, 4 and 5 is shown within a dotted box. This has been done deliberately. It is intended to show those coils can be readily removed from the circuit, and others substituted in their place.

In several types of TV tuners a different RF transformer is switched into the circuit for each channel it is desired to receive. In most tuners the RF transformer is specifically designed to resonate at the frequency of the channel to be received, and thus discriminate very sharply in favor of that channel, and against signals from adjacent channels.

A separate set of transformer coils are used for each TV channel.

An RF amplifier using RF transformers tuned to the frequency of TV channel 4 is shown in Fig.

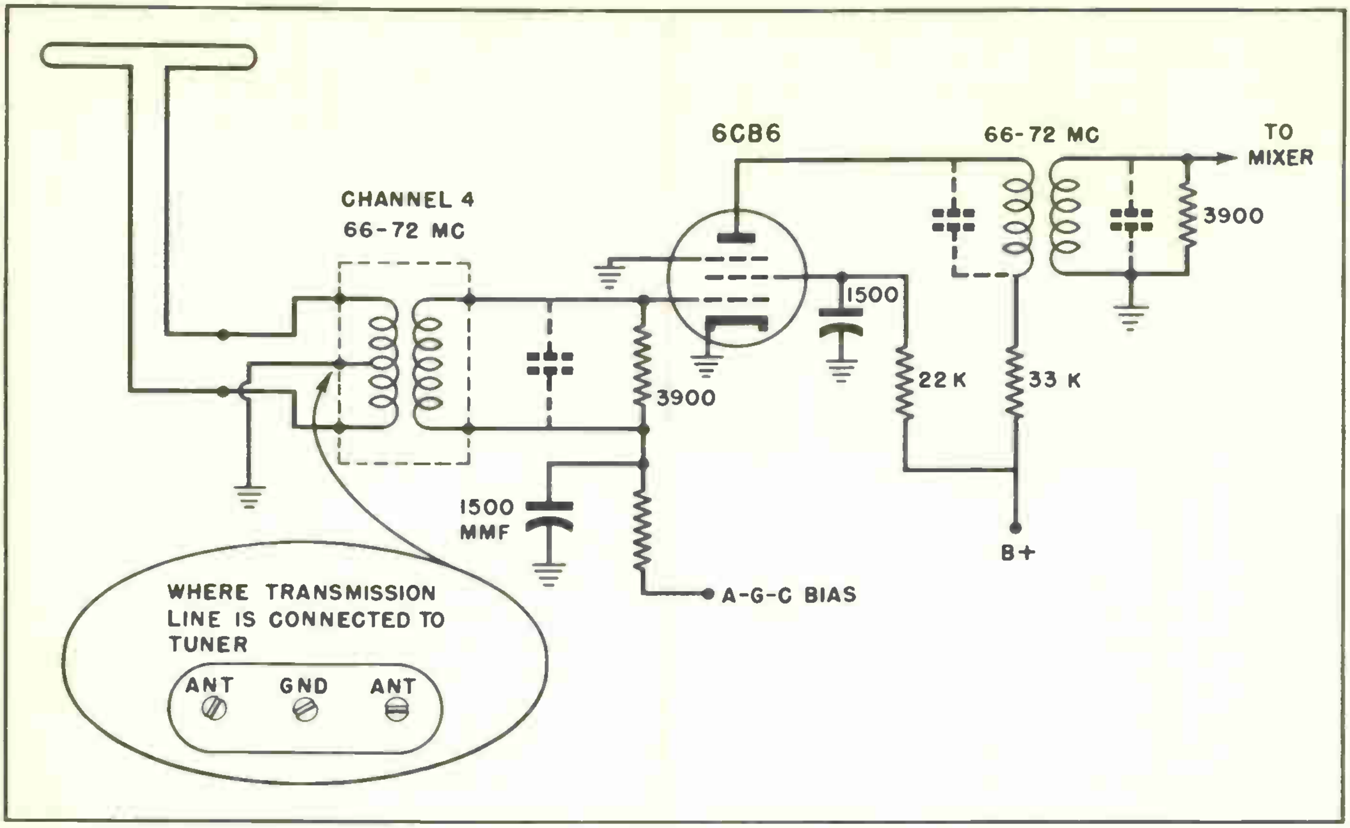

Fig. 6. RF Amplifier using circuits tuned for channel 4.

6. The circuit outlined in that diagram shows the RF transformer, which couples the transmission line to the RF implifier tube, tuned to 66-72 megacycles, which is the range of frequencies used by channel 4. It also shows the coupling transformer between the output of the 6CB6 pentode amplifier and the following mixer circuit tuned to the same frequencies.

Some TV tuners are so designed that both these transformers are changed each time the tuner is switched from one channel to another. This would be the situation shown in Fig. 6. Some present day tuners do not have the coupling transformer, which follows the RF amplifier, tuned to a specific frequency.

There is an even larger number of tuners which use a somewhat different method of coupling the RF amplifier to the mixer. The one shown in rough outline in Fig. 2 is probably the most widely used of all. The method shown in Fig. 2 makes it possible to provide a separate set of tuned circuits for each channel.

A close study of the RF transformers between the transmission line and the input to the RF amplifier tube in Figs. 2 through 6 discloses the manner in which the various parts of the coils are connected to the other parts of the circuit. These transformer coils are usually mounted on some type of rigid support. Each terminal on the individual coils is brought out to a rigid contact point on the supporting base.

Often these supporting bases are mounted on a rotating drum, as is common practice with Standard Coil tuners. Other types of tuners mount them somewhat differently.

However they are mounted, the net result is the creation of a method whereby one set of coils can be removed from the tube circuits and another set inserted in them. Because a completely different set of coils is used for each TV channel it becomes much easier to tune each set of coils so it responds best to the channel it is to handle.

In some types of tuners, especially those made by Mallory and under their patents, the various coils are actually variable inductors. The coils are so mounted that they can be rotated, and the act of rotating them changes the inductance. The physical construction of such variable inductors

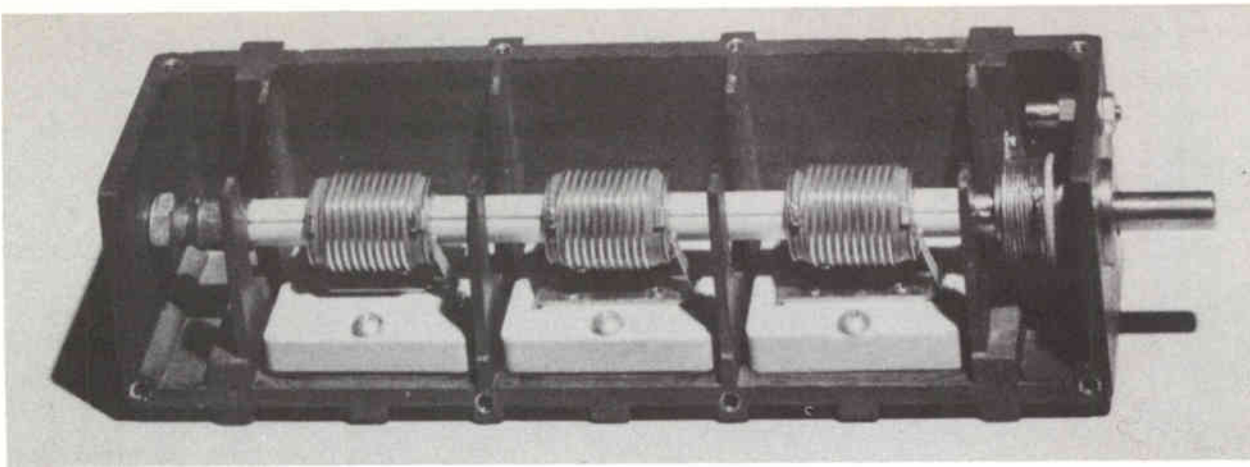

Fig. 7. Coils mounted on shaft to provide continuous Tuning. (Courtesy P. R. Mallory Co.)

can be better understood by studying Fig. 7.

Rotating the shaft at the end of the tuner, which actually projects through the front panel of the TV receiver so it can be adjusted by the user, automatically changes the inductance of each of the three coils shown in Fig. 7. The fact the inductance of the three coils can be changed simultaneously makes it possible to change the resonant frequency of each of the circuits in which those coils are located.

A TV receiver, using a set of coils like those shown in Fig. 7, tunes continuously from one channel to another in a manner very much like that followed in tuning a radio receiver. On the other hand, a TV receiver which switches from one set of coils to another, as shown in Figs. 2 through 6, changes from one channel to another much more abruptly. There is no smooth transition; there is a quick, abrupt change.

A type 6CB6 pentode amplifier is shown being used in the circuits in Figs. 3 and 6. This type tube has found much favor among TV engineers for this purpose. It is a common tube in TV work, one which is used frequently in both RF and IF circuits. It is a miniature tube which has sharp cut-off characteristics.

The 6BC5 is a similar tube which is often used for the same purposes. In fact, the 6CB6 and the 6BC5 are so much alike they can often be substituted for each other without any changes being made in the circuits.

The 6AG5 is another tube of this same general type which is often used for these purposes. At one time the 6AG5 was one of the most widely used of all tubes for TV amplification work. It was used in both RF and IF circuits, but it no longer is used in so many receivers as formerly. There are many circuits where the 6AG5 can be directly interchanged with either the 6CB6 or the 6BC5 without any of the circuit elements being changed.

Section 5. SIGNAL-TO-NOISE RATIO

In one respect the RF amplifier stage in a TV receiver has a greater controlling effect on receiver operation than any other stage. The circuits, and their arrangement, which are directly associated with the RF amplifier tube set the conditions which govern receiver sensitivity.

The matter of sensitivity is always important in all kinds of radio and TV receivers. The greater the sensitivity of any type receiver the better is its ability to reach out and pull in weak signals.

The matter of sensitivity in a radio determines whether it is capable of bringing in distant broadcast stations, or only those in the local area. Much the same is true of a TV receiver.

When a TV receiver is located close to the transmitter the signal from the broadcast station is so strong it will pour into a receiver's circuits without much regard to the sensitivity of the circuits; but, when the receiver is located some 50 to 100 miles from the transmitter the radiated signal is much weaker, and the matter of receiver sensitivity becomes of major importance.

From a purely theoretical point of view it can be supposed that a vacuum tube amplifier circuit is capable of accepting a radiated TV signal, regardless of its weakness, and amplifying it to usable strength. Insofar as the TV signal is concerned that fact is true.

In primary signal areas the TV signal is usually so strong that ambient (close by) electrical noise has virtually no effect on the TV signal, and interferes very little with it in the amplifier circuits of the receiver.

On the other hand, in those areas where the TV signal is weak it may be found that the strength of the electrical noise is almost as great as the TV signal itself. In that case we find when the TV signal is acted upon by the amplifier circuits to strengthen it, the electrical noise impulses are also acted upon and amplified.

When the level of the electrical noise is closely comparable to that of the TV signal we often find the TV picture almost smothered under the random noise pulses. These are the conditions in which the picture is said to be covered by "snow." Every person who has tried to pick up a TV picture in a remote, fringe area is familiar with the phenomenon of TV "snow."

All of which means that the ability of a TV receiver to bring in an acceptable picture does not depend entirely on the receiver's ability to pick up a video signal and amplify it to usable levels; on the contrary, it depends more on the receiver's ability to separate the TV signal from the ambient noise, and amplify the signal without at the same time amplifying the noise.

This brings us face-to-face with the problem of what constitutes "electrical noise," insofar as it affects the video signal in a TV receiver.

There are two general classifications of electrical noise which have a strong determining influence on the minimum TV signal strength which can be accepted and handled.

One is the external noise which is generated by various kinds of electrical apparatus such as neon signs, fluorescent lights, motor brushes, oil burners, and other electrical appliances. Electrical noises originating in automobile ignition systems are also included in this general category, as well as natural electrical noises such as lightning and other types of static.

Another type of electrical noise is generated inside the amplifier tubes themselves. These are random electrical impulses resulting from the varying number of electrons which pass from the cathode to the anode, thermal noises which originate under the influence of the heating action of the filament, and those electrical noises which originate from the accidental physical movements of the various elements within the tube.

Electrical noises which originate within the amplifier tubes are variously referred to as "thermal noises," and "shot effects," and by other more or less descriptive terms. In most cases it is proper to lump all the noises generated inside a tube together, then refer to them by simply calling them "tube noises."

In some cases there is little the design engineer can do about the electrical noises which originate outside the receiver circuits. If those noises are quite strong, and close to the level of the TV signal, they will override the TV signal despite anything that can be done to the receiver circuits. This arises from the inescapable fact the signal noises, themselves, are almost as strong as the TV signals; and in extreme cases may be even stronger than the TV signals.

External arrangement of the antenna and the transmission lines may reduce external noises, but there is little that can be done to the amplifier circuits which will affect them.

The matter of the electrical noises which originate inside the amplifier tubes is another matter. Engineers have come up with some ingenious arrangements which have reduced the effective interference of those noises, and have been able to raise the level of the TV signal to some extent without simultaneously raising the strength of the interfering noise signals.

Engineers have learned that multi-element tubes, such as pentodes and pentagrid converters, generate more internal noise than those with fewer elements, such as triodes. This means that triodes can accept a low-level signal, and amplify it without covering it up with so much background noise as when a pentode is used for that purpose.

They have also discovered that the controlling tube in a receiver circuit, the one which determines the relative levels of the signal and the electrical noise, is the *first* RF amplifier. This means that if they can devise some way of amplifying the strength of the incoming RF carrier signal, without smothering it with tube noise, they have succeeded in adding sensitivity to the receiver. In plain words, it means they have improved the ability of the receiver to reach out and bring in a usable signal from more distant transmitting stations.

Engineers speak of this problem as one which involves the comparative strengths of the signal itself and that of the interfering noise. Since it involves the ratio of the signal strength to the noise level they commonly refer to it as the *signal-to-noise ratio*. Reduced to its basic fundamentals the signal-to-noise ratio of the first stage of any radio or TV receiver is the governing influence which determines the sensitivity of the receiver.

Section 6. GROUNDED-GRID TRIODE AMPLIFIER

Engineers and other technical men have long known that triodes generate much less internal noise than pentodes. They have thought for a long time it would be desirable to use a triode as the first stage amplifier in a receiver, especially in a TV receiver, if they could overcome other drawbacks which make the triode undesirable for high-frequency work.

One of the big drawbacks to the use of triodes in high-frequency circuits is the high inter-electrode capacity which exists between the grid and anode. That high inter-electrode capacity permits signals in the output circuit to feed back into the grid circuits, and thus set up undesirable effects.

To overcome some of the objections of the triode for use in high-frequency circuits engineers came up with a modified amplifier circuit involving a triode which they call a *grounded-grid amplifier*. The major elements of the grounded-grid amplifier are shown in Fig. 8.

At first glance the circuit may appear unconventional. But a closer study reveals the fact the circuit has some real merit.

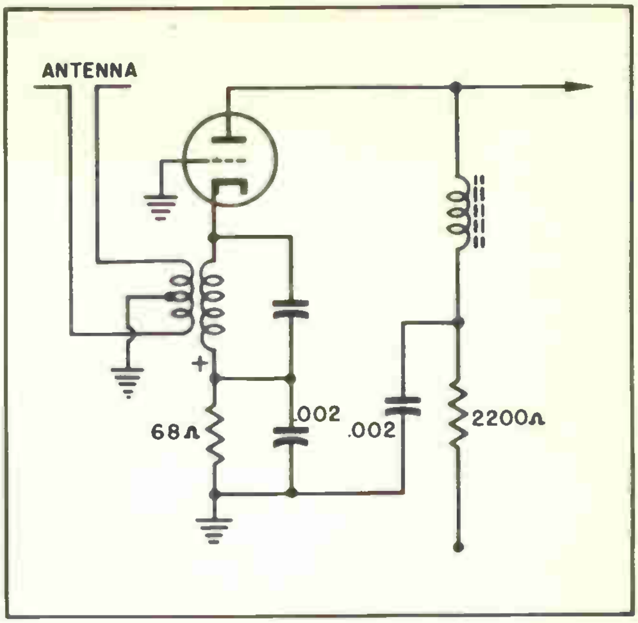

Fig. 8. Grounded-Grid Amplifier.

Normally the cathode of a triode is grounded. It is also normal for the signal to be injected on the grid.

Note the difference in the circuit shown in Fig. 8. The grid is connected directly to ground. This means that any signal fed back from the anode to the grid has no effect on the amplifying ability of the tube because the fed-back signal is immediately by-passed to ground.

Instead of the signal being injected on the grid, as is the normal custom, it is injected on the cathode. Such an unusual arrangement looks, at first glance, as though it would not work. Additional study brings out some interesting points about it.

The AC signal applied to any vacuum tube amplifier is normally applied between the grid and cathode in such manner as to make the grid more or less negative with respect to the cathode. This is a time-honored practice, and there is nothing new about it.

A careful study of the circuit in Fig. 8 discloses the fact that despite its unusual appearance the incoming signal is still injected into the tube circuits between the grid and the cathode.

The grid is connected directly to ground. The incoming signal is injected into the cathode circuit between the cathode and ground. This means that the incoming signal causes the cathode potential to vary with respect to ground, which is merely another way of saying that the cathode voltage is caused to vary with respect to the grid.

Which, of course, when one looks at it in another way, is precisely the same as saying that the grid voltage is varying with respect to the cathode; and that is exactly the same action which takes place in any triode amplifier whenever a signal is applied to the grid.

The important advantage of the grounded-grid circuit is that the input circuit and the output circuit are effectively shielded from each other by the presence of the grid. Tying the grid to ground provides an effective shield between the input circuit and the output circuit.

There is one inherent disadvantage in the grounded-grid circuit which restricts its use to a few specific circuits, such as the first RF stage in a TV tuner. That is the degenerative effect of the circuit.

As the signal tends to drive the cathode increasingly negative it has the same effect as driving the control grid more positive. This means more current will flow through the tube and, of course, through the cathode resistor. The increased voltage developed across the cathode resistor tends to counteract the input voltage.

In plain words the voltage developed across the cathode resistor serves to decrease, or degenerate, the strength of the incoming signal. The degree of degeneration is countered somewhat by the bypass capacitor around the resistor, but some degeneration remains.

Fortunately, the matter of degeneration is not a critically serious matter with extremely low-level signals found in the first RF stage. The advantages of the higher signal-to-noise ratio more than overbalance the slight degeneration present in the circuit.

Section 7. CASCODE RF AMPLIFIER CIRCUIT

In some respects the grounded-grid RF amplifier has definite advantages over a pentode tube when it is used for the same purpose. But it is not the perfect answer when a sensitive RF amplifier is needed for the tuner.

Research scientists and engineers at the Massachusetts Institute of Technology developed a special type RF amplifier for use in Radar work. It employed a pair of triodes connected in cascade, so one fed directly into the other.

The essential details of the MIT circuit are

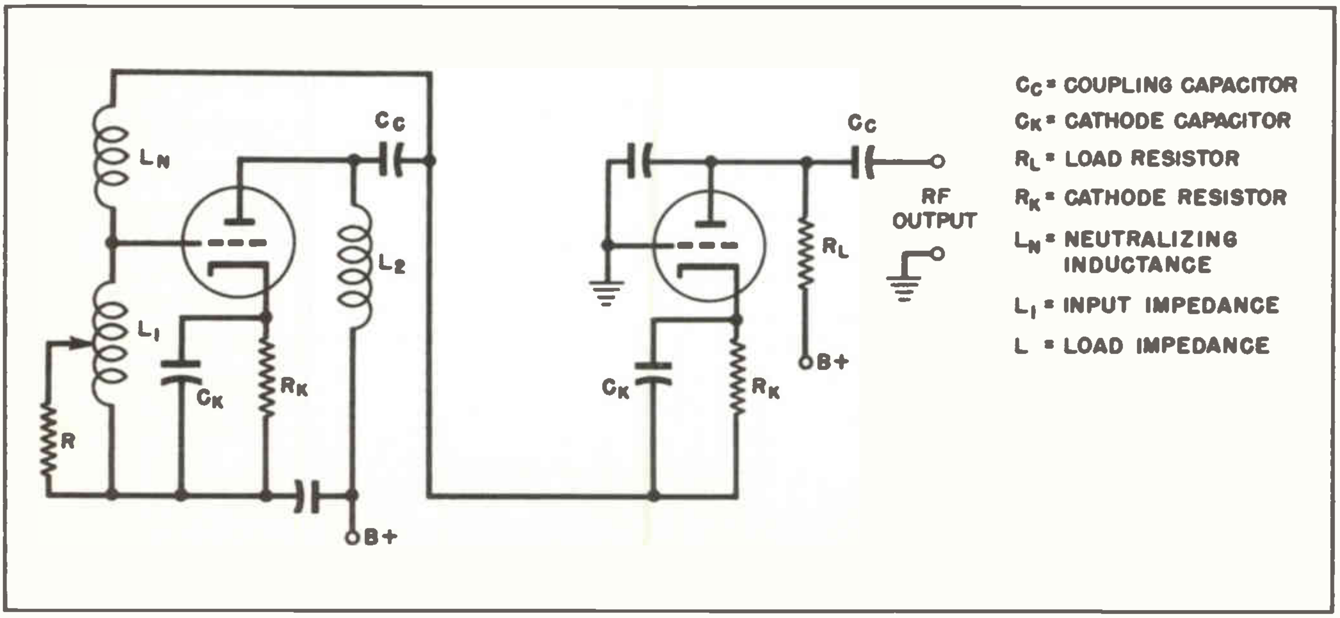

Fig. 9. Original MIT Cascode RF Amplifier.

shown in Fig. 9. It can be seen that the RF signal in the anode circuit of the first triode feeds directly into the cathode circuit of the second triode.

The original MIT cascode circuit was not entirely suitable for commercial TV receiver service, but there were details about the circuit which clearly established its superiority over existing types of RF amplifiers. One of the things which did not appeal to the service-wise minds of TV engineers was the neutralizing circuit employed in the original MIT circuit.

After studying the MIT cascode circuit these practical engineers came up with some modifications which made the circuit usable in TV RF amplifier circuits. When first used in TV amplifier service the cascode circuit was modified to the form shown in Fig. 10.

A pair of triodes connected to operate as a cascode amplifier circuit have an over-all gain slightly greater than that which can be obtained when a single pentode is used. But the more important advantage of the circuit is the materially improved signal-to-noise ratio.

The improved signal-to-noise ratio makes it possible for the receiver to pick up a weaker TV signal, and amplify it to usable levels, without having the signal at the output of the amplifier smothered in the background noise which is normally generated in a multi-element RF amplifier tube.

The circuit in Fig. 10 suggests that two actual triode tubes are used in the cascode amplifier. It is possible, of course, to use two separate tubes in cascade, but such is not the general practice. It is almost universal practice to use a twin-triode with the separate sections coupled in cascade.

When the cascode circuit was first introduced to television work the 6J6 twin-triode tube was the one most widely used. It had proven itself dependable in other types of service in connection with high-frequency amplification such as is necessary in TV tuner work.

As the cascode RF amplifier came into more widespread use, special types of twin-triode tubes were developed. These tubes were specifically designed for use in cascode amplifiers, and they gradually displaced the 6J6.

Probably the most widely used tubes in cascode amplifier service are the 6BK7, the 6BZ7 and the 6BQ7. Improved versions of these tubes are the 6BZ7A and the 6BQ7A and the 6BK7A. The latter tubes can be substituted for the former tubes wherever they were used as standard equipment. The 6BZ7A and 6BQ7A have improved internal construction which enable them to stand up under

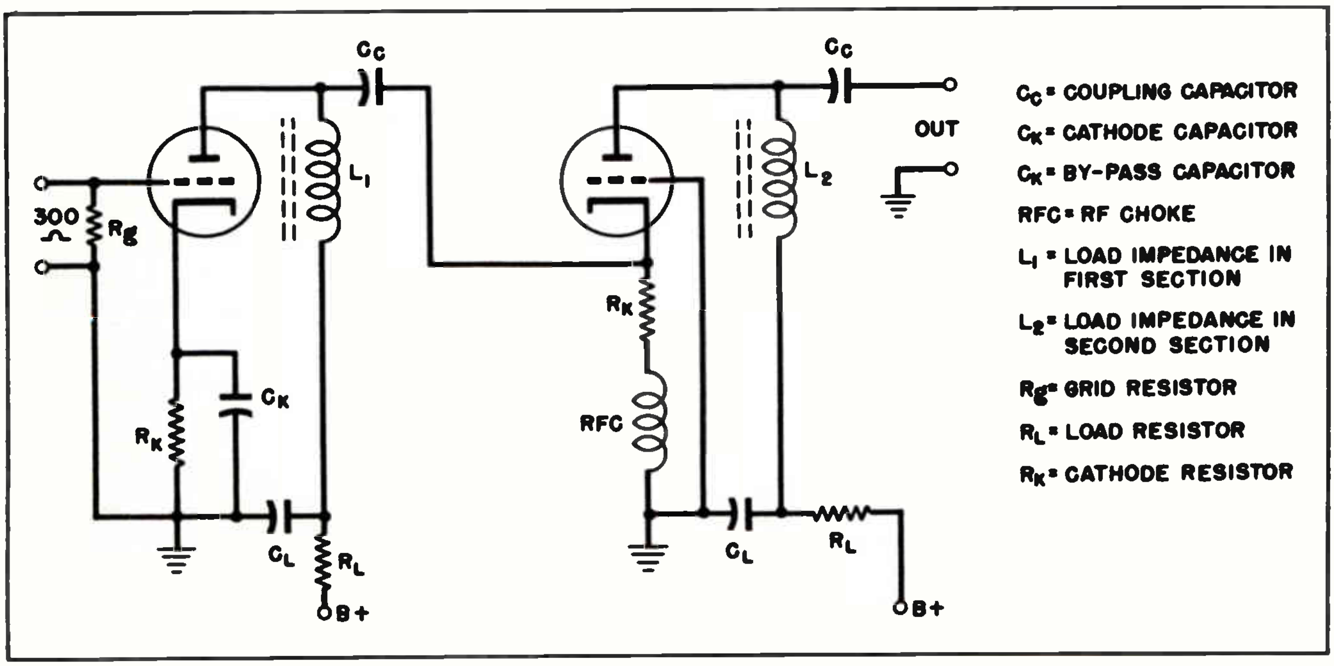

Fig. 10. Cascode circuit modified for use in TV tuner.

rougher service, but the base pin connections and electrical characteristics are the same as for the original tubes.

A careful study of the cascode amplifier reveals that one of the triode sections is connected as a grounded-cathode amplifier while the other is connected in cascade as a grounded-grid amplifier.

Excellent stability in the cascode amplifier is achieved by loading the output circuit of the first section quite heavily. That is the grounded-cathode section.

When the grounded-cathode section of the amplifier is loaded down, most of the power is absorbed. Thus, the tendency for the grounded-cathode triode to oscillate is radically reduced. When properly designed the grounded-cathode section will not oscillate under any normal operating conditions. This reduces one of the objections to the use of a triode in an amplifier circuit of this type.

The manner of loading the output of the first —or grounded-cathode — section of the cascode amplifier is one of the secrets of its successful operation. The loading of the output of the first triode is the low-resistance input to the cathode circuit of the grounded-grid section, which is the second section of the cascode amplifier.

A study of the circuit in Fig. 10 shows the RF output signal from the grounded-cathode section of the cascode amplifier is coupled into the second section, or the grounded-grid section, through a coupling capacitor. This practice is used by several manufacturers in their tuner section.

The Standard Coil Products Company has modified the cascode circuit still further. It couples the first section of the amplifier directly into the second section. This can be better understood by studying Fig. 11.

Standard Coil has simplified the cascode circuit so both triode sections are connected in series between B+ and B−. The full B+ voltage is applied to the anode of the second triode. This arrangement causes approximately one-half the B+ voltage to be applied between the anode and cathode of the second triode, and the other half of the B+ voltage to be applied between the anode and cathode of the first triode.

Because the cathode of the second triode section is approximately 120 to 125 volts positive with respect to ground it is not possible to tie the grid of the second triode directly to ground. Insofar as RF signals are concerned the second grid is effectively grounded through the 800 mmfd. capacitor. It is also grounded for DC through the ingenious resistor network arrangement. The exact manner in which that resistor network is arranged is well worth a little study. Fig. 11

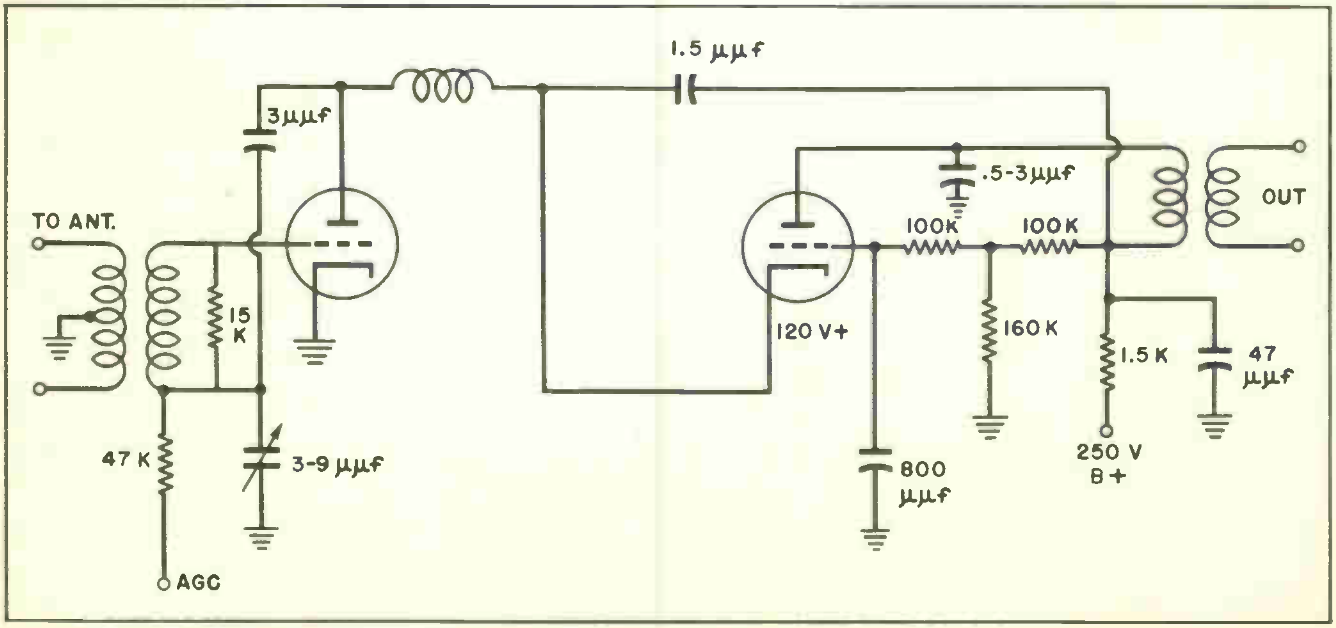

Fig. 11. Modified Cascode Circuit used in Standard Coil Tuners.

shows the network more clearly than descriptive words.

Our explanation of the cascode circuit in this section will serve to introduce this highly useful type of amplifier. However, little purpose will be served by examining the circuit exhaustively at this time. It will be covered in much greater detail in a later lesson.

Section 8. THE MIXER STAGE

After the amplified RF carrier signal leaves the RF amplifier in the tuner it usually passes directly into the mixer tube. In a few receivers there is a second RF stage, and in a few isolated cases some other action takes place before the signal reaches the mixer. But the almost universal practice in modern receiver tuners is to send the amplified RF carrier directly from the RF amplifier to the mixer.

Contrary to the common practice in *radio* mixer circuits, the mixer tube in most TV receivers is a triode tube. Commonly, it is one of the sections in a twin-triode. Probably the most widely used mixer tube in TV tuners is the 6J6, although other tubes are capable of doing the mixing job.

The circuit in Fig. 12 is one example of how the 6J6 can be used as a combination oscillator and mixer. This circuit has been used in many TV tuners, but is not now being used so widely as some other arrangements. Nevertheless, it is still in use.

The RF carrier signal from the RF amplifier is fed to the grid of the mixer section of the twin-triode. The signal is coupled through an RF transformer which can be tuned from one frequency to another as the receiver is switched from one TV channel to another.

The other section of the twin-triode tube functions as the oscillator tube. A small portion of the oscillator signal is coupled from the oscillator grid to the grid circuit of the mixer tube. It is coupled from one grid to the other through a small variable capacitor. The capacitor has a capacity of only 1 to 2 mmfd., but that is sufficient to couple the high-frequency signal generated by the oscillator.

The oscillator circuit shown in Fig. 12 is a Colpitts oscillator. The Colpitts circuit has found considerable favor for TV oscillator work, although it is by no means used universally.

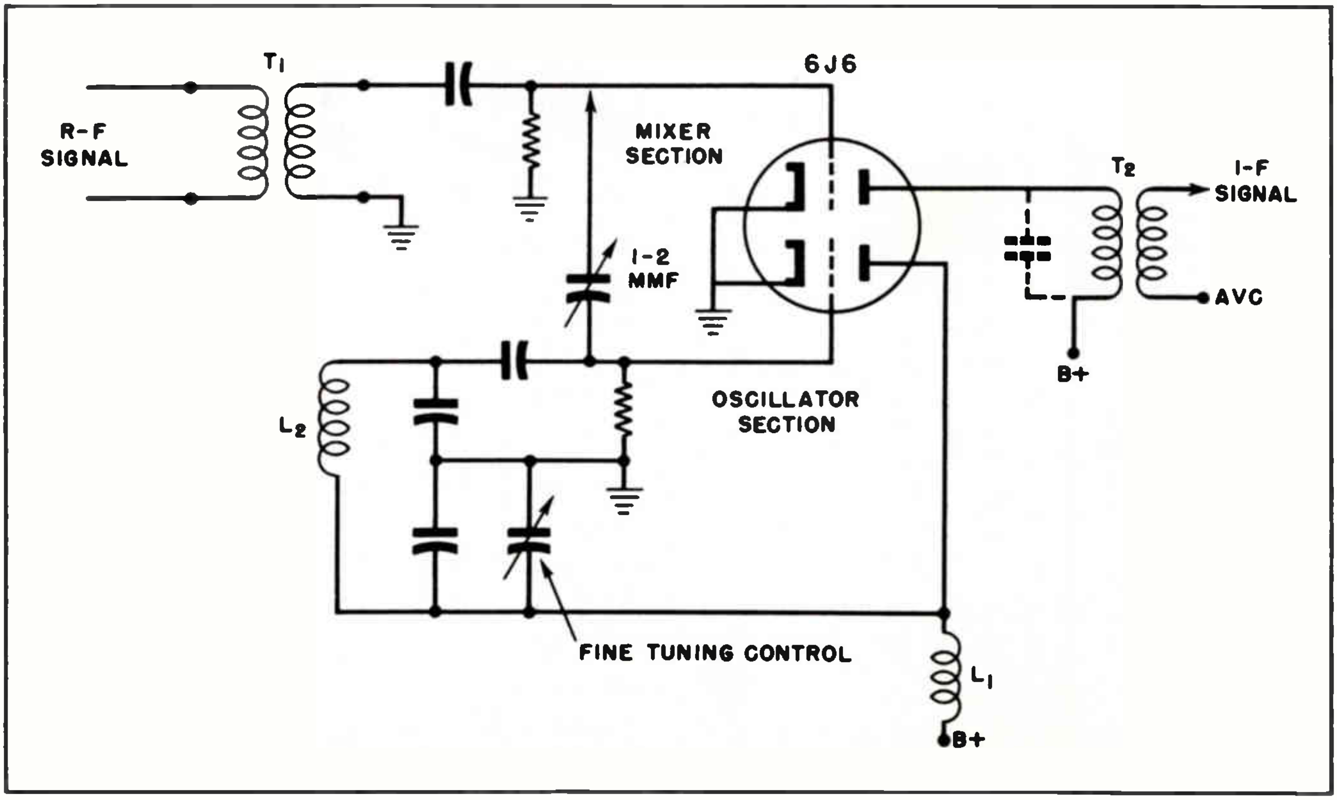

Fig. 12. Mixer-Oscillator Circuit.

A modified version of the Colpitts oscillator which utilizes the inter-electrode capacitances of the tubes is often used in high-frequency work. It is called the Ultra-audion.

The Ultra-audion operates on the same principles as the Colpitts, but instead of having actual physical capacitors, as shown in Fig. 12, the only capacitors in the circuit are those within the tubes themselves. Some designers have favored the Ultra-audion oscillator for high-frequency oscillator work, but the difficulty of stabilizing the frequency has discouraged other designers from using it. The slightest degree of difference in the inter-electrode capacitance within a tube causes an Ultra-audion oscillator to generate a different frequency. Such instability is clearly undesirable in TV work.

The physical and electrical characteristics of the Ultra-audion oscillator are discussed at greater length in a later lesson where we examine the peculiarities of high frequencies, and high-frequency oscillators, more closely.

By providing no grid biasing for the mixer tube, beyond that provided by a possible connection to the AVC circuit, we have what is definitely a non-linear amplifier. With two separate signals feeding into the grid, one from the RF amplifier and the other from the oscillator, a heterodyning action takes place between them. The two signals mix together so a difference frequency appears in the output circuit.

The output of the mixer, like the output of all mixer circuits, feeds into the first I-F stage, which is tuned to accept the difference frequency.

The first mixer stage in *UHF tuners* is frequently a crystal diode. There are peculiar reasons why this is true, reasons stemming from the extremely high frequencies involved in UHF work. We have a completely separate lesson on UHF tuners which you receive later in the course. We merely mention the matter of the crystal diode at this time because you may become acquainted with it from some outside source, and wonder why it has not been mentioned here.

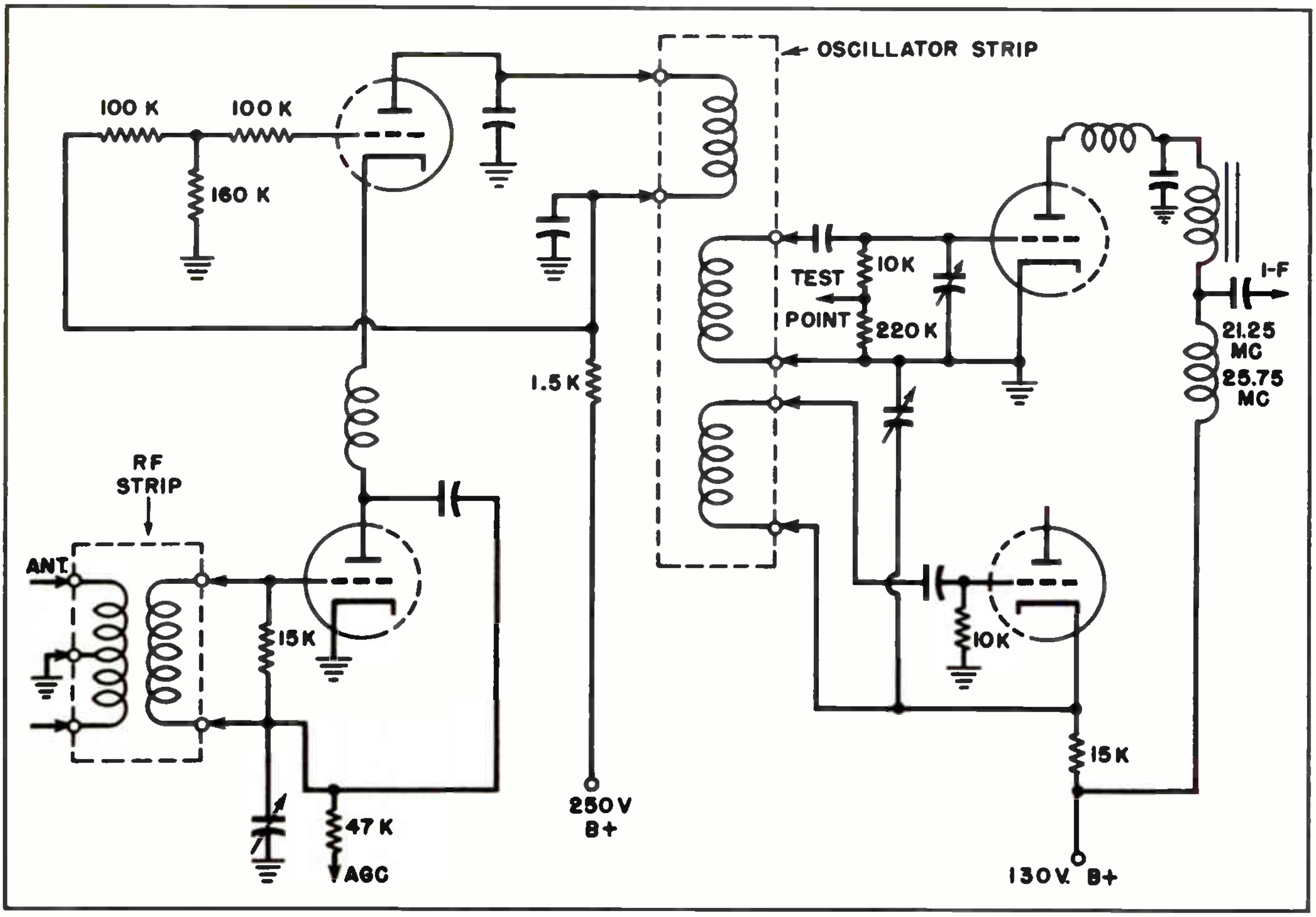

Fig. 13. RF, Oscillator and Mixer Circuits in a Standard Coil Cascode Tuner.

Another group of circuits used in oscillator-mixer circuits is shown in Fig. 13. That is the circuit used by Standard Coil Products in their Cascode Tuners.

In this connection it is well worth mentioning that Standard Coil, in company with other tuner manufacturers, continues to build both pentode tuners and cascode tuners. The pentode tuners are fully adequate for local TV reception, or for use any place where the signal is strong and the noise level reasonably low. The cascode tuners are used in the higher priced receivers where greater sensitivity is needed.

Cascode tuners cost considerably more than pentode tuners, and where price is important the pentode types are still used. There are probably as many pentode tuners still being built as the newer cascode type.

In Fig. 13 we see the coils which couple the RF amplifier to the mixer, and which couple the oscillator to the mixer, positioned within a dotted box which is labeled "oscillator strip." This oscillator strip is similar to the rigid mounting strip on which the RF transformer coils are mounted.

The oscillator strip, like the RF strip, is physically mounted on a rotating drum, or "turret" as it is called. The exact manner in which these strips are mounted on the turret is shown in the photograph in Fig. 14.

The strip on which the oscillator and coupler coils are mounted is shown in the photograph. It is in the group nearest the shaft. These are the strips on which six contact points are visible.

An examination of the circuit in Fig. 13 shows there are six electrical connections to the coils mounted on the oscillator strip. Two each for each of the three coils. Each of these connections are made by means of a separate contact. The contacts themselves are clearly visible in Fig. 14.

Turning our attention to the "RF" strip in Fig. 13 shows there are five electrical connections between the coils mounted on the strip and the outside electrical circuits. There are three connections to the primary of the transformer and two connections to the secondary.

The individual strips on the section of the turret farthest from the shaft have five electrical contacts. These can be seen by examining Fig. 14. These are the "RF strips" of the tuner.

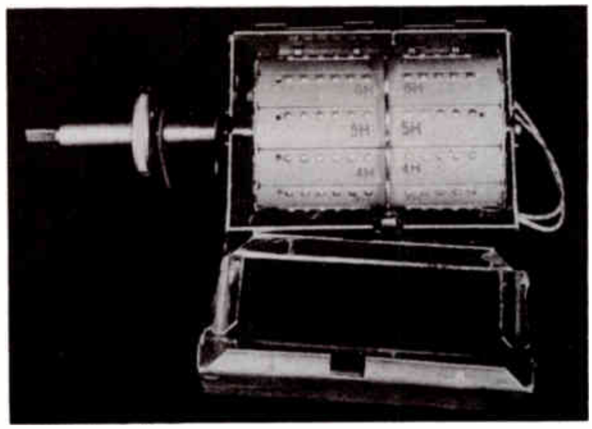

Fig. 14. Oscillator and RF Mounting Strips positioned on turret of Standard Coil tuner.

Section 9. THE OSCILLATOR

The oscillator circuit in a Standard Coil Products tuner consists of one section of the mixer-oscillator tube, and the circuits associated with that tube. In particular, it includes the coil mounted on the oscillator strip on the rotating turret.

The turret has twelve RF strips mounted on it, and twelve matching oscillator strips. There is one RF strip and one oscillator strip for each channel, thus making twelve pairs of strips for the twelve VHF TV channels.

If it is desired to receive channel 2, for example, the turret is rotated until the RF strip containing the transformer coils tuned to the frequency of channel 2 make contact with the RF amplifier circuits in the tuner. Rotating the turret, until the RF strip for channel 2 makes contact with the RF amplifier circuits, automatically moves the oscillator strips until the strip carrying the coils for channel 2 make contact with the oscillator and mixer circuits.

In plain words, when the turret is rotated until it is in position to receive channel 2, the RF coils tuned to channel 2 will be in the RF amplifier circuit, and the oscillator and coupling coils tuned to channel 2 will be in their respective circuits. If there is a channel 2 carrier on the air the signal will pass through the RF transformer for channel 2 to the RF amplifier, then pass through the channel 2 coupling coils to the mixer. At the time the turret is rotated into the channel 2 position the coils needed by the oscillator to generate a signal to heterodyne with the channel 2 carrier will be moved into the oscillator circuit.

Stability of the oscillator in the tuner of a TV receiver is always a matter of considerable concern. Physical dimensions of the coils and other components in the oscillator circuit tend to change whenever there are changes in temperature. They also change with age and with changes in humidity conditions.

All of which means that many things affect the physical conditions of the oscillator components. And anything which tends to change the physical conditions of these components affects the frequency of the oscillator.

A frequency drift of as little as 1% at 200 megacycles means a drift of 2 full megacycles in the actual generated frequency. It is not difficult to see what happens to the difference frequency at the output of the mixer tube should the oscillator frequency drift by that amount.

Most TV tuners incorporate some type of "fine tuning" control. Often this is nothing more than a low-capacity, variable capacitor. Its purpose is merely to add or subtract capacity to or from the oscillator circuit to bring its frequency back to what it should be.

Provisions of some kind are included in nearly all commercial TV tuners to adjust the frequency of the oscillator. In the case of the Standard Coil tuner, the frequency of the oscillator for each channel can be adjusted separately. The oscillator coil can be adjusted from the front of the receiver without taking the tuner from the chassis, without removing the chassis or the back panel from the receiver. This ability to adjust the oscillator sections of the tuner from the front has contributed much to the popularity of the Standard Coil tuner.

Many things contribute to instability of the oscillator in the TV tuner. Vibrations from the speaker often have a disastrous effect on it, especially after the tube or its associated circuits become aged. Various means have been used to reduce speaker vibrations, such as mounting the oscillator tube base in rubber, and placing a heavy lead shield around the tube to damp out the vibrations.

Probably the most effective protection from speaker vibrations is the present tendency to mount the speaker anywhere except on the chassis. Mounting the speaker on the cabinet instead of the chassis, or mounting the speaker in rubber, does much to reduce the injurious vibrations.

It is critically important that all leads to the oscillator tube be very short. They should not only be short, they should also be heavy. Heavy wire tends to reduce inductance in the leads.

If an attempt is made to repair anything connected with the oscillator circuits of a TV receiver these bits of advice should be kept clearly in mind. Changes in the leads, such as lengthening them, or changing their position, may change the electrical characteristics of the oscillator circuit to such an extent it is thrown badly off-frequency, or results in the generation of unwanted parasitic frequencies. If that occurs the oscillator probably will not function properly.

While we have devoted much attention to the turret tuner built by Standard Coil Products Company it should not be thought they are the only manufacturers of turret type tuners.

Outstanding among the other large manufacturers which build turret tuners are Philco and Zenith. Their tuners differ from the Standard Coil tuners in details, but the essential principles are much the same. Some of the older Zenith turret tuners had the RF and oscillator coils mounted on a single strip. Newer models use separate strips.

Despite the fact Philco builds turret tuners they also use Standard Coil tuners on some models.

Section 10. TAPPED COIL TUNERS

In the early days of television many manufacturers used continuous coils, which were tapped at intervals, as inductances for the tuned circuits in the tuner. Taps from the coil were tied to a multi-pole switch.

By switching from one position to another on the tapped coils it was possible to introduce, or remove, inductance to or from the circuits. This was enough to change the frequency constants, and thus make it possible to switch from one channel to another.

Fig. 15 is a schematic diagram of the RF section of an early model Capehart television receiver. There was one pair of coils for the coupling between the antenna and the input to the RF amplifier tube. Another pair of coils coupled the RF amplifier to the mixer tube. And the third pair of coils was a part of the tuned tank circuit for the oscillator.

This circuit is typical of the RF circuits used in many early model receivers, although little used now.

The circuit looks complicated, and it was complicated. It was always difficult to maintain the circuits in adjustment.

The coils were mounted directly on a multi-wafer, multi-pole band switch. The mounting was not nearly so rigid as could have been desired. Moving the receiver from one location to another always risked the possibility the coils would be accidentally jarred from their normal position, and the tuned circuits be thrown out of adjustment.

The exact manner in which coils in tuner circuits, such as the one shown in Fig. 15, were mounted on band switches varied from one model to another. One method which was popular among several manufacturers for several years is shown in Fig. 16. Other manufacturers used different systems.

It is interesting to note the manner in which the coils are mounted on the switch. At predetermined locations on the continuous coil it is soldered to terminals on the switch. Then, when the switch is rotated from one position to another, the active number of coils is changed. Thus, the inductances of the coils is changed.

The exact amount of inductance in any of the

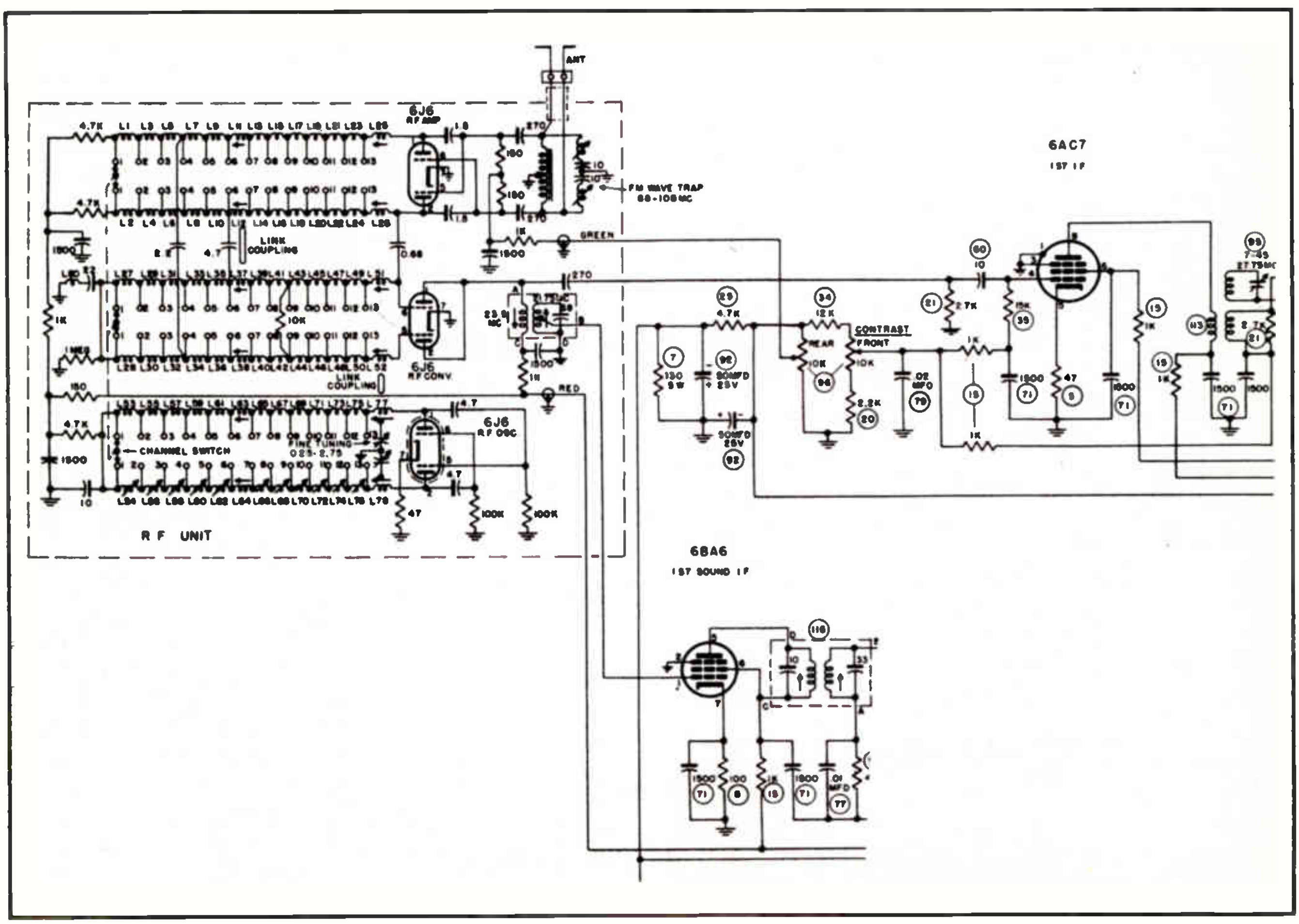

Fig. 15. Front end of early model Capehart.

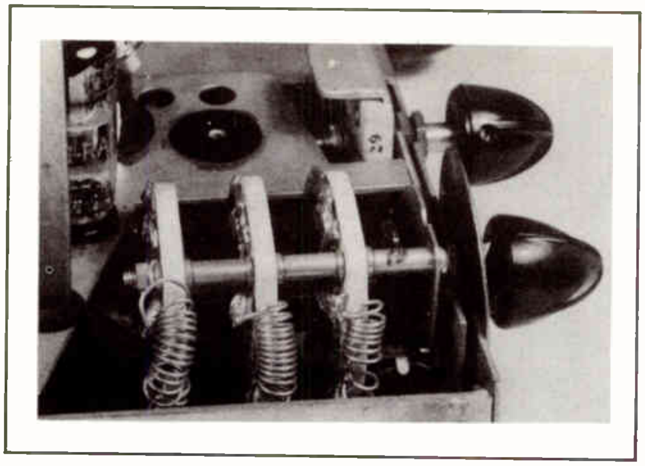

Fig. 16. Band-switching arrangement for Tuned Circuits in early model tuner.

coils at any given time depends on the amount of coil which is actually in the active circuit at that instant.

This type of tuner has fallen into disuse, at least as it was designed during the early days of television. A few manufacturers, notably Motorola, continue to use modified versions of that tuner; but the newer models are greatly improved over the older ones, and are much more reliable.

Section 11. CONTINUOUS TUNERS

Several manufacturers have come up with tuners which could be tuned in much the same way a radio receiver is tuned. Such tuners tune from one channel to another in a smooth continuous manner as the control knob is rotated. There is no abrupt switching from one channel to another.

It is hard to recall which manufacturer was the first to use continuous tuning, but that honor, if there is any honor in it, probably rests with the Hallicrafters Company. They were among the first to advertise the superior results which could be obtained by using continuous tuning.

Hallicrafters used very much the same system they used in their high-frequency communications radio receivers. They had one set of coils for the low-band channels from 2 to 6. Then they switched in a different set of coils for the high-band channels from 7 to 13.

The actual tuning from one channel to another was done by rotating a variable gang-capacitor in a manner almost identical with the practices in high-frequency radio.

It was not necessary for the viewer to switch from one band to another. The band switching was handled automatically as the tuning knob was rotated from the position for channel 6 to channel 7.

A diagram of the tuner section of a Hallicrafters television receiver is shown in Fig. 17.

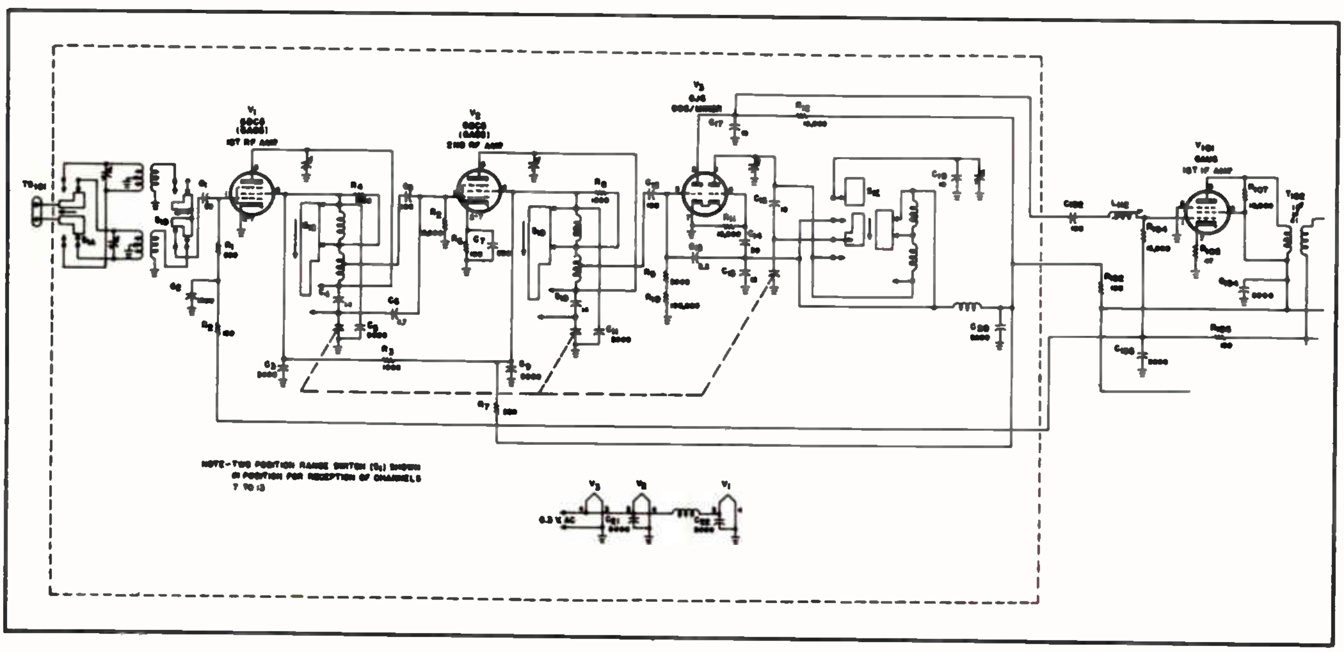

Fig. 17. Continuous Tuner used by Hallicrafters.

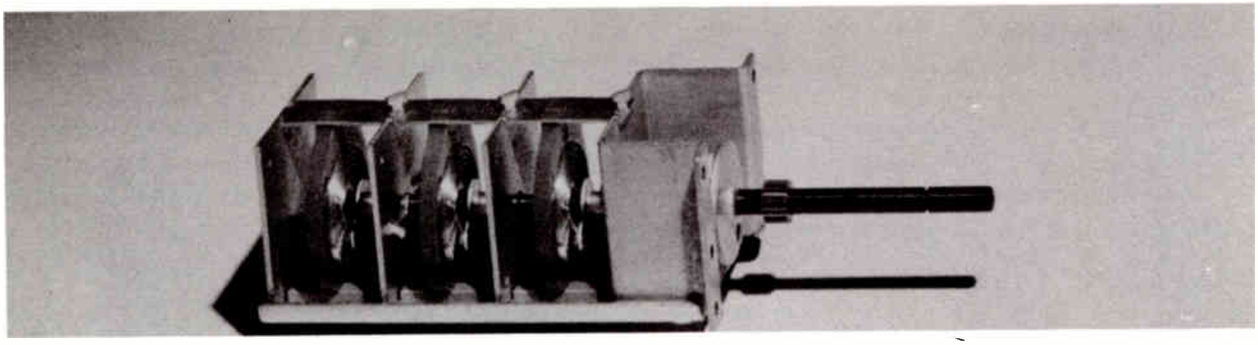

Fig. 18. Three-Gang Spiral Inductuner.

Another, and radically different, type of continuous tuner was developed by P. R. Mallory Company of Indianapolis. The Mallory Company has never manufactured television receivers, but they have always been one of the largest, and best known, manufacturers of component parts for radio and television receivers.

Physical arrangement of the continuous coils on the original Mallory tuner, which they call the *Inductuner*, was shown in Fig. 7 in this lesson. The tuner worked very well, but there were objections to its size and there were demands to make it smaller.

Mallory reduced the size by arranging the spiral inductors into a different shape. They arranged the inductors as shown in Fig. 18.

The inductuner was sensitive, and its continuous tuning features was intended to appeal to persons who had been accustomed to tuning radios. It was installed in many of the finest television receivers ever to reach the market, among them being receivers built by Dumont, Crosley and others.

This tuner was never fully accepted by the receiver manufacturers nor by the general public. Despite all their efforts, the tuner continued to be bulky and heavy. This did not appeal to the manufacturers nor their engineers. Furthermore, its cost remained high when compared with other types of tuners.

The public did not fully approve of the continuous type of tuning. Users were always getting mixed up trying to bring in both the sound and the video at maximum strength, and becoming vexed when they could not do it. No amount of explaining ever convinces users it is impossible to bring in both the sound and video at maximum strength; they do not understand there must always be some sort of compromise.

In those tuners which switch abruptly from one channel to another there is no chance to compare the relative strengths of the signal for the two carriers. Both come in together. Adjustments are made by the service technician when the receiver is installed, and the customer has nothing to do with them. Experience has taught this makes for greater satisfaction among the users.

Section 12. RF INTERFERENCE FROM ANOTHER RECEIVER

It is not generally known that a radio or television receiver can set up electrical impulses which create interference in other nearby receivers. Yet such receiver-generated electrical interference is sometimes one of the most annoying things with which TV servicemen have to contend. At least, such was true of the earlier models.

Receiver engineers have worked hard to eliminate, or diminish, such interference between neighboring receivers. They have had a marked degree of success. Yet such interference is still a real thing in some localities.

It must be kept in mind that the high-frequency oscillator in a television receiver generates a signal which is easily capable of radiating to considerable distances unless it is carefully shielded. If this generated signal gets into the antenna circuit it is capable of radiating with sufficient strength to carry long distances.

Something of the manner in which this can

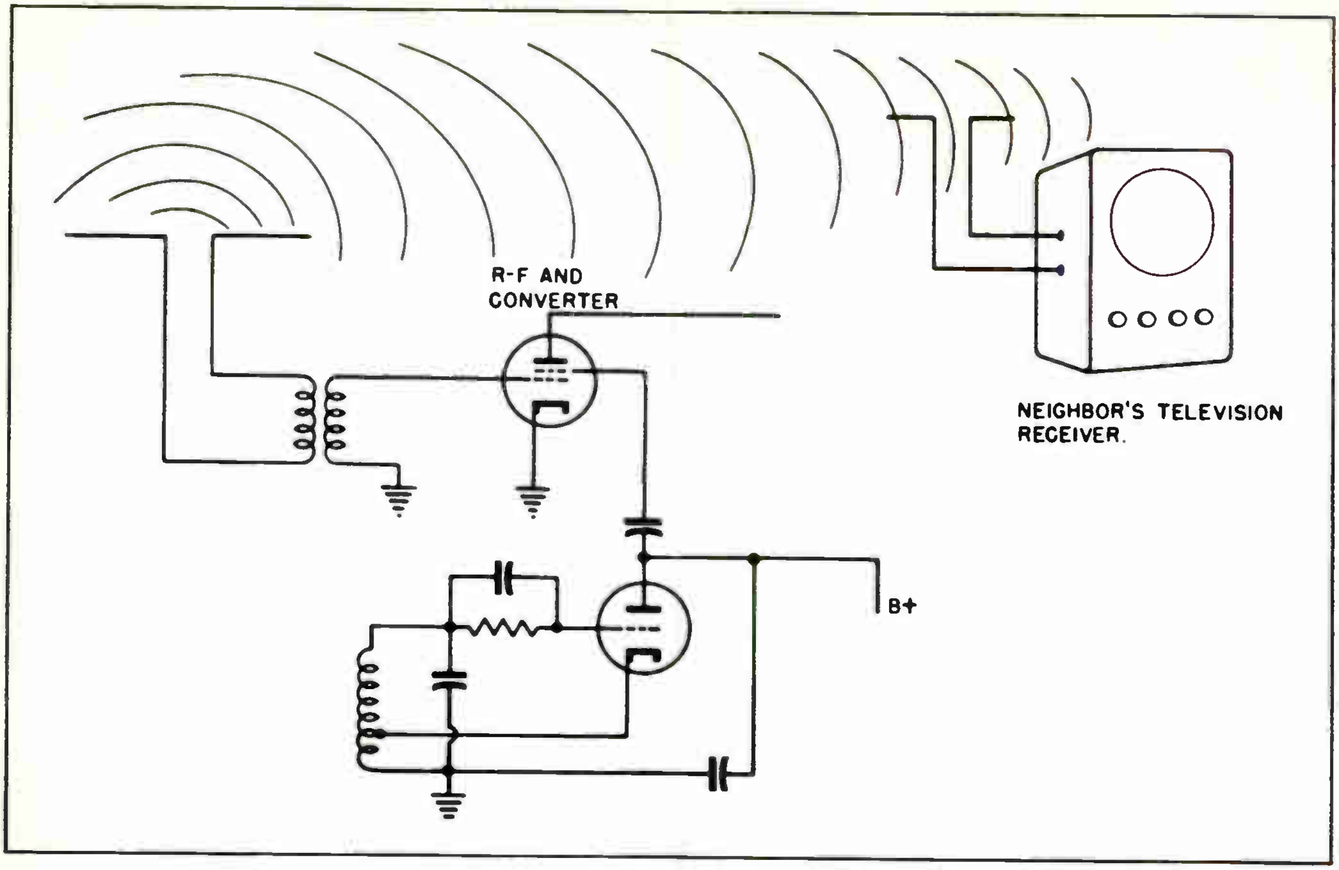

Fig. 19. TV Oscillator can create interference in neighboring receiver.

be done is illustrated in Fig. 19. The action is somewhat exaggerated in the diagrammed illustration since a circuit of this type is not likely to be found in a modern receiver. Nevertheless, the manner in which the signal can reach the antenna is shown in fairly accurate general outline.

It has become almost universal practice in TV receiver design to use an RF amplifier between the antenna circuit and the converter tube. Presence of the RF amplifier is quite effective in isolating the antenna from the oscillator circuit and the antenna, so very little signal from the oscillator can reach the antenna.

The present tendency toward higher I-F frequencies moves the oscillator signal frequency much farther away from the RF carrier frequency. When the oscillator frequency is 41 to 45 megacycles different from the RF carrier signal the oscillator signal is often completely outside the range of frequencies which nearby receivers can receive. Thus, even should the oscillator signal be radiated from a receiver, it will cause little interference because it is outside the range of frequencies to which neighboring receivers are sensitive.

More careful, and more adequate shielding of the tuner section and its oscillator circuits has helped reduce interfering radiation. The RF and oscillator section in a receiver, such as that shown in Fig. 16, has little or no shielding. Signals generated in the oscillator circuits can easily find their way to the antenna, and thus be radiated. Where the oscillator circuits are carefully shielded, as in Fig. 1, radiation is radically reduced.

Radiation interference from a nearby television receiver creates a characteristic pattern on the screen and picture of a receiver. Vertical, or slanting, wavy lines, like those in Figs. 20 and 21, show up on the screen to interfere with the picture.

Sometimes the interference lines are quite faint. This is when the interfering signal is from a distance, or is weak. On other occasions it can be so strong as to ruin the picture.

Sometimes the lines will slant to the upper

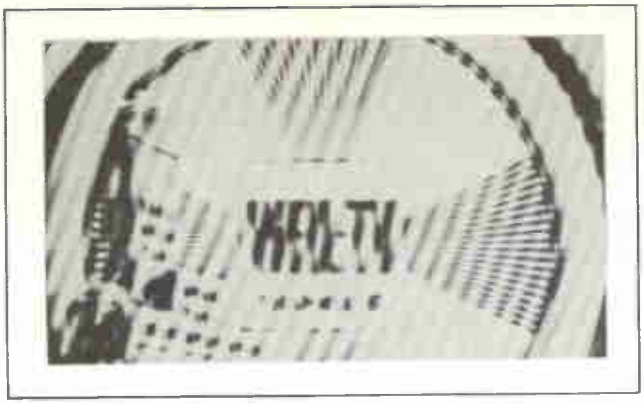

Fig. 20. Pattern caused by interference from nearby receiver.

right, as in Fig. 20. Other times they will slant toward the upper left, or straight up and down. It is not at all unusual for the lines to slant one direction for a short time, then change over to slant in the other direction. The exact slope of the slanting lines, and the number of them, depend entirely on the frequency of the interfering signal.

The lines are actually light and dark areas on successive lines of the picture which are made by the beat signal which results from heterodyning the signal frequency with the interfering frequency.

Interference patterns of this general nature can be created by nearby FM receivers as well as by television receivers. FM radio broadcast stations also are troublesome if the TV receiver is located near the transmitter.

Early model TV receivers were much worse offenders than modern receivers. Well designed modern receivers rarely radiate sufficient signal to cause any noticeable interference. Nevertheless, a good serviceman should be thoroughly familiar with such interference so it will be recognized if it becomes troublesome.

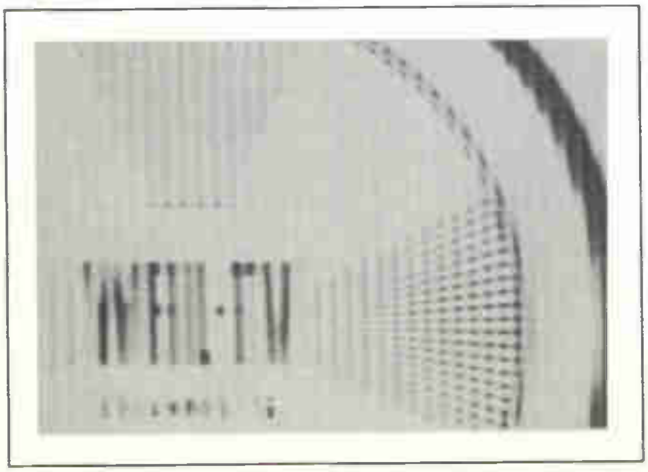

Fig. 21. High-frequency interference from nearby receiver.

Section 13. TRAPPING OUT INTERFERENCE

If the interference is sufficiently strong to be annoying there is only one effective way to get rid of it. That is to trap it out before it reaches the tuner of the receiver with which it is interfering.

Of course, if the offending receiver can be located, it is often possible to shield it in some manner so it will no longer radiate. But often it is much more difficult to locate the offender than to protect against it.

Usually the most effective trap is a stub of transmission line connected directly to the terminals of the receiver where the transmission line from the antenna is connected. The trapping stub is merely a short piece of transmission line which is connected to the antenna terminals of the tuner at the same place where the transmission line is connected. The manner of connecting the stub is shown in Fig. 22.

A short piece of transmission line, such as that shown, becomes a resonant circuit at *some* frequency. This means the length of the stub is a critical matter, and the length must be such that it will resonate at the frequency of the unwanted interfering signal.

There is not sufficient space in this lesson to describe the electrical properties of a short resonant line, such as the stub described here. An entire lesson will be devoted to the peculiar properties of very high frequencies, and to wave-trap stubs such as the one described here. But the manner of using the stub can be mentioned so you can become acquainted with the fact such wave-traps exist, and are used.

The wave-trap can be short-circuited at the end, instead of permitting it to remain open. That is often done. But the length of the line will be different when the line is short-circuited.

When the practical serviceman is faced with the problem of an interfering signal he often

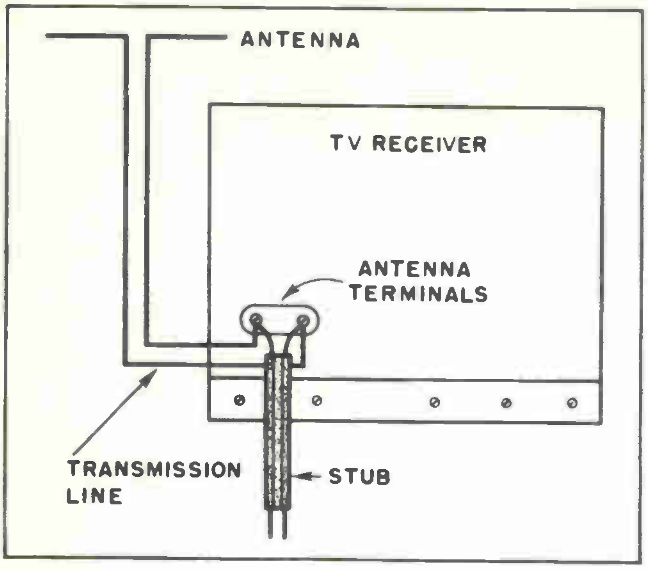

Fig. 22. Connecting a wave-trap stub to antenna terminals of receiver.

connects a piece of transmission line to the antenna terminals of a receiver as shown in Fig. 22. Most often he does not know the frequency of the interfering signal, thus cannot calculate the exact length of the wave-trap stub.

Instead of trying to calculate the length, he merely cuts the stub to a length greater than he thinks is needed. Then he takes a pair of heavy scissors, or tin snips, and methodically snips off the end of the stub a little at a time until the interfering signal disappears. Usually such a practice is faster, and more practical, than attempting to calculate the exact length.

Another method which is used by some servicemen to attenuate an interfering signal is to wrap a piece of tin foil around the transmission line a short distance from where it is connected to the terminals of the receiver. The tin foil changes the characteristic impedance of the transmission line at the location where it is wrapped around the line.

Then the tin foil is moved up and down the line until the interference pattern disappears from the screen of the receiver. When the interference disappears the tin foil is fastened to the line at that location.

Using a piece of tin foil in this manner is quick, easy and convenient. Usually it will work.

But it does not always work. Sometimes the interfering signal is so strong it cannot be attenuated in this manner. On other occasions the presence of the tin foil changes the characteristic of the transmission line to such an extent that it interferes with some other signal the user desires to receive. Sometimes a metal paper clip will act in a similar manner if the clip is made from the right kind of metal.

Section 14. RADIATION FROM RECEIVER CHASSIS

Experience has shown that the nature of high-frequencies generated by the oscillator in a TV tuner is such that they often get into the metal chassis of a receiver, then radiate from the chassis itself.

Advanced receiver design usually employs a short piece of co-axial line between the output of the mixer tube and the input to the I-F circuit to carry the signals which are present. The co-axial line couples the signal from the mixer to the I-F amplifier, but prevents it getting into the chassis. Keeping the RF signals from the chassis prevents the flow of RF currents in the chassis, and thus reduces radiation from that source.

Section 15. TUNER INPUT FILTER CIRCUIT

RF carrier signals used in television operate above 50 megacycles. Since this is true there is no reason why tuner input circuits of a TV receiver need be sensitive to frequencies lower than 50 megacycles, or be capable of passing them. Exclusion of all frequencies below 50 megacycles automatically excludes many interfering frequencies which would create undesirable effects if permitted to reach the receiver circuits.

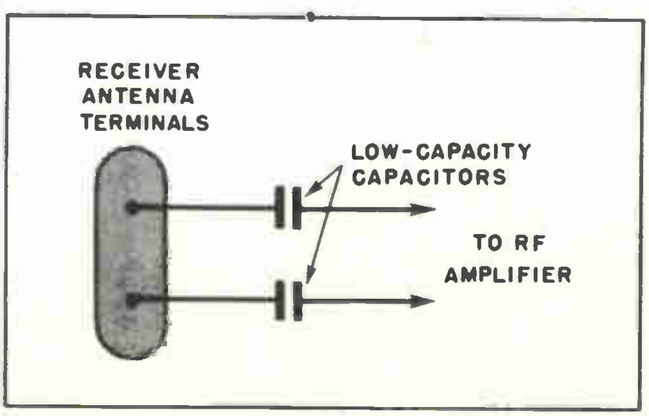

Fig. 23. Tuner Input Filter

An input filter consisting of a pair of low-capacity capacitors in the transmission line connecting the antenna terminals with the RF amplifier is shown in Fig. 23. The exact value of the capacitor used for this purpose varies from one receiver to another, but one value used in a number of receivers is 470 mmfd.

An input filter which cuts off quite sharply just below 50 megacycles, or just below the frequencies for channel 2, consists of the capacitors coupled with an inductance. A circuit diagram of such a filter is shown in Fig. 24.

By careful design a circuit like the one shown in Fig. 24 can sharply reject all frequencies below 50 megacycles, but permit those above 50 megacycles to pass into the RF amplifier circuits. Frequencies below 50 megacycles are shunted from one side of the line to the other through the inductance, and are prevented from reaching the RF circuits. Those above 50 megacycles are too high to pass through the inductance, but pass readily through the capacitors. Thus TV signal frequencies are free to reach the RF amplifier, but the lower noise frequencies are kept out.

It should also be remembered that the FM broadcast band occupies the radio spectrum between 88 megacycles and 108 megacycles. FM broadcast signals are often strong, and usually it is highly desirable that they be excluded from the RF amplifier of a TV tuner.

To prevent FM broadcast signals reaching the RF amplifier in a TV tuner some tuner manufacturers install a wave-trap, or band-cutoff filter, between the high pass filter and the RF amplifier. Such wave-trap, or band-cutoff filter, is designed to exclude all frequencies between 88 and 108 megacycles.

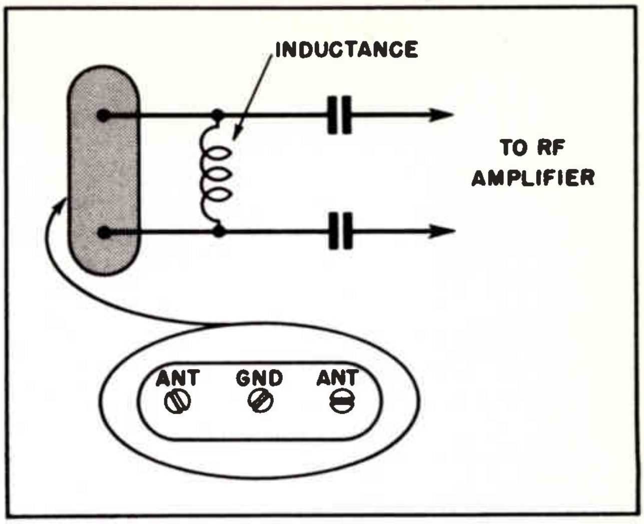

Fig. 24. Tuner Input Filter using Inductance and Capacity.

A wave-trap of this type serves other purposes besides that of excluding the FM broadcast signals. It helps reject signals which would set up image interference. Image frequencies from signals on channel 2 are especially, and effectively attenuated by the action of the wave-trap.

In appearance, these filters and wave-traps are quite small, and apparently insignificant. Remember, the capacity of the capacitors is quite small, since a very small capacity is adequate for the frequencies which pass through the circuits. For the same reason, the inductances involved are also quite small. The entire filter network can be easily mounted on a single terminal strip, or may occupy only a very small space inside the chassis of the tuner.

The sequence in which the signals pass through the filter and wave-trap is shown in Fig. 25. Some tuners arrange the trap and filter in some other sequence.

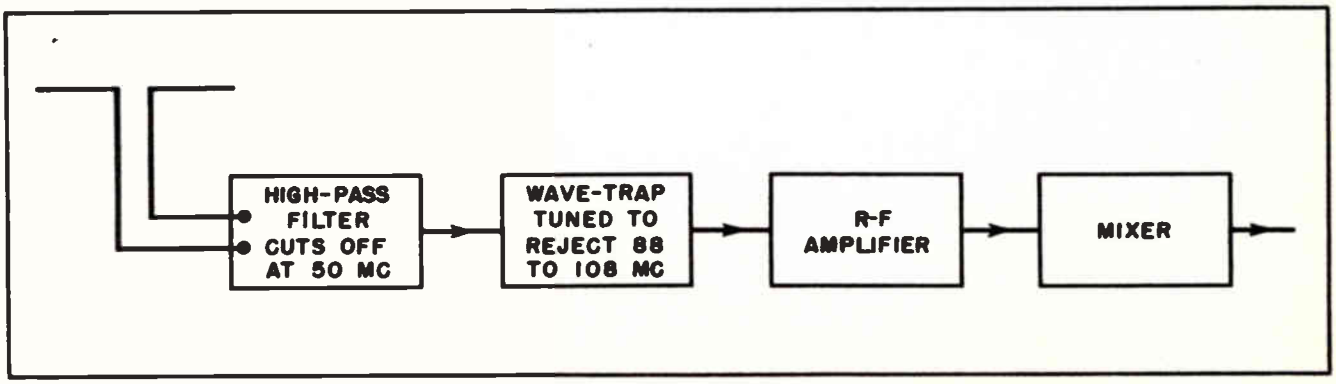

Fig. 25. Filters through which TV signals pass before reaching RF Amplifier.

Section 16. USABLE SIGNAL STRENGTH LEVELS

From time to time engineers and others have come up with figures which they assert are the minimum levels at which TV signals are usable. TV users continue to scoff at those figures, and proceed to bring in TV pictures where the engineers insist such reception is impossible.

A definition of what constitutes a minimum picture is one that varies with the individual involved. Persons living in a strong signal area, and accustomed to clear sharp pictures, have one set of standards. Those living in remote fringe areas have other standards.

It is a peculiar thing, yet we know it is true, that TV reception which is entirely acceptable to a group of people living in a remote fringe area would be completely unacceptable to a person accustomed to reception in a strong signal area.

Ambient noise level also has a strong determining influence on the usability of a TV signal. A signal which might be completely smothered in the ambient electrical noise at one location may be sufficiently strong to bring in an acceptable picture at another location equally distant from the transmitter, and where the signal itself is no stronger. (Ambient is nearby or surrounding.)

A rule-of-thumb estimate of what the signal strength should be is that the signal-to-noise ratio should be approximately 30 to 1. This means the RF signal peak-to-peak voltage should be approximately 30 times as strong as the RMS voltage of the ambient electrical noise.

Since there is a distinct difference in the ambient noise level in cities and that which is found in rural areas, it follows that a much stronger signal is normally needed in a city to over-ride the noise level than is needed in a rural area. This is the reason an acceptable signal can often be picked up on a farm which is remote from the broadcast station, whereas the same station may not be picked up in a small city a short distance from the farm, and equally distant from the transmitter.

It has been found that an acceptable picture can be obtained in a rural area with a signal strength of 200 to 600 microvolts at the antenna, if the ambient noise level is low. The exact amount of signal voltage depends on the amount of noise introduced by the RF amplifier of the receiver.

At the other extreme, in cities, where the ambient noise level is high, an antenna signal strength amounting to as much as 5 millivolts to 50 millivolts may be necessary.

Section 17. TROUBLE IN THE TUNER

Tuner trouble makes itself known in several ways, depending to a large extent on the exact nature of the trouble.

If all stations but one, or all stations but two, come in sharp and clear, it is reasonable to suspect the tuner. The fact that some stations are picked up, and signals from them pass through the following sections of the receiver, justifies the assumption those circuits are working properly for all stations. Therefore, the fact some stations do not come in properly points to trouble in the tuner.

A tuner may work perfectly on one channel, or two channels, or on several channels, yet not work on one or more others. The reason why this is true can often be traced to a defect in some part of the circuit which is used during the reception of that particular channel, but not used during the reception of other channels.

Excessive snow on the screen of the picture tube usually points to trouble in the tuner. The trouble is certain to be in the tuner, or in the transmission line or the antenna. Excessive snow clearly indicates the signal is not strong enough at the RF amplifier to over-ride the level of the ambient electrical noise.

Snow in the picture very often means the RF amplifier, or mixer-oscillator tubes are weak. Replacing those tubes often clears up the trouble without further adjustment.

When the receiver picks up some stations, but not others, it may mean the oscillator tube is getting weak. The tube may work at some frequencies but not at others. The quickest and easiest way to check on such suspicion is to replace the existing oscillator tube with another one known to be good. If the new tube brings in all stations it is a good sign the old one was not oscillating on some of the frequencies.

It is not at all uncommon for an oscillator tube, which is reaching the end of its usefulness, to continue to work on lower frequencies, but not work on higher ones. It is little use to check such a tube on a tube tester, since a tube tester does not indicate whether a tube will oscillate.

If high-frequency channels and low-channels can be received, but not some channel in between, it may mean there is some defect in the circuits connected with the channel which cannot be received, or it may mean the oscillator for that channel is off-frequency.

This matter of an oscillator circuit for one channel getting off-frequency is not an unusual one. Any of several things can occur to disturb the frequency of the oscillator for any given channel. The exact nature of the defect often depends on the type of tuner, and the manner in which the oscillator frequency is determined.

Most turret-type tuners adjust the frequency of the oscillator by changing the inductance of the oscillator coil. That is usually done by moving a powdered iron core into the coil, or out of it. The actual moving of the core is normally accomplished by screwing it into the coil form, or screwing it out. The actual adjustment is usually done by inserting a screwdriver into the slot provided for that purpose.

It is possible for that iron core to be jarred from its proper position by a hard bump, such as sometimes happens when a receiver is moved. More often, the coil gets out of adjustment through experimentation by a "screwdriver happy" mechanic. Some people cannot resist the temptation of twisting anything that can be turned by a screwdriver.

All of which means that when a mid-frequency channel fails to come in, but those above it and below it come in all right, one should check the adjustment of the oscillator for the channel which cannot be received. In some cases it is even necessary to remove the old oscillator strip and insert a new one. Fortunately, such strips are readily obtainable for most kinds of turret-type tuners. Most radio and TV supply houses carry them in stock.

If there is anything seriously wrong with the mechanical condition of a tuner, or the electrical trouble is of such nature that it is difficult to locate, one is always justified in replacing the existing tuner with a new one.

If the trouble is definitely traced to the tuner, and it is clear the trouble results from a mechanical defect, it is usually better to replace the tuner than try to repair it.

There are several reasons for this advice. The tuner is a delicate part of a TV receiver, it is easy to get out of adjustment, especially during repairs. Regardless of the care one takes to do a good job repairing the tuner, it may happen that circuit constants are changed to such extent it will no longer work properly.

Sometimes repairs may be satisfactory temporarily, then recur. Such recurrences are always provoking to the owner, and the owner is inclined to blame the serviceman who repaired the tuner.

All in all, it is better policy to replace a tuner than to attempt to repair one.

Replacing a tuner is expensive for the custom er, but it is much easier for the serviceman than attempting to repair the old one.

Fortunately, modern TV tuners are reaching such a high degree of perfection they give relatively little trouble. Considering all the things which could go wrong with a tuner it is always surprising just how little trouble modern tuners actually give.

NOTES FOR REFERENCE

TV tuners can be grouped into three general classes; those which change channels by means of a ganged-wafer switch, those which use rotating turrets, and those which employ continuous tuning like radio receivers.

The Standard Coil Products tuner is used in more television receivers than any other tuner. In fact, it is used in more receivers than all others combined.

Most receiver manufacturers prefer to buy tuners from companies which specialize in such manufacture than to make tuners themselves.

If there is anything seriously wrong with a TV tuner, other than the need to replace a tube, it is usually advisable to replace it rather than attempt to repair it.

Most TV tuners consist of an RF amplifier stage, a mixer stage and an oscillator.

The 6J6, a twin-triode, is commonly used as the oscillator-mixer tube in TV tuners.

Most VHF tuners employ at least one stage of RF amplification ahead of the mixer stage. *This is not true of UHF tuners.*

An RF amplifier stage aids selectivity, reduces radiation from the oscillator, improves the signal-to-noise ratio, and makes for greater sensitivity.

The RF stage in a TV tuner does not provide so much gain as a comparable stage in a radio receiver.

The higher frequencies at which a TV RF amplifier works, the great band-width of frequencies it must pass, and the types of tubes which are available hold the maximum gain to about 10 to 20.

It is necessary for the input impedance of the tuner to match the characteristic impedance of the transmission line.

Most TV tuners are designed so that they can be matched to the impedance of a 300-ohm transmission line or to the impedance of a 75-ohm line. These two impedances are the ones most widely used in TV receiver systems.

Where outside noise levels are high it is often advisable to use a coaxial transmission line between the antenna and the tuner.

Many types of tuners are so designed that a different set of transformer coils are used for each channel.

Tuners which use a different set of RF transformer coils for each channel usually have a different set of oscillator coils for each channel. Some old model Zenith tuners have the RF coils and oscillator coils mounted on the same strip.

The RF transformer coils and the oscillator coils for the various channels in a Standard Coil Products tuner are mounted on a rotating drum, which is commonly called a "turret."

The RF amplifier tube in a TV tuner may be a pentode, or a triode, or a twin-triode connected in a special type of circuit called a *cascode amplifier*.

When a pentode is used as the RF amplifier in a TV tuner it is usually a 6CB6, or a 6BC5, or a 6AG5 or some other tube with similar characteristics.

Twin-triodes used in cascode amplifiers in TV tuners are usually a 6J6 or a 6BK7 or a 6BQ7 or a 6BZ7 or some other tube having similar characteristics.

The term *sensitivity* is used to describe a receiver's ability to pick up weak signals.

Sensitivity of a receiver is usually controlled by the signal-to-noise ratio of the first RF amplifier.

Electrical noise which interferes with the reception of TV signals can be created outside the receiver by neon signs, fluorescent lights, electrical appliances and other electrical sources, both natural and man-made.

In addition to external electrical noises the amplifier tubes themselves generate a certain amount of electrical noise.

Electrical noise generated inside a vacuum tube consists of *thermal* noises resulting from the application of heat, *shot effects* noises resulting from the random flow of electrons from the cathode to the anode, and *microphonic* or mechanical noises resulting from tiny movements of the tube elements which affect the amplification factor of the tube.

All amplifier tubes generate electrical noises, but only those used as low-level amplifiers have any material effect on the sensitivity of the amplifier in whose circuits they are used.

Tubes with few elements, like the triode, generate fewer noises than multi-element tubes like the pentode. The pentagrid converter generates more internal electrical noise than any other amplifier tube.

In RF amplifier service the *cascode amplifier* has been found to have greater amplifying ability, and a better signal-to-noise ratio, than pentodes or other tubes which can be used for that purpose.

When the electrical noise at the first RF amplifier of a TV tuner is strong, compared with the signal voltage, the screen of the picture tube is speckled with white interference spots which are commonly referred to as "snow."

The grounded-grid amplifier consists of a triode tube whose grid is connected to ground. Such arrangement effectively shields the input circuit from feedback through inter-electrode capacitance from the output circuit.

A grounded-grid triode amplifier does not possess the gain of one connected in the conventional manner. Lack of gain results from degeneration.

Contrary to the practice in radio work, the mixer stage in TV tuners often uses a triode.

Tuners which use cascode RF amplifiers have much greater sensitivity than similar tuners which employ pentode RF amplifiers; but, the cascode type tuners cost considerably more than the pentode type tuners. Because of this fact tuners using pentode RF amplifiers remain nearly as popular as the more sensitive cascode tuners.

Oscillator circuits of a Standard Coil Co. tuner can be adjusted from the front of the receiver without removing the chassis from the cabinet, or removing the back panel from the receiver. This adds to the popularity of Standard Coil tuners.

The oscillator for each channel of a Standard Coil tuner can be adjusted separately. The tuning knob of the receiver is rotated to the channel to be adjusted, then a minor screwdriver adjustment is made to the oscillator slug through a hole behind the escutcheon plate.

When the tuning knob of a Standard Coil tuner is rotated to a given channel the oscillator slug controlling the frequency for that channel is automatically positioned behind the hole for the adjustment. This makes it a simple matter to adjust the oscillator frequency for each channel while the pattern on the screen is observed.

Experience has shown it is unwise to mount the speaker on the chassis of a TV receiver. Vibrations from the speaker set up microphonic conditions in the tuner tubes, and cause erratic operation of the receiver. Modern receivers rarely have the speaker mounted directly on the chassis, but many older ones do.

Continuous type tuners, which the user tunes through the various channels in a manner similar to tuning radio receivers, have been developed by several manufacturers. They have not proven as popular as other types of tuners.

Because the video carrier comes in on one frequency, and the sound carrier comes in on another frequency 4.5 megacycles away, some users find it difficult to adjust their continuous tuners to a compromise between the two frequencies. Their inability to bring in both the sound and video at maximum strength tends to irk them, and they think there is something wrong with their receiver. This is particularly true if the receiver uses dual-channel I-F amplification.

It is impossible to bring in both sound and video signals at maximum strength on any TV receiver; but when the tuner is switched abruptly from one channel to another the user is not aware of that fact.

Interference from a nearby FM receiver, or another TV receiver creates a distinctive pattern on the screen of the TV receiver.

Symptoms of interference from another receiver does not denote anything wrong with the receiver in which the symptoms are present. Interference can often be reduced or eliminated by special types of wave-traps.

The most common type of wave-trap for trapping out interference from a nearby receiver is a *tuned line* consisting of a short piece of transmission line connected to the antenna terminals of the TV receiver. The length of the *tuned line* wave-trap is critical for the frequency to be trapped out.

Practical service technicians usually find the correct length of the *tuned line* by first connecting a piece of transmission line they know is too long, then cutting it off piece-by-piece until the correct length is found.

Early model TV receivers were chronic offenders by radiating interference signals throughout the neighborhood. Improved designs, and better shielding in newer models have reduced such interference.

To reduce electrical noise, and other types of interference, it is a common practice to insert a high-pass filter and wave-trap in the line from the antenna to the RF amplifier. Such filter keeps out the lower frequencies which cause interference.

Ambient noises and electrical disturbances, referred to in this lesson, means those noises and disturbances close by, in the vicinity, or in the surroundings.

NOTES

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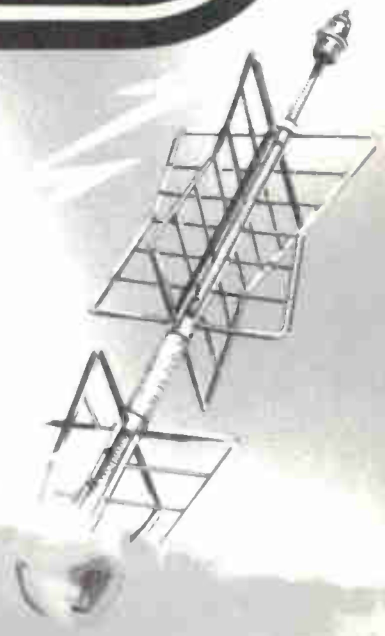

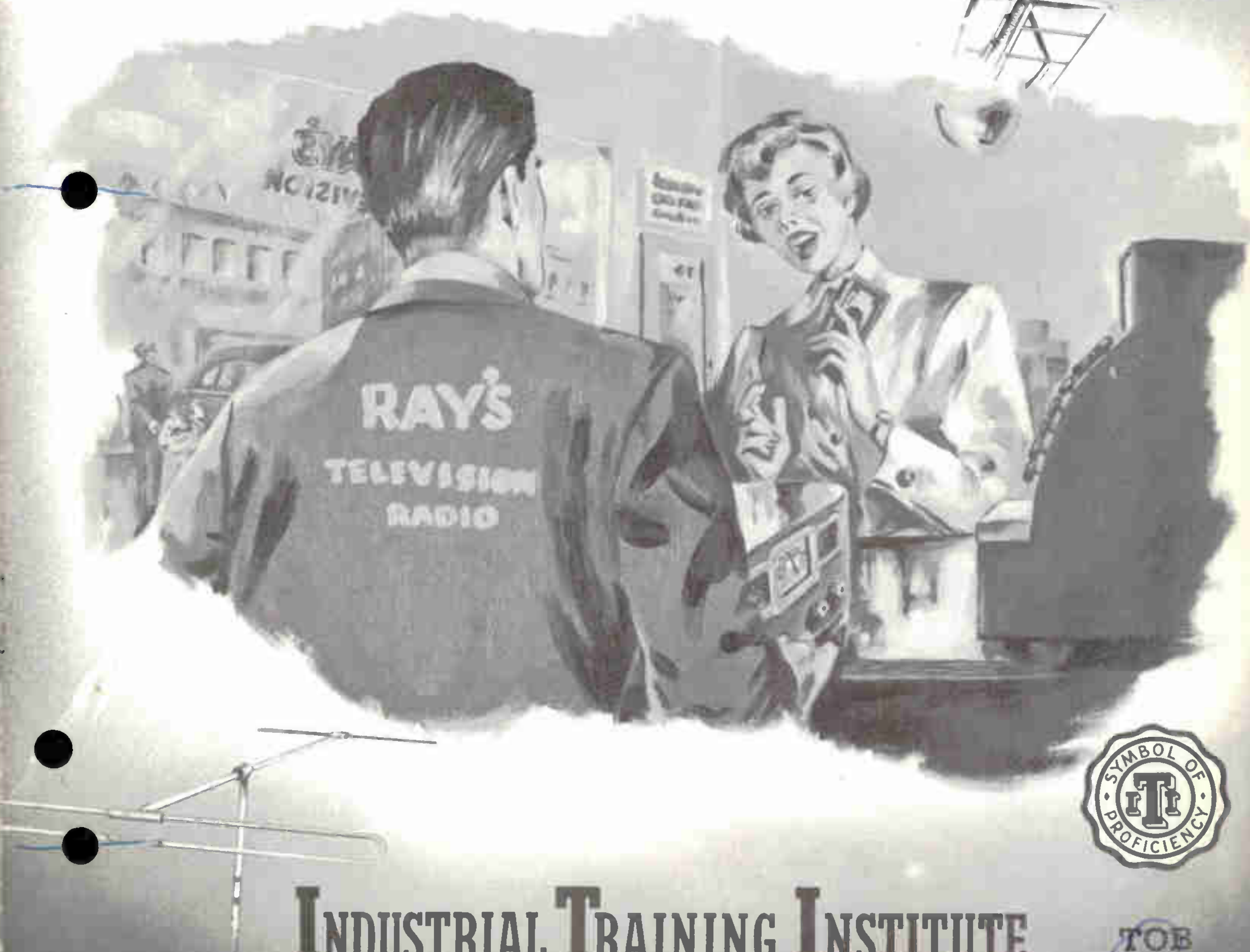

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RADIO TELEVISION

DECIBELS

Contents: Introduction - Definition of a Decibel - The Basic Reference Level - Decibels and Logarithms - The Characteristic and the Mantissa - How Decibels are Calculated - Some Practical Examples of Decibel Gain - Practice Problems - Notes for Reference.

Section 1. INTRODUCTION

In one of our lessons not long after the beginning of this course we explained to you that the human ear does not respond to sound levels in a linear manner. By this we meant that while the ear may detect the changing of the level of sound produced by a loudspeaker when the power applied to the loudspeaker is changed from possibly one watt to two watts, there is a strong possibility the ear would not detect any change in the sound level if the power is changed from 19 watts to twenty watts. In each case the amount of power applied to the loudspeaker is changed by one watt. But while the ear will readily note the change in one instance, it cannot do so in the other.

Somewhat later in our course we went another step and explained to you that the eye responded to light changes in much the same manner. When there is little incident light, such as we find on a dark night, the striking of a match can be detected at a great distance. But in daylight we would never detect the striking of a similar match unless the match were quite close and we happened to be looking right at it.

All of us are fully aware of these things even though we may never have taken the time to actually think about them nor tried to figure out the reason why such things should be true. If we did take the time to really think about them we would soon realize they are another of Nature's wonderful protective

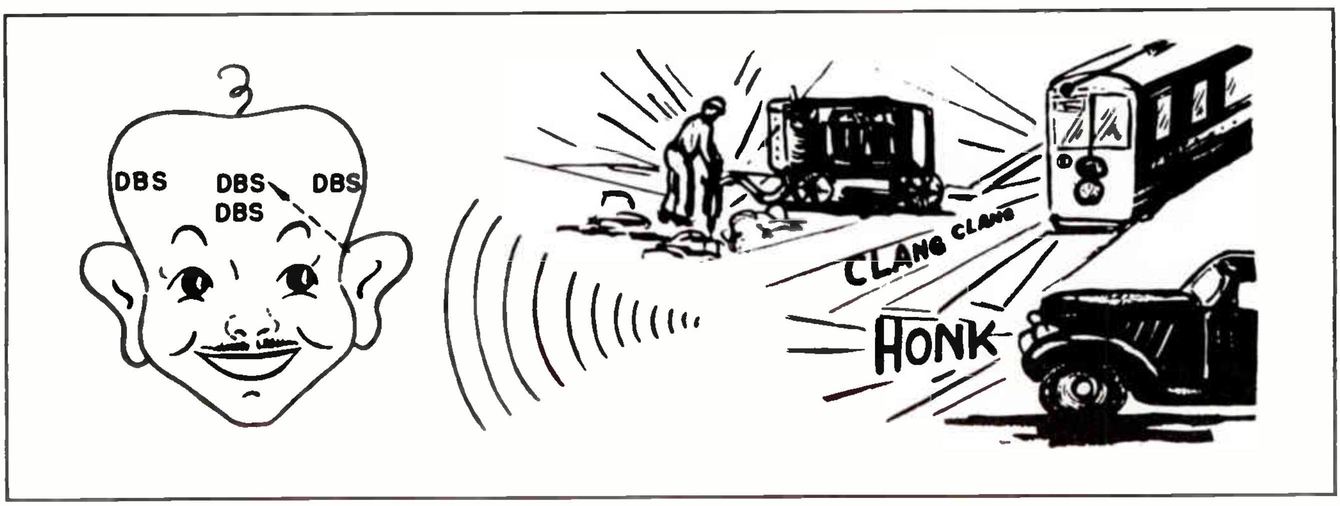

Fig. 1. We Hear in Decibels.

measures. Unless our ears and eyes did respond to sound and light levels in this manner, neither of them would be much good to us. Possibly that is putting the matter just a bit strong, but it is undoubtedly true that unless our eyes and ears did respond in the manner mentioned here, their usefulness to us would be radically reduced.

When there is very little sound present, our ears are able to detect a very slight noise. The old saying that "It is so quiet you can hear a pin drop" is not far from the literal truth. When things are very quiet, a barely whispered word can be detected and understood by a normal pair of ears. Yet in the presence of considerable noise you would probably have to shout to make the same person hear you. What this means is that as the noise or sound level rises it is necessary to increase the sound disproportionately in order for a pair of normal ears to detect the additional sound. This peculiar property of the human ear makes it possible for it to detect and hear very faint noises when the average level of sound is low. We can say it gives the ear sensitivity, yet at the same time the ear is able to protect itself from injury when the sound level is high.

Very much the same thing is true of the eye. It is very sensitive to low levels of light when the general level of illumination is low, yet within limits it is able to observe very high levels of illumination without damage to itself. To put this in other words, the eye is able to observe the illumination given off by the striking of a single match or that of a single lightning bug so long as the night is dark; yet, when the general illumination is multiplied more than a million times by the light from the sun, the eye is still able to function properly without being damaged by the enormously increased amount of light.

Scientific investigators have found that the eye and the ear respond to changes in the general level of illumination or of sound in a manner that follows a logarithmic curve.

A number of years ago radio and sound engineers found it necessary to create a new unit of measurement by which to measure the differences in the level of a sound or the difference in the level of the electrical power which created the sound. They, of course, had the older units of measurement such as the volt, the ampere and the watt. All of these were standard units, and they were constantly used in ordinary electrical work. But the time came when it became necessary to measure power levels and sound levels by some unit which would instantly tell those interested just how those levels would affect the human ear. It was not enough for an engineer to know that by changing the design of a circuit he could obtain perhaps five additional watts from it. The important thing was not how many additional watts of power could be obtained but how that power would affect the listener.

For example, he might be able to place a wattmeter or a voltmeter across the output of an amplifier which was feeding a loudspeaker and be able to satisfy himself by the meter readings that the power into the loudspeaker had been increased by some five or ten watts. But his ear listening to the loudspeaker might be unable to detect any difference in the sound level.

And to carry this illustration another step further, the engineer might have placed his voltmeter or his wattmeter across the output of some other amplifier feeding another loudspeaker and found that there a change of as little as two or three watts would be readily noticeable.

The difference, of course, would result from the fact that the first amplifier would be already feeding a lot of power to the loudspeaker and the addition of five or ten watts was not sufficient to affect the output to the extent that it was noticeable to the listener. In the second example the original output was probably only one or two watts to begin with, so that the addition of two or three watts was a comparatively large amount, and was readily perceptible.

The need for a new unit of measurement became so urgent that electrical, radio and sound engineers finally created a new one. It was a unit that would tell instantly whether or not a change in the voltage or power in a circuit was enough to be perceptible to the human senses, particularly the ear. The new unit was called a *decibel*.

The decibel provided a simple method of measurement of how the output of an amplifier would sound to the human ear. It is always important for the radio, television and sound technician to know this. A thorough knowledge and understanding of volts, amperes and watts is not enough, for the simple reason that the human ear does not hear in any of those units. The ear hears in decibels.

It is interesting to note that the original unit was the *bel*, and was named for the inventor of the telephone, Alexander Graham Bell. It was first used by the engineers of the telephone companies. But it soon became evident that the *bel* was somewhat too large for convenient use, so the *decibel* quickly became the more commonly used unit. The decibel means one-tenth of a bel, which is another way of saying that the bel is ten times as large as the decibel. In our work we use the *decibel* so much and the *bel* so little that many of us almost forget there is such a thing as a *bel*.

the difference in the sound to be perceptible. In that case, 1 decibel would represent a considerable increase in the power. The important thing is that the decibel does not measure the change as being a change of so many watts. It measures the change in the effect it has on the human ear, and thus tells those interested whether or not the change can be detected by the ear.

In some cases it might be desirable to measure the effect in decibels that would result from an increase in the power to an amplifier. As an example of this, the owner of a radio or television receiver might request some change to be made in the receiver so that a greater volume could be obtained

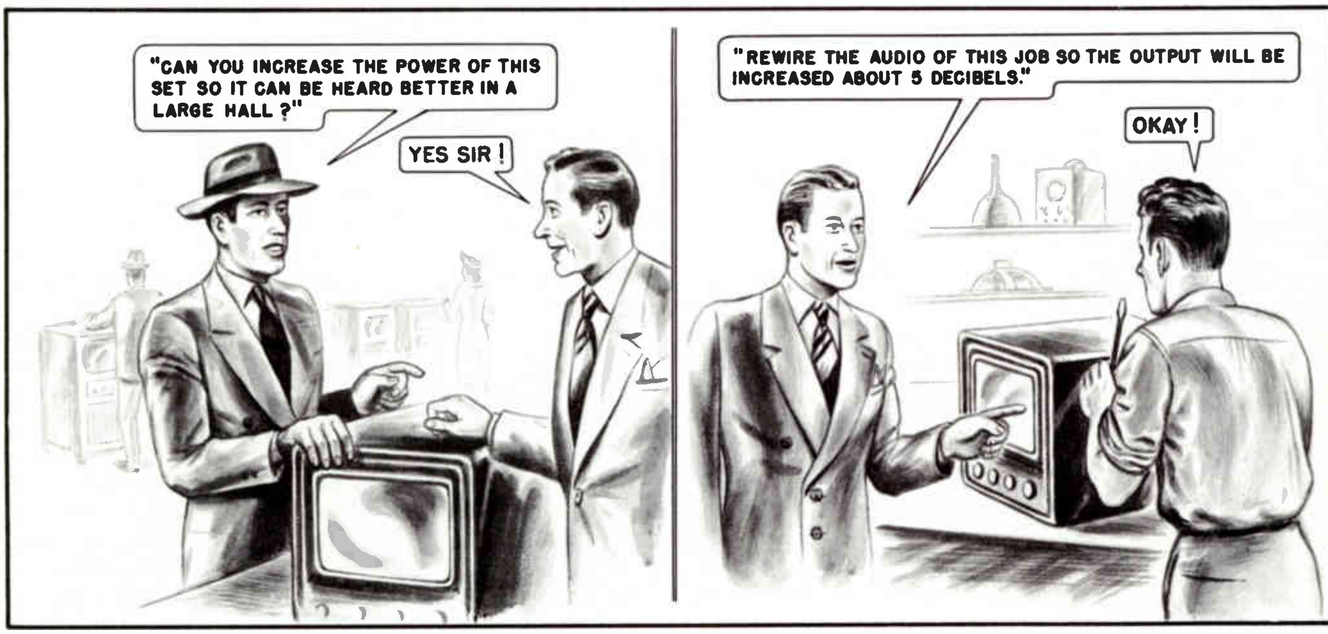

Fig. 2.

Section 2. DEFINITION OF A DECIBEL

The best definition of a decibel is that it measures *that change in the level of sound which is just perceptible to the human ear.*

This means that any change in the level of sound that is just perceptible to the human ear amounts to one decibel. If the sound level is low, a very small increase in the power applied to a loudspeaker could be detected by the human ear. Thus at low levels, 1 decibel increase in the volume of sound would represent only a very small increase in the power.

On the other hand, if the level of sound is high it would take a considerable increase in the power to the loudspeaker for

from it, or it might be that the owner wanted to feed the power into a public address system. You could go to work and figure out the possibilities of installing new types, or different types, of tubes in the receiver, and thus be able to obtain more watts of power from the receiver. Your meters and other instruments might tell you that you were actually obtaining considerably more power output from the loudspeaker. But unless the owner of the receiver could *hear* a greater output you would probably have a hard time convincing him the increased power was there.

The point is this: The actual number of watts you increased the power would be relatively unimportant unless you had actually increased the number of decibels of output. By having a good understanding of decibels you would be able to determine ahead of time whether the change you intended to make would improve the output of the receiver enough for it to satisfy the customer.

But the use of the decibel is equally important in determining losses of power. An example of this is that you may plan to install a certain kind of transmission line but are uncertain as to the effect the losses in the transmission line will have on the operation of the equipment to be used with it. Such a transmission might lead from a radio receiver to a distant loudspeaker, or it might be a lead-in transmission line from an antenna to a television receiver.

You might find your losses seemed inconveniently high, yet when you figure them out in decibels you find the loss in decibels to have little effect on the ear of the listener. These are just a few examples of the use of the decibel in your everyday work. But they are only a few.

A good radio and television man is almost lost without a knowledge of decibels. Many antenna manufacturers rate their antennas as having a gain of so many decibels. Other manufacturers of transmission lines rate their lines as having losses of only so many decibels. Still other manufacturers will rate their amplifier units as having a gain under certain conditions of so many decibels and possibly a different gain in decibels under other conditions. Without a good understanding of decibels you would find it hard to even read the technical literature used to describe the operation of certain kinds of radio, television and other electrical equipment.

At the beginning of this section we said the best definition of a decibel is that it measures *that change in the level of sound that is just perceptible to the human ear.*

That is a true definition. Yet it is only part of the real definition. That definition is often extended, or expanded, to include another. This second definition is that zero (0) decibel is the *threshold* of sound. By this is meant that a sound which has such a low level that it is barely perceptible to the human ear under ideal conditions is equivalent to zero decibel (0 DB).

As we progress with our studies in this lesson we will see there is really no conflict between the two definitions. The first covers the use of decibel measurement under *all* conditions of sound. The second uses the decibel method of measurement in determining the *lowest* level of sound that can be heard by the human ear, or to put it in other words, the decibel system is used to measure the amount of sound that can be heard by the human ear when no other sound is present. In this case, that amount of sound said to be the *threshold* of hearing for the human ear is taken as the zero reference level.

We will find later that scientific experiments have determined that the .006 watts of sound power is the lowest level that can be heard by the human ear when no other sound is present. That is a very low amount of power. It is six one-thousandths of a watt.

We have gathered together in this lesson all the necessary data for a comprehensive understanding of the subject of decibels. This is a subject that many writers approach with an air of mysticism, while others approach it with an apparent feeling of bafflement.

One wonders sometimes just why this should be. We are almost tempted at times to believe that some of the writers are themselves mystified by the subject. But we must admit that this does not seem entirely reasonable. It may be that some writers are unable to resist the urge to make the subject seem hard and thus try to enhance their own feeling of importance. One great mathematician said many years ago that the hardest thing about mathematics was trying to unravel the difficult words with which other mathematicians had wrapped up their meaning. Possibly the same thing is true in the case of decibels.

We have tried to leave out of this lesson those things which sometimes tend to make the study of decibels somewhat difficult. We know there are some mathematicians who will think we have over-simplified the subject. But we have not written this lesson for the mathematician. We have written it for you, and have tried to write it in a way you can understand. We have put into the lesson everything you will need to know in order to work intelligently with decibels, and we see no need to add anything else to the lesson that might tend to distract your mind from the subject at hand and possibly make it harder for you.

Section 3. THE BASIC REFERENCE LEVEL

In the preceding section we explained that one concept of a decibel was as a unit of measurement which is used to measure the amount of power needed at any level for a change to be detected by the human ear. At another place in the same section we also mentioned that another concept of the decibel is that it measures the *lowest* level of sound that can be heard by the human ear.

As was also mentioned previously, it has been determined by scientific experiment that the lowest level of sound that can be heard by a normal ear when no other sound is present is that volume of sound which is produced by .006 watts of electrical power. In electrical work and sound work .006 watts is taken as the basic reference level.

Now in the use of decibels as a method of measurement it is the common practice to take the lowest level of sound that is perceptible to the human ear as being zero decibel. This is also written, or spoken of, as 0 DB. The reason for this is that the lowest level that can be heard by the human ear is the zero level insofar as *hearing* is concerned.

If the volume of sound is then raised enough for the change to be perceptible to the human ear, that change, or increase, amounts to 1 decibel. If the sound volume is raised still further so the additional change is again perceptible to the human ear, that additional change amounts to another decibel. And so it goes as the volume of sound is increased again and again. The main thing to keep in mind is that each change in the level of the sound volume which is perceptible to the human ear amounts to an additional decibel.

But it should also be kept in mind that the lowest level of sound that is perceptible to the ear under ideal conditions is called *zero decibel*, or *0 DB*. You might be inclined to ask why the lowest level of sound that is perceptible to the human ear is 0 decibel instead of being 1 decibel? After all, the sound has been raised from zero to some definite level; why should this definite level, which is undeniably higher than zero, be called "zero decibel"?

This brings us back to the situation of the decibel being a unit of measurement. While a sound level amounting to zero decibel is truly on the threshold of sound insofar as the human ear is concerned, scientific investigators can easily prove that there are sound levels below those which the ear can hear. If, then, we called the threshold of sound 1 decibel instead of zero decibel it would mean that zero decibel would have to be a condition where absolutely no sound of any kind existed. Such an arrangement would make difficulties for those who must constantly use the decibel as a unit of measurement.

As has been mentioned several times in our course, the decibel was originally created to measure the power necessary to change the level of sound by an amount that would be perceptibel to the human ear. Our ordinary conception of the decibel, then, is that it is used to measure those sounds which the ear can hear; by this we mean, to measure those sounds which are greater than zero decibel.

But the decibel has even greater usefulness for us. It can be used not only to measure those sound levels which the ear can hear, it can also be used to measure those sound levels which are much too low for the ear to hear. For this reason it has become the common practice to refer to those levels which can be heard by the ear as being "plus decibel", or +DB. Those levels of power or sound which are too low to be heard by the human ear are referred to as being "minus decibel", or -DB.

From all your studies of radio and television it should be easy for you to understand that most radio and television men are constantly working with power levels which are far below the level which are perceptible to the human ear. In fact one of the biggest jobs in our work is to build up extremely weak signals to a value which the human ear is capable of hearing.

Another common example of this is the signal picked up by an amplifier from a microphone. The electrical signal created in the microphone by sound striking the microphone diaphragm is usually far too weak for the ear to detect. It is a common practice to speak of the output of such a microphone as being -10 DB or -20 DB or some other value. This means that the level of the signal is so low that it must be raised many times before it is strong enough to be heard by the ear.

To put all this in slightly different words we can say that zero decibel is that

Fig.3. The Signal from a Microphone is so Weak it must be Measured in Minus DB. (Courtesy Shure Bros., Chicago.)

level which is barely perceptible to the human ear; any sound level lower than that does not exist so far as the ear is concerned; any sound level higher than that is measured by the rule that any perceptible change amounts to an additional decibel.

And since the decibel should be tied to some electrical unit in order for us to use the decibel as a unit for measuring changes in power levels, it has been found most convenient to peg zero decibel to the amount of electrical power necessary to create a sound that is just barely perceptible to the human ear. This has been found by experiment to be .006 watts. Therefore, .006 watts, or six milliwatts, is taken as the zero reference level when using the decibel system of power measurement.

Section 4. DECIBELS AND LOGARITHMS

For some undetermined reason many persons think of logarithms as being something mysterious and as being beyond the understanding of the average person. Why this should be is hard to understand. There is really nothing hard about logarithms except the pronunciation of the name. Probably the failure of the bulk of the American public to properly appreciate the use of logarithms stems from the method by which they are handled in so many public schools.

It is an unfortunate situation, but it is nevertheless a true one, that many of our mathematics teachers in the public schools today do an unbelievably poor job of teaching mathematics, and particularly a poor job of teaching logarithms. Possibly the teachers themselves should not be criticized too much since the texts most of them are forced to use are so poorly written. Many of the texts appear to have been written by college professors for the edification of other college professors rather than as a medium for teaching an interesting subject to students who are trying to learn something.

It is not our purpose in this lesson to try to teach you logarithms. To treat the subject of logarithms in the manner they deserve would take more time and space than we can devote to it here. But to enable you to use decibels in an intelligent manner it is necessary for you to understand the basic operation of logarithms. In this lesson we will explain the basic fundamentals of logarithms so you will be able to use decibels in your work.

If you are already familiar with the use of logarithms you may possibly think our explanation here is overly simplified. But remember -- we are not trying to teach logarithms; we are merely trying to explain enough about them so as to make decibels more understandable. On the other hand, if you have not had an opportunity to learn logarithms, or to take advantage of their usefulness in our kind of work, you will probably find it profitable to go into them somewhat more deeply than we can go here. If you are in position to do so, you will find it highly profitable to take a side course in mathematics, including logarithms. The longer you stay in radio and television work, the more useful you will find such knowledge to be.

When a person is first introduced to the word *Logarithms*, the natural question for one to ask is: What is a logarithm?

A logarithm is an exponent.

And, you may ask, what is an exponent?

Perhaps it would be easier to give you an example of an exponent than to try to describe one to you.

See this number -- 10^2. That little number *2* is an exponent.

Okay, you may say, so it is. But what does it mean?

The little *2* is used to designate the number of times the figure 10 is to be multiplied by itself. In this particular case it means 10 is to be used twice in a multiplication. Another way of saying this is to say that 10 is to be raised to its *second power.* But this last is the professional mathematician's way of saying it.

If 10 is to be used twice in a multiplication, or to be raised to its second power, just how do we go about doing such a thing?

It's simple. We merely multiply 10 by itself. In that way the number 10 would be used twice in a multiplication. Thus: 10 x 10.

There is still another way of looking at this matter. We can say that 10^2 represents another number. And so it does. It represents the number which we can obtain by using 10 twice in a multiplication. In this case it represents 100. This is because 10 x 10 = 100.

For this reason we can say $10^2 = 100$. Or, 10^2 represents 100.

So far this is no different than the things you learned in elementary grade school.

By the same line of reasoning we can say that 10^3 means using the figure 10 three times in a multiplication. 10 x 10 x 10. In this case $10^3 = 1000$ because 10 x 10 x 10 = 1000. If you have any doubt about it, figure it out for yourself. We could also say that 1000 can be represented by expressing it as being 10^3.

Going a step in the other direction we can say that 10^1 equals 10 because in this case the number 10 is used only once in the multiplication.

Now you may be surprised to learn something you have always thought to be hard is as simple as that. *Logarithms are merely those exponents.*

A logarithm is merely the number of times the figure 10 must be multiplied by itself to obtain the number. In the case of the number 1000 we know that 10 must be multiplied by itself 3 times. Therefore,

Log 1000 is 3.

By the same line of reasoning we know that in the case of the number 100 that 10 must be multiplied by itself 2 times. Here find:

Log 100 is 2.

And in the case of the number 10 itself, we have already explained that 10 is used in the multiplication only one time. Therefore, in this case:

Log 10 is 1.

Bringing these three cases together we find:

Log 1000 is 3,
Log 100 is 2,
Log 10 is 1.

This could be carried considerably further. We would find that:

Log 10,000 is 4,
Log 100,000 is 5,
Log 1,000,000 is 6.

All a logarithm amounts to is the number of times the figure 10 is used in a multiplication. A logarithm is merely an exponent.

Now, you will say, all this is very interesting. But we have already used all the numbers between 1 and 6 as logarithms, and have merely been able to express six different numbers in the terms of their logarithms. And in order to express only six numbers in the terms of their logarithms we have had to go all the way up to 1,000,000. Suppose it became necessary to express some other common number in the terms of its logarithm. How could that be done?

Before going into a full answer of that question, let us first say that any existing number can be expressed by raising the figure 10 to some power, *or to some fractional power.*

It is in that last phrase that we find the secret of the usefulness of logarithms as a method of mathematical notation. Even though some number cannot be represented by raising 10 to some *even* power, it can be represented by raising 10 to some *fractional* power.

As an example of this, we know that raising 10 to exactly the 2nd power gives us 100, and raising it to exactly the 3rd power gives us 1000. It seems to follow as a natural result that if 10 is raised to some fractional power between 2 and 3 it will give us some number between 100 and 1000. Suppose, for the sake of an example, that we raise 10 to its 2.5 power. It can be proven that if we raise 10 to its 2.5 power we will obtain the number 316. In that case we could say that,

$10^{2.5}$ equals 316.

Another way would be to express the number itself in the terms of its logarithm. This we could do by writing it in this way:

Log 316 is 2.5.

Now to avoid any possibility of error in your thinking, we do not mean multiplying 10 x 10 x 5. Doing so would give us the wrong answer. As a matter of fact, it is difficult to raise 10 to its 2.5 power by ordinary arithmetic. We would like to ask you to accept our word for it that such a thing can be demonstrated.

To go another step further we can raise 10 to its 2.6 power. In this case we would find that by raising 10 to its 2.6 power will give us the number 398. And, by following the same reasoning we have given you earlier in this lesson, we could write the number 398 in the terms of its logarithm. We could write:

Log 398 is 2.6.

We could go further and find that:

$10^{2.7}$ equals 501,
$10^{2.8}$ equals 631,
$10^{2.9}$ equals 794.

We can go even further and make the fractional powers even more exact. By this we mean, *carry them out to more places.* More decimal places.

$10^{2.9}$ as shown above is equal to 794.
$10^{2.95}$ equals 891
$10^{2.955}$ equals 902
$10^{2.99}$ equals 977
$10^{2.999}$ equals 998

Please do not try to memorize any of the above numbers. That is unnecessary, in fact should be avoided. To point out what we are trying to say, it would be well to mention that each of the numbers mentioned above can be expressed in the terms of its logarithm, We have seen that $10^{2.7}$ is equal to 501. We can turn this around and express the number 501 in the terms of its exponent, or logarithm. It can be done thus:

Log 501 is 2.7

We can also say:

Log 631 is 2.8
Log 794 is 2.9
Log 891 is 2.95
Log 902 is 2.955
Log 977 is 2.99
Log 998 is 2.999

You will note that as the number we are trying to express in terms of its logarithm approaches 1000 the logarithm approaches closer and closer to 3. This is because the logarithm of 1000 is 3.

In the above examples we have expressed only a few numbers in the terms of their logarithms. The truth is that any number, regardless of what it is, can be expressed as a power of 10. This means that every number has a logarithm.

It is obviously impossible for any person to try to remember all these logarithms. In fact it is far too much trouble to even try to figure out the logarithm of a number each time it is needed. There are many people who use logarithms constantly as a means of calculation who actually do not know how to find a logarithm without consulting a table of logarithms. And this is just as well. These tables have been arranged for our convenience. Some of these tables have been worked out to unbelievably fine degrees of accuracy. Fortunately in our work we do not need to observe such degrees of accuracy; thus the use of logarithms in our work becomes even more simple.

If you understand all this you may still want to ask about those numbers between 10 and 100. Just how are they expressed in the terms of their logarithms. As a matter of fact they are expressed in the same way as those we have just mentioned, with the exception that the figure 1 (one) is used before the decimal point in the logarithm instead of the figure 2 (two). We found that the number 316 could be expressed by its logarithm in this manner:

Log 316 equals 2.5

Now suppose we take a similar number between 19 and 100. For the sake of convenience, suppose we take 1/10th of 316. That would be 31.6.

If we look up the logarithm of 31.6 in a table of logarithms we will find that it is 1.5. This means we would have to raise 10 to its 1.5 power to obtain the figure 31.6. Another way to say this would be:

Log 31.6 equals 1.5

To carry this explanation a little further let's take another number that is similar to the ones we were working with before. We found that the logarithm of 398 is 2.6. We learned that this meant that 10 had to be raised to its 2.6 power to obtain the number 398.

Now let's take a similar number between 10 and 100. Let's use 1/10th of 398. That would be 39.8.

If we were to take a table of logarithms and look up the logarithm of 39.8, we would find that it would be 1.6. We could express this in another way. We could say:

Log 39.8 equals 1.6

So far we have seen that:

Log 31.6 equals 1.5

and Log 316 equals 2.5

Now let's see what the log of a number ten times greater than 316 would be. Ten times 316, of course, would be 3160. If we looked up the log of 3160 in a table of logarithms we would find the logarithm would be 3.5. This, of course, could also be expressed:

Log 3160 equals 3.5.

By placing these numbers along side of each other we find that:

Log 31.6 equals 1.5
Log 316 equals 2.5
Log 3160 equals 3.5

We could do some other things with the other numbers we have examined. We have seen that the logarithm of 39.8 is 1.6 and the logarithm of 398 is 2.6. If we were to look up the logarithm of ten times 398, which is 3980, we would find it to be 3.6. We could tabulate these numbers in this fashion:

Log 39.8 equals 1.6
Log 398 equals 2.6
Log 3980 equals 3.6

You have no doubt noticed in each of these cases that the portion of the logarithm after the decimal point was the same in each instance. To point this out even stronger, take the case of the three numbers 31.6, 316, and 3160. In the logarithm of each of these numbers we find that portion of the logarithm which follows the decimal point is the same in each case. In each of these cases it is five.

As a matter of fact, you could carry this much farther. You would find that the numbers 31,600, 316,000 and 3,160,000 would all have logarithms which had the same numeral following the decimal point.

The same thing would be true of the other group of numbers. We see that 39.8, 398 and 3980 all have the same number, a 6, following the decimal in their logarithms. We would also find that 39,800, 398,000 and 3,980,000 also would have a 6 as the portion of the logarithm that follows the decimal.

As a matter of fact we could set up a system of tables using that portion of the logarithm which follows the decimal point. It could be arranged somewhat in the manner as shown in Table I on the following page.

The point we are trying to emphasize with Table I is that a logarithm which has the figure 1 (one) following the decimal can be used to represent any of the numbers to the right in the table. It can be used to represent 1.26, 12.6, 126 or any of the other numbers to the right.

Naturally a single number that could represent so many numbers would be of little use to us for most purposes. We would need to know exactly which of those numbers any particular logarithm represented. That is the function of the part of the logarithm ahead of the decimal.

For any number between 0 and 10, the logarithm ahead of the decimal would be zero (0). Thus the logarithm of 1.26 would be 0.1.

TABLE I

Log.	Could Be Used To Represent These Numbers							
.1	1.26;	12.6;	126;	1260;	12,600;	126,000;	1,260,000;	12,600,000
.2	1.585;	15.85;	158.5;	1585;	15,850;	158,500;	1,585,000;	15,850,000
.3	1.995;	19.95;	199.5;	1995;	19,950;	199,500;	1,995,000;	19,950,000
.4	2.51;	25.1;	251;	2510;	25,100;	251,000;	2,510,000;	25,100,000
.5	3.16;	31.6;	316;	3160;	31,600;	316,000;	3,160,000;	31,600,000
.6	3.98;	39.8;	398;	3980;	39,800;	398,000;	3,980,000;	39,800,000
	And Could Be Carried On With The Other Decimal Portions.							

Any number between 10 and 100 would have the figure 1 (one) in front of the decimal. This was suggested to you earlier in this lesson. Thus the logarithm for 12.60 would be 1.1.

Any number between 100 and 1000 would have the figure 2 (two) in front of the decimal. Thus the logarithm of 126 would be 2.1.

Section 5. THE CHARACTERISTIC AND THE MANTISSA

From the foregoing section you will probably be able to see that certain numbers can be readily represented by an exponent of 10 which is called a logarithm. You have also been able to see that such exponent or logarithm will in most cases be composed of a whole number and a decimal. Even more than this, you will also have been able to see that each portion of the logarithm tells a story of its own.

That portion of the logarithm in front of the decimal point tells the relative size of the number. If the number is between zero and 10, the numeral in front of the decimal point will be zero (0). If the number is between 10 and 100, the numeral in front of the decimal point in the logarithm will be 1. If the number is between 100 and 1000, the numeral will be 2. If the number is between 1000 and 10,000, the numeral will be 3. And so it goes.

The numeral in front of the decimal point in the logarithm has a name. It is called the *characteristic* of the logarithm.

There is another way to use the characteristic of the logarithm to determine the size of the number it represents. One rule is that *the characteristic is always one less than the number of digits in the number.*

Thus, all numbers between zero and 10 have only one digit. According to the rule, such numbers would have a logarithm whose characteristic is one less than the number of digits. Since there is only one digit in the number, the characteristic would be zero (0). This is exactly what we learned in the preceding section.

Further than this, those numbers between 10 and 100 would have two digits. The characteristic would be one less than the number of digits. One less than two digits would be 1 (one). And here again we find that this is also just what we learned in the preceding section.

The rule always holds good.

The second part of the logarithm, the part that follows the decimal point, also has a name. It is called the *mantissa.* That's a funny name, but it is what it is called. We have no choice but to follow along.

Just as the *characteristic* has a function to perform in representing some number, so has the *mantissa* a definite function to perform. It is the mantissa that is set up in the form of tables. Some of these tables are so elaborate they can fill a book. Their accuracy is amazing to a person who has never had an occasion to work with them.

But the principal advantage of logarithms lies in the way they can simplify complicated calculations. This is particularly true of those cases which require the use of trigonometry to solve a problem.

Even in ordinary calculations logarithms can be tremendously useful. You no doubt recall the difficulty of working square root and cube root problems. The use of logarithms reduces such problems to simple division. As a matter of fact, logarithms can reduce multiplication and division to addition and subtraction, and reduce squaring and cubing and square roots and cube roots to multiplication and division. It is actually possible to extract the fourth and fifth roots by the use of logarithms in a matter of minutes instead of spending hours trying to find such roots by other methods. You will find that logarithms makes it possible to work some problems that simply could not be worked out by ordinary arithmetic at all.

But this is getting away from our discussion of the *mantissa*.

Since every number can be expressed as an exponent of 10 it stands to reason that the difference between one number and another must be expressed by a difference in the value of the *mantissa*. We have prepared a three place logarithm table in Table II. (See Page 13.) That table shows the mantissa to three decimal places for every number from 1 to one hundred. It would not have been necessary to have made the table quite so extensive, a table of the numbers between 10 and 100 would have been sufficient. But we thought it might be a little more understandable if we made it all the way from 1 to 100.

You will note from studying the table that 2 has the same mantissa as does 20. Likewise, 3 has the same mantissa as does 30. The same is true of 4 and 40, 5 and 50, and so forth.

Now let's see just how this table is used to express a number as a logarithm. Let's take a number between 10 and 100. For the sake of convenience let's choose the figure 25. A glance at the table of logarithms tells us that the mantissa of the logarithm of 25 is .397. Remember, the mantissa is that portion of the logarithm which follows the decimal point in the logarithm. Therefore you must always put a decimal point in front of the mantissa.

We have now found that the mantissa for 25 is .397. But this is only part of the logarithm. A logarithm always consists of two parts, *the characteristic and the mantissa*. The logarithm tables lists only the mantissa, not the characteristic.

Now we must have a characteristic for our logarithm for 25 before the logarithm will be complete. Now, if you remember your rule for finding the characteristic, you know the characteristic in this case must be 1. This is because the number contains two digits, and the rule says the characteristic is always *one less* than the number of digits.

So, if the characteristic is 1 and the mantissa is .397 we can put them together and have the complete logarithm for the figure 25. The logarithm for 25 is 1.397. In other words, if 10 is raised to its 1.397 power the result would be equal to 25.

If we wanted to find the logarithm for 250, the problem would be just as simple. The mantissa would be the same, .397. But there would be a different characteristic. Since there are three digits in the number 250, the characteristic of the logarithm for 250 would be 2. Therefore, the logarithm for 250 would be 2.397.

By following the same rules we would find that the logarithm for 2500 would be 3.397. And the logarithm for 25,000 would be 4.397. This means that 10 would have to be raised to its 3.397 power to be equal to 2500 and to its 4.397 power to be equal to 25,000.

Let us take another example. Suppose we find the logarithm for the number 59. By looking at the table we find that the mantissa of the logarithm for 59 would be .770, but the table does not give the characteristic. However, by following the rule for finding the characteristic we know it will be 1. This means the logarithm for 59 is 1.770.

The same rules will also show us that the logarithm for 590 would be 2.770. The logarithm for 5900 would be 3.770. .

Now you are probably thinking that all this is a silly business. We take a simple number like 25 and then use another number like 1.397 to represent it. And then we have the nerve to say that we are going through all this process to simplify the number 25. If you have never had any experience with logarithms you are probably beginning to think we have lost our minds or something. At this stage of our explanation there certainly doesn't seem to be anything simple about logarithms. Nor any sense to them.

Perhaps it would be well for us to give you a little demonstration of the usefulness of logarithms. Suppose we want to multiply 25 by 59. We could do that by following the simple rules of multiplication, or we could do it by the use of logarithms. In this particular case it might be more simple to use the ordinary processes of arithmetic to multiply 25 by 59, but there are many other cases where it would be much more simple to use logarithms.

There is a mathematical rule that says that to multiply two numbers all that is necessary is to add their logarithms. So we will use the logarithms of 25 and 59 which we have already found.

Log 25	=	1.397
Log 59	=	1.770
Adding the Logs		3.167

3.167 is the logarithm of the product of 25 and 59. You may say, so what. The number we want is the actual number, not the logarithm.

The table of logarithms can be used both ways. We can use it to look up the logarithm of a number. Or, if we know the logarithm, we can use it to look up the number. Since our logarithm is 3.167 we turn to the logarithm table and see what number is represented by the mantissa .167.

Looking at the log table we do not find .167 listed. But we do know it is located somewhere between .146, which is the mantissa for 14, and .176, which is the mantissa for 15. By inspection, estimation, or actual figuring, it can be found that .167 must be about three-quarters of the way from 14 to 15. 14 plus three-quarters could be written 14 3/4 or it could be written 14.75. One is a fraction and the other is a decimal. In our present work it is usually easier to work with decimals.

If the mantissa .167 represents 14.75 the next thing is to see just how many digits should be in the number. By looking at the characteristic 3 of the logarithm 3.167 we know there must be *four* digits in the number. This means the product of 25 and 59 must be 1475. If you multiply these two numbers together in the usual way you will see that this is true.

Now let us repeat again the rule for using logarithms in multiplication. TO MULTIPLY TWO NUMBERS TOGETHER add the logarithms of the two numbers, then find the number that logarithm represents.

Many times in radio and television work we find it necessary to multiply several numbers together. Suppose we multiply 25 by 59 by 50 by 20 and see what the result would be. By ordinary arithmetic each of these numbers would have to be multiplied separately. By logarithms we merely find the logarithm of each of the numbers, add the logarithms together, then find the number that logarithm represents.

Log 25	=	1.397
Log 59	=	1.770
Log 50	=	1.699
Log 20	=	1.301
Adding logarithms		6.167

Now all we have to do is find the number represented by 6.167. We learned from our previous problem that the mantissa .167 represented 14.75. We see the characteristic of the logarithm is 6. From our rule we know that the number must have one more digit than the characteristic. This means the number must have seven digits. We must add enough zeros to 14.75 to give the *whole number* seven digits. This means the number which is the product of 25 and 59 and 50 and 20 must be 1,475,000. If you have any doubts you might try figuring it out by the ordinary processes of arithmetic.

Radio and television men find logarithms very useful in working impedance problems, and other problems involving reactance and such like. This is especially true where it is necessary to multiply some figures and divide others.

Division by means of logarithms is just as simple as multiplication. Instead of adding the logarithms together as in the case of multiplication you merely subtract the logarithm of the divisor from the logarithm of the dividend.

Suppose, by way of example, you had occasion to divide 1475 by 59. You could do it by the ordinary method, or you could do it by the means of logarithms. In our previous examples we have already learned that the mantissa of the logarithm of 1475 is .167 so in this particular case we will not need to go to the trouble of looking it up. We also know that the characteristic

TABLE II

NUMBERS	Mantissas of Logs	NUMBERS	Mantissas of Logs	NUMBERS	Mantissas of Logs
0	...	34	531	68	832
1	000	35	544	69	838
2	301	36	556	70	845
3	477	37	568	71	851
4	602	38	579	72	857
5	699	39	591	73	863
6	778	40	602	74	869
7	845	41	612	75	875
8	903	42	623	76	880
9	954	43	633	77	886
10	000	44	643	78	892
11	041	45	653	79	897
12	079	46	662	80	903
13	113	47	672	81	908
14	146	48	681	82	913
15	176	49	690	83	919
16	204	50	699	84	924
17	230	51	707	85	929
18	255	52	716	86	934
19	278	53	724	87	939
20	301	54	732	88	944
21	322	55	740	89	949
22	342	56	748	90	954
23	361	57	755	91	959
24	380	58	763	92	963
25	397	59	770	93	968
26	415	60	778	94	973
27	431	61	785	95	977
28	447	62	792	96	982
29	462	63	799	97	986
30	477	64	806	98	991
31	491	65	812	99	995
32	505	66	819	100	000
33	518	67	826		

Three Place Log Table.

of the logarithm of a number which has four digits is 3. Therefore the logarithm of 1475 is 3.167.

We also already know that the logarithm of 59 is 1.770, so in this case we will not have to go to the trouble of looking it up.

By our rule for division by use of logarithms we subtract the logarithm of the divisor from the logarithm of the dividend. Therefore:

Log 1475	=	3.167
Log 59	=	1.770
Logarithm of quotient	=	1.397

Now we merely have to look in the log table to find the number that corresponds to a mantissa of .397. Since we have been working with these numbers before, we already know that the number represented by .397 is 25, and since the number must have two digits it is 25.

For the purpose of complete understanding, let us now emphasize the rule for using logarithms for division. *Subtract the logarithm of the divisor from the logarithm of the dividend. This will give you the logarithm of the quotient.*

Where there are several multiplications and several divisions to be done, such as is often the case in radio and television work, it becomes a simple matter to find the answer by merely adding together the logarithms of those numbers which are used to multiply and subtract the logarithms of those numbers which are used to divide. This will give you the logarithm of your answer. Then all that is necessary is to look up the number which corresponds to that logarithm. That will be your answer.

If you want to raise a number to some power you merely multiply the logarithm of the number by the power you want to raise the number to. For example, if you want to raise a number to its third power (cube it) you merely multiply the logarithm of the number by 3. That will give you the logarithm of your answer. If you want to raise a number to the fourth power, you multiply the logarithm of the number by 4. That will give you the logarithm of your answer.

It is in finding roots that logarithms are usually the most useful to radio and television men. Most of us have trouble extracting square roots. Very few of us can actually do a good job of extracting cube roots by ordinary arithmetic. And extracting the fourth root is almost an impossible matter by the use of ordinary arithmetic. But extracting any root is a very simple matter if you use logarithms.

In radio and television work it is often necessary to raise a number by one power then extract some root of the result. Thus in one problem we have to find both a power and a root. These can be most confusing and provoking problems when we try to work them out by using ordinary arithmetic. But in using logarithms they become very simple problems.

In finding roots of a number you merely divide the logarithm of the number by the root you want to find. In finding square roots, for example, you merely divide the logarithm of the number by 2. This will give you the logarithm of the root you want to find. If you want to extract a cube root you merely divide the logarithm of the number by 3. In extracting the fourth root you divide the logarithm of the number by 4. And so forth.

One thing that makes the use of logarithms so convenient is that once you have found the logarithms of your original numbers you can perform really complicated computations without again having to go back to your log tables until your figuring has been finished.

Suppose you had a problem like this one:

$$\sqrt[4]{(25 \times 59)^3}$$

Here we have two numbers which are to be multiplied together. Then they must be raised to the third power. Finally the 4th root must be extracted. Problems similar to these are by no means uncommon in radio and television work. Yet they can easily stump a man who does not understand logarithms. And the use of logarithms reduces such a problem to a very simple one. Since we are again using the same numbers we have used before, we will not have to look up the logarithms of 25 and 59.

Log 25	=	1.397
Log 59	=	1.770
Add Logs		3.167

The next step is to find the cube of this product. We multiply that logarithm by 3. Thus:

$$\begin{array}{r} 3.167 \\ \times\ 3 \\ \hline 9.501 \end{array}$$

This is the logarithm of the number resulting from the cubing. Since we are not interested in this actual number we do not have to look it up in the logarithm tables.

The next step is to find the 4th root of that number. We do that by dividing 9.501 by 4. Thus:

$$4\,\overline{)9.501} = 2.375$$

2.375 is the logarithm of the final answer. Looking up the number in the logarithm table which is represented by the mantissa .375 we find there is no such actual number in the table. But since .375 lies between .361 and .380, and since .361 represents 23, and 380 represents 24, we know the number must be between 23 and 24. We can arrive at the actual number by whatever method seems to be necessary. If an approximate answer is satisfactory we can say the number lies between 23 and 24, then looking at the characteristic of the logarithm we know there are three digits in the number. That tells us then that the number must be between 230 and 240.

If the answer has to be more accurate than that we can examine the mantissas a little more closely. Then we will see that .375 is about three-quarters of the way from .361 to .380. Therefore the number must be about three-quarters of the way from 230 to 240, or about 237.5. This should be a close enough answer for any radio or television problem.

You should not think, however, that because we have been doing considerable estimating that logarithms merely give approximate answers. Actually the contrary is true. They are highly accurate. Remember that we have been working with only three-place tables. No generally published tables of logarithms ever use less than four places. Four-place tables are ten times as accurate as three-place tables such as we have shown you here. And with what is called *interpolation* they can be many times closer yet. Five-place tables would be about 1000 times as accurate as we have shown you here, and can be used to even greater accuracy.

It is not that logarithms are not amazingly accurate. It is merely that in our work we do not require such a high degree of accuracy.

Section 6. HOW DECIBELS ARE CALCULATED

It is not intended that the elementary discussion we have given you on the use of logarithms should be construed as exhausting the subject. What we have tried to do is to give you the barest fundamentals you will need to understand and work with decibels.

Because decibels are designed to measure power levels and sound levels according to the manner in which they affect the human senses, and since two of the human senses respond to stimuli in a manner which follows a logarithmic curve, it becomes necessary for you to understand the basic principles of logarithms in order to fully understand decibels.

There is a definite mathematical definition of a decibel which has been set up so that power losses or gains could be measured and their effect could then be determined according to their ability to affect the human senses. This mathematical definition of a decibel is given as:

$$\text{Decibel} = 10 \log \frac{P_2}{P_1}$$

Now let's study that formula for a few moments and see just what it tells us. Let's take the last part of it first. P_1 and P_2 represent two power levels. If the power level is being increased, P_2 is the second, or higher, power. P_1 then would be the first, or lower, power.

$\frac{P_1}{P_2}$ represents a ratio between the two powers. We could put some actual values into the formula, then it would begin to take on a little more meaning to us.

Suppose that we had an amplifier that was delivering 10 watts and we wanted to increase the output to 40 watts. 10 watts would then be represented by P_1, and the 40 watts would be represented by P_2.

We could then rewrite our formula again. It would now look like this:

$$\text{Decibel} = 10 \text{ Log} \frac{40}{10}$$

Since 40 divided by 10 is equal to 4, the equation, or formula, could again be rewritten like this:

$$\text{Decibel} = 10 \text{ Log } 4.$$

What this means is that the decibels of gain would be equal to 10 times the logarithm of 4. We can look up the logarithm of 4 in the table of logarithms. There we find the mantissa of the logarithm of 4 is .602. Since the number is between 1 and 10, the characteristic would be zero. Therefore, the logarithm of 4 is 0.602.

The formula tells us that the gain in decibels is equal to 10 times the logarithm of 4. The logarithm of 4 is 0.602. When we multiply 0.602 by 10 we obtain 6.02. And this is the gain in decibels when we raise the power from 10 watts to 40 watts.

Always keep in mind that what must be found is the *logarithm of the ratio* of the two numbers — that is, the ratio of the two powers. Always find the two powers. Then find the ratio between them. Find the logarithm that corresponds to that ratio. Finally, multiply the logarithm by 10. This will give you the decibel.

In the example given here we were solving for a *gain* in decibels. If there had been a loss in power we would still put the larger of the two powers above the line, and proceed to solve in the regular manner. It is never any problem trying to decide whether you have a loss or a gain. If you have more power at the output than at the input you have a gain. If you have less power at the output than at the input, you have a loss. The formula for decibels merely tells you the *change* in power levels in the terms of decibels. It is up to you to tell whether it is a gain or a loss.

Probably we should mention that it is possible to tell by the results of your calculations whether you have a gain or a loss. But from what we have told you here, we think it is better for you to decide by inspection whether you are solving for a gain or a loss.

It should be emphasized that when you are solving for decibels you should not solve for the logarithm of the number above the line and the logarithm of the number below the line. *That is incorrect.* First, find the ratio of the two powers. Second, find the logarithm of that ratio. Finally, multiply that logarithm by 10. This gives you the decibels.

Section 7. SOME PRACTICAL EXAMPLES OF DECIBEL GAIN

Suppose you have an amplifier that you want to raise the power from 1 watt to 2 watts. You want to find the gain in decibels.

$$\text{Decibels} = 10 \text{ Log} \frac{P_2}{P_1}$$

P_1 = 1 watt

P_2 = 2 watts

Therefore,

$$\text{Decibels} = 10 \text{ Log} \frac{2}{1}$$
$$= 10 \text{ Log } 2$$

From the tables, Log 2 = 0.301

$$\text{Decibels} = 10 \times 0.301$$
$$= 3.01$$

From this we see that raising the power of the output 1 watt will give you 3.01 decibels of gain.

Take another example of raising the output power from 1000 watts to 2000 watts. Here again we have the decibel formula:

$$\text{Decibels} = 10 \text{ Log} \frac{2000}{1000}$$
$$= 10 \text{ Log } 2$$
$$= 10 \times 0.301$$
$$= 3.01$$

So we see that we get just as much gain in decibels by raising the power level of one amplifier by a total of 1 watt from 1 watt to 2 watts as we were able to get out of another amplifier when the output was raised a total of 1000 watts from 1000 watts to 2000 watts.

Decibels are also widely used to measure the loss of power in a line by attenuation. There the loss in decibels is measured by taking the value of the input to the line and dividing the value of the power at the output. This will give the ratio of the input power to the output power. Then the logarithm of that ratio is found. Finally, the logarithm of that number is multiplied by 10 to give the loss in decibels.

Decibels are also used to measure the gain in antennas, and gains and losses in other kinds of circuits and equipment. It would pay you well to study over this lesson quite carefully before going on to the next lesson. You will find use for the information in this lesson very quickly in your studies.

We are including some work practice problems so you can exercise your knowledge before it gets stale. We suggest that you work out these problems, using the logarithm table we have furnished you. While the table we have given you is very sketchy by most standards, nevertheless, if you are able to master it you will be able to handle most any of the problems you will meet up with.

We have not thought it necessary to use the terms anti-logs and co-logs in this lesson. Neither have we gone into a discussion of the logarithms of numbers less than 1. Nor have we thought it necessary to go into the details concerning interpolation. All these are things that a person should know to be able to use logarithms to their fullest. But we have not felt that this was a proper place for such discussion. We have gone into logarithms only deep enough to enable you to fully understand decibels. If you are weak in logs, or think you would like to know more about them, it is suggested that you take up their study on the side.

We have scarcely mentioned the use of logarithms in the solving of problems in trigonometry. It is well worth mentioning, however, that most practical trigonometry problems become simple exercises in ordinary arithmetic when logarithms are used to solve them. There are special logarithm tables set up for the purpose of solving trigonometry problems. If you are interested in these things, you might find it well worth your while to investigate these possibilities a little farther.

PRACTICE PROBLEMS

Find the numbers represented by these logarithms:

1.	2.716	6.	3.863
2.	3.778	7.	2.732
3.	1.826	8.	4.954
4.	3.991	9.	5.993
5.	2.755	10.	2.975

Find the logarithms of these numbers:

11.	930	16.	4050
12.	6400	17.	1600
13.	5.4	18.	1.9
14.	670	19.	7.7
15.	665	20.	9.11

Answers:

1.	520	6.	7300	11.	2.968	16.	3.607
2.	6000	7.	540	12.	3.806	17.	3.204
3.	67	8.	90000	13.	0.732	18.	0.278
4.	9800	9.	985,000	14.	2.826	19.	0.886
5.	570	10.	945	15.	2.823	20.	0.959

(over)

NOTES FOR REFERENCE

Decibels are a unit of measurement which are based upon the logarithmic response of the human ear.

Decibels can be used to measure power gains and can be used to measure power losses.

Decibels can be used to measure gains or losses of power which have such low values they cannot be detected by the human ear.

Decibels are used to measure the gain of commercial amplifiers and pre-amplifiers.

Decibels are used to measure the loss of attenuation of transmission lines.

Manufacturers of television transmission lines rate the attenuation loss of their lines in the units of decibels.

Antenna gain is often rated in decibels.

The output of microphones is usually rated in decibels.

The basic reference level in the decibel system of measurement is .006 watts.

Sound levels within the range of the human ear are rated in plus DB.

Sound and power levels below the range of the human ear are rated as minus DB.

The basic formula for decibels is:

$$\text{Decibel} = 10 \text{ Log } \frac{P_2}{P_1}$$

The formula means that the decibels amount to 10 times the logarithm of the ratio between the two powers, or the two sound levels.

A logarithm is an exponent.

The characteristic of a logarithm is that portion in front of the decimal point.

The mantissa of a logarithm is that portion which follows the decimal point.

The characteristic in the logarithm of a number is always one (1) less than the number of digits in the number.

The mantissa in the logarithm of a number must always be found by looking them up in a table of logarithms.

Two or more numbers can be multiplied together by merely adding the logarithms of the numbers.

Numbers can be divided by subtracting the logarithm of the divisor from the logarithm of the dividend.

A number can be squared by merely multiplying the logarithm of the number by 2.

A number can be cubed (raised to the 3rd power) by merely multiplying the logarithm of the number by 3.

A number can be raised to any power by merely multiplying the logarithm of the number by the power to which the number is to be raised.

The square root of a number can be found by dividing the logarithm of the number by 2.

The cube root of a number can be found by dividing the logarithm of the number by 3.

Any root of a number can be found by dividing the logarithm of the number by the root to be found.

NOTES

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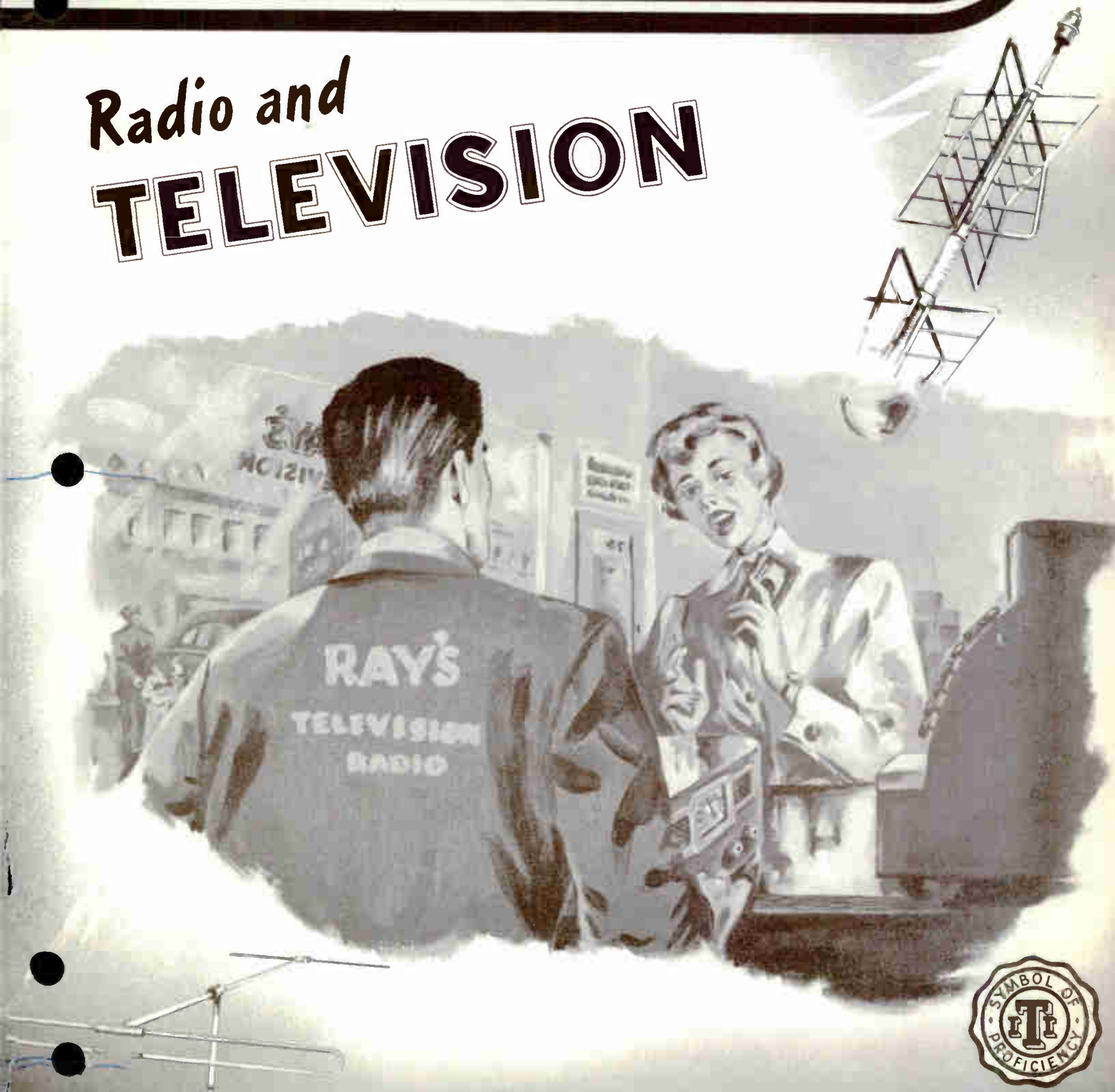

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RADIO TELEVISION

TRANSMISSION LINES

Contents: Introduction - Low Frequency Transmission Lines - Current Flow in Long Lines - Characteristic Impedance - Reflections - Impedance Matching - Attenuation Constant - Commercial Transmission Lines - Notes for Reference.

Section 1. INTRODUCTION

In many of our previous lessons we have mentioned the subjects of transmission lines, characteristic impedance, surge impedance, line reflections and such like on a number of occasions. Each time these things were mentioned we told you that at what we considered the proper time we would go into this subject and explain it to you in detail. We have deliberately delayed the presentation of this material until this time for a number of reasons. The subject itself is not one of the easiest things to understand. We wanted to delay it until we had been able to explain many other things. This other knowledge which you have acquired during your studies will be of great help to you when you begin studying this lesson.

The average radio man will often find it convenient to understand the peculiar properties of transmission lines. Yet in radio work there is not the compelling necessity for thoroughly understanding transmission lines that there is in television work. Much of the reason for this lies in the fact that the ordinary radio service man does not normally need to concern himself so much with the signal strength losses between antenna and receiver that is a constant headache to the television technician. Nor is there the frequent use of ordinary transmission lines as circuit constants in radio receivers that there is in television receivers.

It should always be kept in mind that the television technician is dealing with frequencies every day which are so high as to be merely hearsay to many radio men. These *very high frequencies* possess special properties which make them appear different from the ordinary radio broadcast frequencies, and often the properties of transmission lines are taken advantage of in working with these frequencies. In a following lesson we will take up a detailed discussion of the

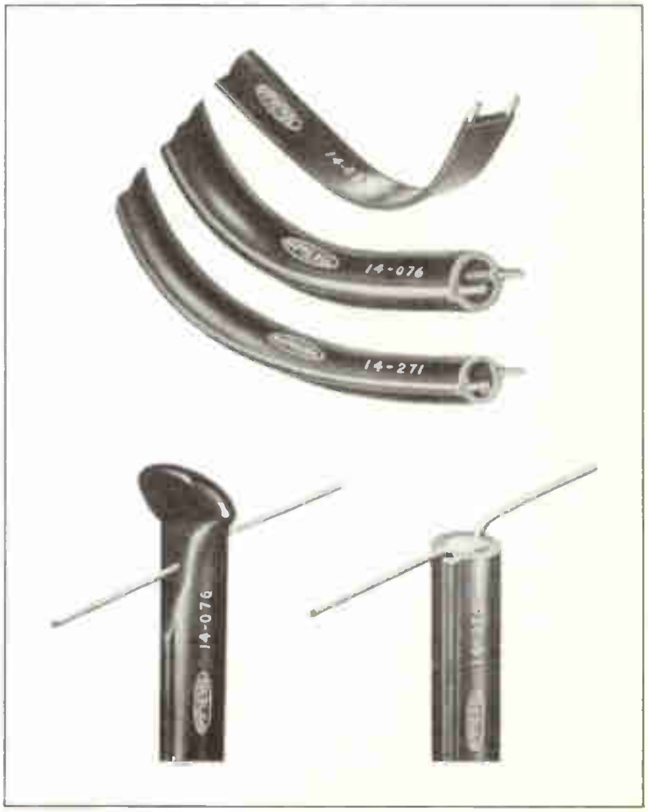

Fig.1. Several Types of Transmission Line.
(Courtesy American Phenolic Company)

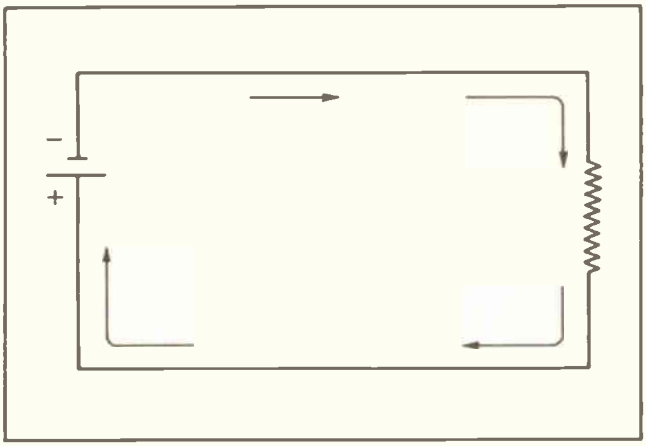

Fig.2. The Current in a Series Circuit Which Has a Battery as a Source.

peculiarities encountered at the *very high frequencies*. In that lesson we will explain to you how the properties of transmission lines which we discuss in this lesson are used to create oscillator circuits capable of stable operation at frequencies far above any of those conventional oscillator circuits we have studied in our previous lessons.

Since the television service is now operating at frequencies considerably above 200 megacycles and there are many indications that frequency channels even higher yet will soon be assigned to that service it becomes compellingly necessary for you to learn as much about the peculiarities of those frequencies as you possibly can. As the frequencies rise higher and higher the information contained in this lesson will become increasingly important to you.

Section 2. **LOW FREQUENCY TRANSMISSION LINES**

At power-line frequencies, and also at many of the higher frequencies encountered in radio work, it is the customary practice for us to think of current as flowing "around" a circuit. As shown in Fig. 2, this constitutes the familiar series circuit which was first mentioned so early in our course. In Fig. 2 the current in the circuit flows continuously in one direction since the source is the constant voltage provided by a battery.

Very much the same thing is also true in Fig. 3, even though we find there the source of power is an alternating voltage produced by some kind of mechanical alternator. There we find the current throughout the entire circuit flowing in the direction of the solid arrows during one instant, then flowing in the opposite direction as indicated by the dotted arrows during the succeeding instant. In this circuit the current alternately flows first in one direction, then in the other.

But note this: during the instant the current is flowing in one direction in *any* portion of the circuit, it is also flowing in the same direction throughout *all the other portions* of the circuit. Furthermore, when the current flows in the opposite direction in any portion of the circuit it is also flowing in the same direction throughout all portions of the circuit.

You may wonder just why we are putting so much emphasis on this point. It has been discussed so many times you probably feel by this time that it is now self-evident. Nevertheless, to prevent any possible misunderstanding of what is to follow in this lesson we feel it is necessary to repeat and emphasize this important fact.

You will recall that on many occasions we have mentioned some peculiar action of electricity, or of electrons, or of some related item, and then explained to you just what the action was. You will probably also recall that quite frequently we would qualify our statement by saying that "at ordinary frequencies", or "at low frequencies", or "at radio frequencies" the action would be such and such. You may have wondered why we qualified so many of our statements. The reason has been that while certain actions have resulted in certain occurrences at ordinary frequencies we ourselves were fully aware the situation could be considerably different under the conditions we find when working with the very high frequencies. But we did not want to risk confusing you at that time by getting into a discussion of such action at high frequencies.

To return to our study of the ordinary series circuit we find in Fig. 3. You will recall that ordinary power-line current goes through 60 complete cycles each second, meaning that it reverses itself 120 times each second. You will also remember that electrical impulses travel through a conductor at a speed of 186,000 miles per second.

What this all adds up to is that when we are working with the ordinary 60-cycle power line current the electrical impulse will travel out along a conductor for a distance of 1550 miles before it has to reverse itself and start back at the next reversal. Since few, if any, actual electrical circuits have any such length it means that at ordinary power-line frequencies, and in practical circuits, the current will flow in one direction in the circuit, and will continue to flow in that direction for a relatively long period of time *throughout the entire circuit,* until the time comes to reverse itself.

If we take a circuit which is as much as a mile long, for example, and apply a 60-cycle voltage to it the current will appear to start flowing in all parts of the circuit at the same time, and will continue to flow in that direction for a relatively long period of time before the current reverses itself. This is because the electrical impulse can cover the one mile of distance in such a small fraction of the time that is devoted to one-half cycle.

But let's see what happens when we increase the frequency. Suppose we raise the frequency from 60 cycles per second to 500 cycles per second. At this frequency we find that instead of the electrical impulse being able to travel 1550 miles per second before it has to reverse itself it will be able to travel only 186 miles before it has to reverse itself. (This is determined by dividing 1000 into 186,000.) Even so, 186 miles is a long distance compared to the length of most ordinary circuits, and for all practical purposes we could apply that frequency to a circuit a mile long and the current would appear to rise and fall instantaneously throughout the entire circuit.

Thus we can see that thus far our old rules that the current is always the same in all parts of a series circuit still holds good. This is true even though we have applied A-C voltage to the circuit instead of D-C.

Having gone this far suppose we now see what would happen to our one-mile circuit if we applied 93 k.c. to it. This, of course is the same as 93,000 cycles. Since there are twice as many reversals per second as there are cycles this means that at 93 k.c. the current will be reversing itself 186,000 times per second.

If we applied 93 k.c. to a circuit a mile long we would find that the electrical impulse at the beginning of a cycle would be able to just barely travel around the circuit when it would have to reverse and start back again. Now if we can assume that the current

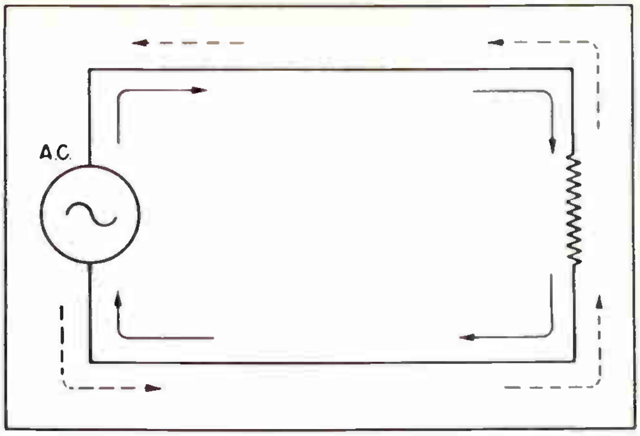

Fig.3. Current in a Series Circuit Where Ordinary A-C Generator is the Source.

in the circuit is caused to flow as a result of the electrical impulse, or voltage, it means that at the beginning of the cycle the current will immediately begin to flow in the portion of the circuit nearest the voltage source, but the current would not begin to flow in other parts of the circuit until the voltage pulse reached those other parts. This means that current would begin to flow in the part of the circuit nearest the voltage source immediately upon the application of the voltage source but it would not begin flowing in more distant parts of the circuit until slightly later when the voltage pulse reached those parts.

Further than this, the current would only barely begin to flow in the most distant part of the circuit a mile from the source when the source voltage would be reversed. We would then have the spectacle of the current flowing in one direction at a point in the circuit a mile distant from the source, but flowing in the opposite direction in the portion of the circuit immediately adjacent to the source.

We are now beginning to encounter a condition which differs rather radically from anything we have previously dealt with. It will be well worth your time to go back and read over again the material in this section before you begin to read the next section. Even though you may find this new idea rather difficult to grasp immediately do not let it bother you. You will find it clearing up as you go along.

Before we leave this section it would be well to repeat one bit of information in a slightly different form. We have always assumed that the current is the same in all

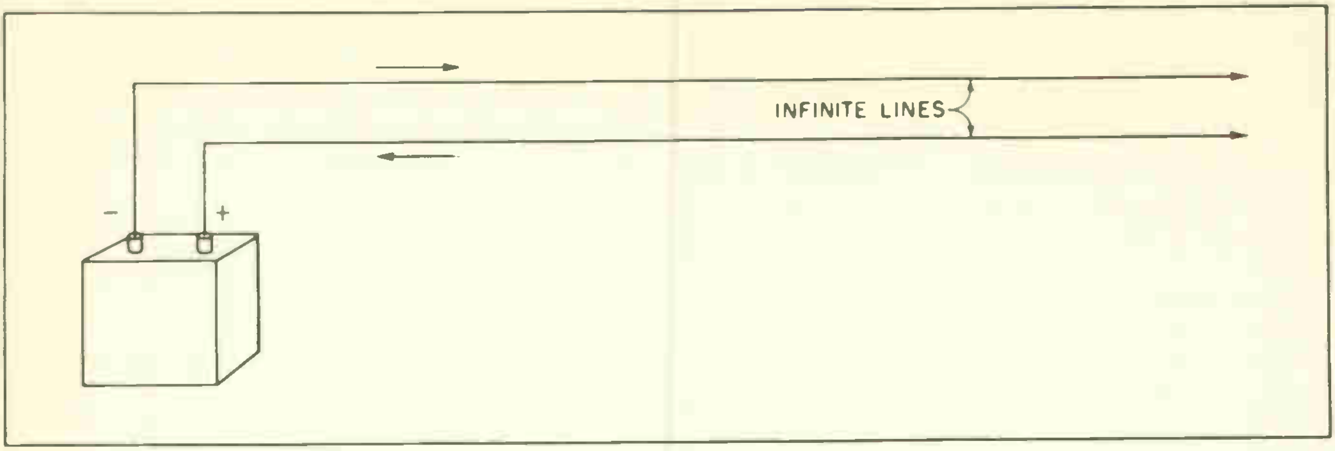

Fig.4. A Battery Connected to an Infinite Line.

parts of a series circuit. We have given you that information in the form of a general rule early in the course, and under ordinary conditions that assumption is true.

But, that assumption can be true *only* if electrical and magnetic effects can take place instantaneously. The fact is, though, that such action is *not* instantaneous.

This means that while we can consider many electrical and magnetic effects as being instantaneous at ordinary frequencies, the fact remains that it does take a definite period of time for these things to happen, and when we raise the frequency materially we eventually reach a point at which we must begin to take this time element into consideration.

Section 3. CURRENT FLOW IN LONG LINES

Since the realization has now been brought home to us that action within an electrical circuit is *not* an instantaneous condition, let us see what would happen in a very long line to which is connected a source of voltage. We will begin our illustration of this action by first observing what would happen if a battery were to be connected to a very long line. (See Fig. 4.)

In thinking of this illustration try to imagine a pair of lines of *infinite* length connected to the battery. By *infinite* length we mean they are so long we have no way of measuring them -- regardless of how far you go along the lines they continue to go still further.

Actually, of course, there is no such thing as lines of infinite length. This is the reason we have to imagine them. But there are many cases in technical discussions where it becomes convenient to *think* in terms of infinity in order to properly explain what would happen in the cases of lines of *finite* length.

Referring back to Fig. 4, suppose we could simultaneously connect both wires to the proper terminals of the battery at the same instant. At the instant the connections were made the negative terminal of the battery would cause electrons to move through the wire away from the battery. At the same instant the positive terminal would attract electrons and cause them to flow toward the battery.

Since the electrical action is not an instantaneous one we would find the electrons moving in the conductors at points near the battery, but during the first instant there will be no movement of the electrons in those parts of the wire which are distant from the battery.

Remember, now, we are referring to an *instantaneous* action, say during the first microsecond after the connection is made to the battery, or even during the first fraction of a microsecond.

Then, as time passes, we will find electrons moving in parts of the conductor farther and farther distant from the battery. This means that if the lines are infinitely long it might take a very long time for the electrons to move in the most distant parts of the line.

At the end of one microsecond the effects of the impressed voltage of the battery will be felt approximately 300 meters away. This is close to 1000 feet. At the end of the second microsecond the effect will be felt 600 meters away, or approximately 2000 feet. At the end of one second the effect of the impressed voltage from the battery will be felt 300,000,000 meters away, or approximately 186,000 miles.

An important point to note in this connection is that the electrons will move within the conductor to form a current even though there is no connection between the wires at the far end. This means that current will begin to flow even though we may have what we have come to know as an open circuit.

It is better to think of this current as a *charging* current, a current which is acting to charge a capacitor. You will remember from your lesson on capacitors that current will rush in one side of a capacitor and will rush out the other despite the fact there is no actual electrical connection between one side and the other. In many respects an infinitely long line has the same properties as a capacitor. It has metal conductors (the wires) separated by a dielectric (the insulation and the air).

But there is a difference between the electrical properties of a long line and a capacitor. In the case of a capacitor we can usually ignore the matter of inductance. The leads to the capacitor are so short the matter of inductance is of negligible concern, and except in the case of high-capacity capacitors at high frequencies we seldom need concern ourselves with the effect of inductance in the capacitor.

This is not true in the case of infinitely long lines. Because of its length the matter of inductance becomes of considerable importance. This means there are two electrical properties connected with the long lines which must be considered. First is the capacitance which exists between the lines as indicated by Fig. 5. Second, is the inductance of the lines themselves. Although the lines are actually straight wires as shown in Figs. 4 and 5, they could be represented electrically as shown in Fig. 6. That illustration shows the two wires in the form of two endless inductances.

If the inductances and capacitances are both taken into consideration, as they both must be, they could be represented as in Fig. 7. Even that illustration is not entirely accurate since it represents the capacity as being a group of individual capacitors. Actually the capacity is a continuing thing, being equally distributed throughout the entire length of the lines.

Before we go any further it would be well to pause for a moment and explain two terms which have not been previously made entirely clear. This is the matter of "lumped" capacity and inductance, and "distributed" capacity and inductance.

If we were to go into a radio supply house and purchase a capacitor or an inductor they would sell us an electrical component which has a definite amount of capacity or inductance lumped, or placed, or located at one place. It is so much "lumped" capacity, or inductance, because it is all congregated at one spot. Therefore we call such capacity or inductance "lumped" constants.

On the other hand we always have a certain amount of capacity existing between conductors in electrical circuits, and a certain amount of inductance distributed along the

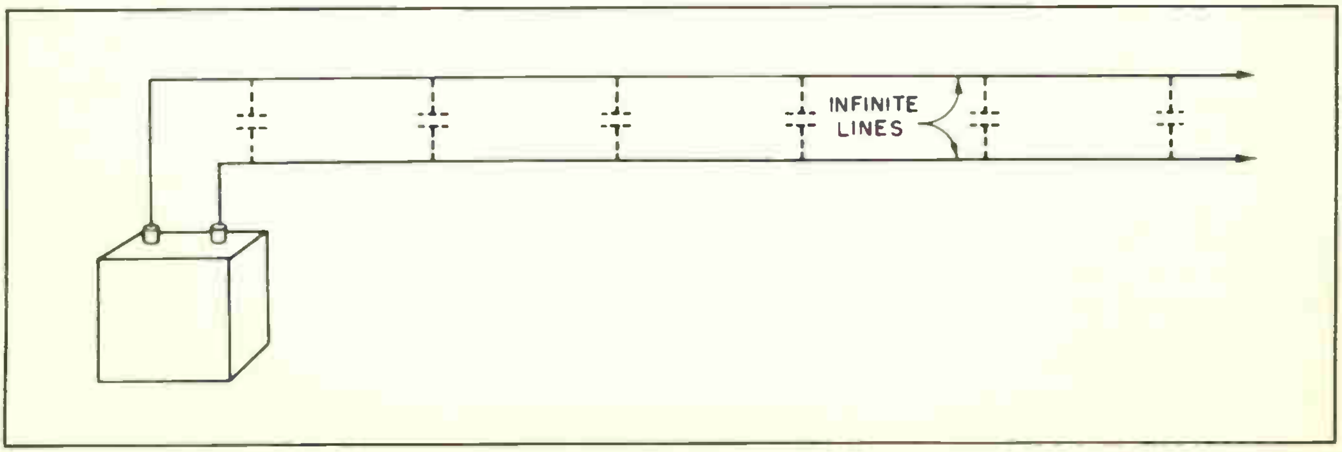

Fig. 5. There is Distributed Capacitance Between the Wires of a Pair of Conductors.

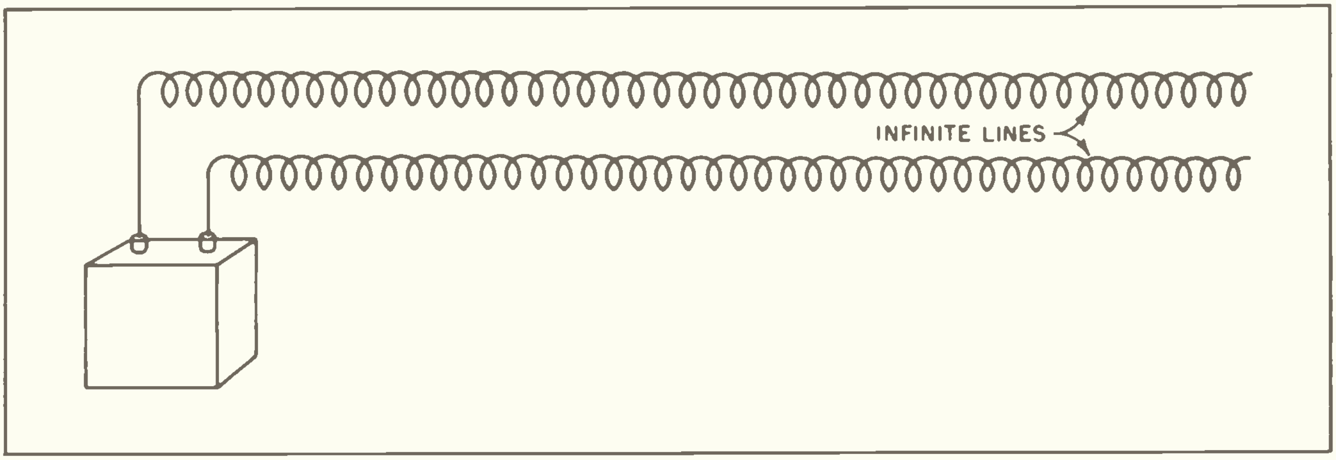

Fig.6. All Conductors Contain Distributed Inductance.

length of a wire. Since these electrical effects are not all located at one spot, that is, are not "lumped" in one location, we say they are "distributed" throughout the circuit. Therefore it is customary to speak of such capacity and inductance as being "distributed capacity" or "distributed inductance".

It is somewhat difficult to represent such distributed capacity and inductance schematically. To get around such difficulty it has become the general practice to represent it as shown in Fig. 8. There we show the distributed inductance and capacitance as several inductances and capacitances. The capacitances are in parallel and the inductances are in series. In this way the continuing electrical properties which are distributed continuously along the line can be treated as though they were lumped in several concentrations. There are several ways of determining the amount of inductance which will exist in any particular conductor.

Usually the total impedance will depend upon several physical characteristics of the wire. By this is meant the total physical length of the wire, the physical diameter of the wire, and the spacing between the wires.

One widely used formula for determining the inductance of a pair of wires a mile long makes use of the radius of the wires and the distance between the two wires. The formula is given as:

$$L = 1.482 \log \frac{d - r}{r} \times 10^{-3} \text{ henries per mile.}$$

Here we find:

L = total inductance in henries per mile,
d = distance between the centers of the two wires,
r = the radius of each wire.

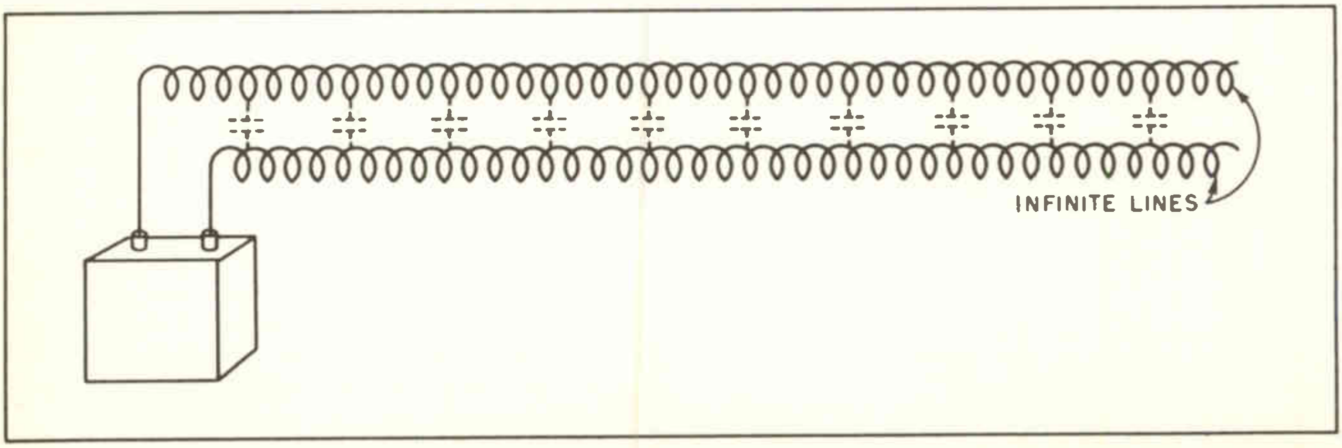

Fig.7. Any Pair of Wires Used to Conduct Electrical Energy Contains Both Inductance and Capacitance.

The units used in measuring the radius of the wires and the distance between their centers can be any unit of measurement, just so long as they are the same. The units of measurement can be millimeters, centimeters, inches or mils. The important feature is that they should all be the same. The preceding formula applies specifically to two wires which are parallel to each other.

There is another similar formula which applies to what are called "co-axial" cables. A co-axial cable consists of one conductor being placed within another tubular hollow conductor. (See Fig. 28.) When two conductors are so placed they will both have the same center axis, in other words they will be *co-axial*. This means the center of the inside conductor will have the same center as the center of the outside conductor.

never have to calculate such inductance. In these days it is not so necessary to work out the exact inductance of a long line as was once the case. Nevertheless, it is comforting to know that should the occasion ever arise where you did have to determine such inductance you would be able to do it.

The determination of the amount of capacitance in such a circuit is a much more difficult matter than the determination of the inductance. The total capacitance will depend upon the distance between the conductors and the type of dielectric. Since the dielectric will normally consist of both air and some other insulating material the determination of the total capacitance in a circuit is quite a difficult task by means of calculation alone. Should it ever be necessary to determine the capacity in a particular circuit it is usually more convenient to measure it than to calculate it.

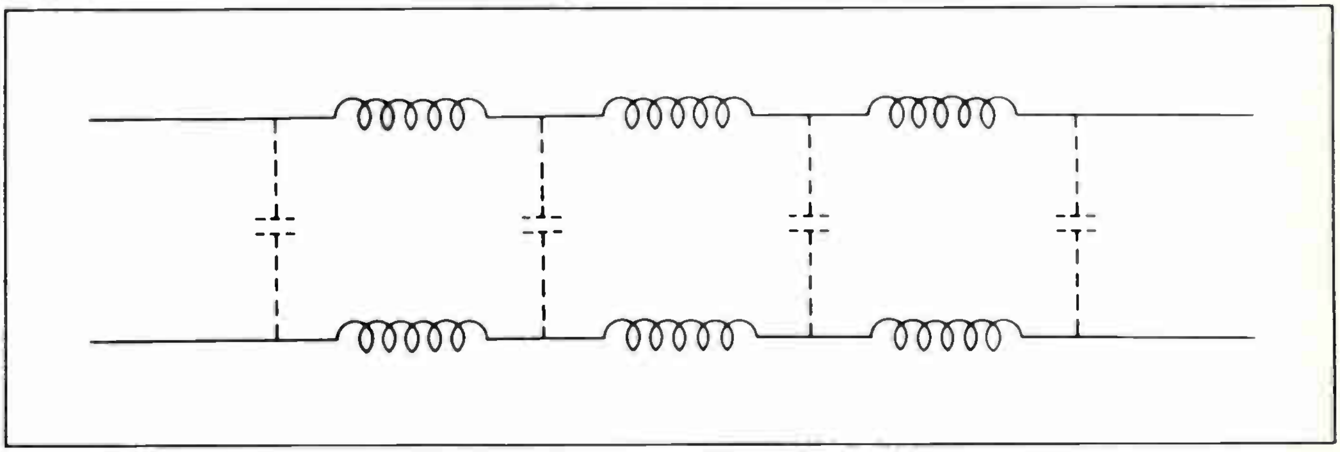

Fig. 8.

There are certain advantages to a co-axial cable, and they are widely used for many purposes. The inductance of two conductors so positioned with respect to each other must be calculated in a different manner from that of two conductors which parallel each other. The formula for finding the inductance of a co-axial conductor is given as:

$$L = 0.741 \log \frac{a}{b} \text{ mh/mile.}$$

where

b = the radius of the outer conductor,
a = the radius of the inner conductor.

Now you may think that it is not very practical to use the two formulas we have just given you to obtain the inductance of a long line. And perhaps it isn't. You may

The important thing at the moment is that you should understand that at the instant the two long lines in Fig. 4 are connected to the battery which provides a source of voltage a current will begin to flow in the two wires. Current will flow regardless of whether or not the two wires are connected at the far end.

Remember further, the time element involved is a very important factor. During the first microsecond current will begin to flow within the first 300 meters of line. During the second microsecond the current will begin to flow in the second 300 meters of the line.

Now, instead of the battery as a source of voltage suppose we provide our A-C gener-

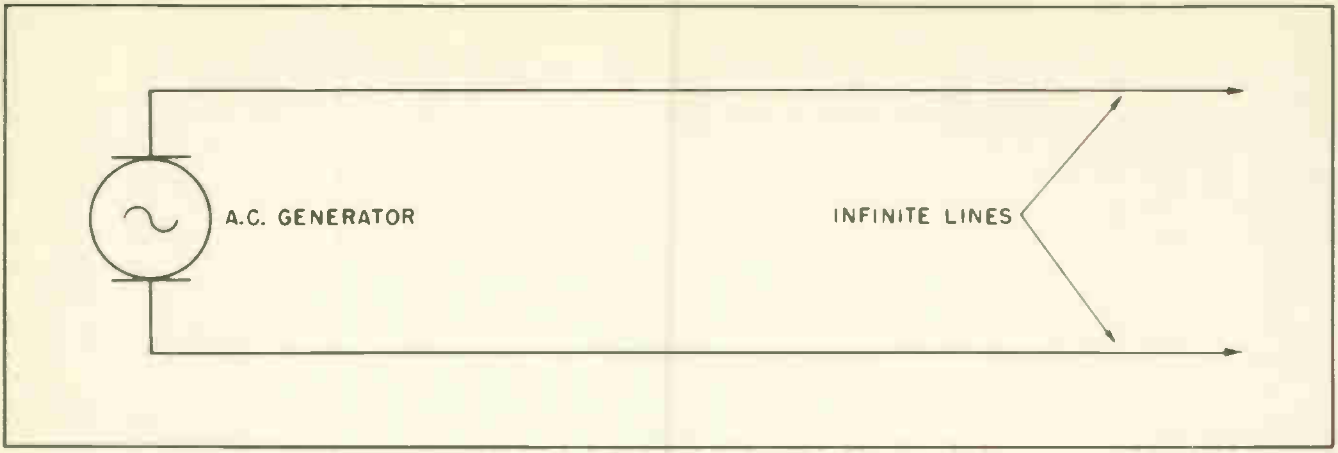

Fig.9. An A-C Generator Connected to an Infinite Line.

ator again. This is shown in Fig. 9. Here we see an A-C generator capable of generating 500,000 cycles of A-C feeding into our long line.

In Fig. 10 we see the 500,000 cycle generator feeding a signal into the long line. The entire line is not shown but we can see the first two sections of the line, each of which is 300 meters long. At the instant shown in Fig. 10 the upper connection to the alternator is negative and the lower connection is positive.

At a frequency of 500,000 cycles per second each half-cycle will be one microsecond long. During the first half-cycle the negative terminal of the generator will cause electrons to move away from the alternator. During this half-cycle the effect of the negative voltage at the terminal will be able to reach out for a distance of 300 meters as shown in Fig. 10. But during that period there will not be enough time for the influence of the negative voltage at the terminal to reach out further than that distance.

The other line will be affected in a like manner. The positive terminal of the alternator will attract electrons from the lower line. During the period of one-half cycle, which is equivalent to one microsecond, the electrons will be affected for a distance of 300 meters from the alternator as shown by the arrows along the lower line in Fig. 10.

At the end of one microsecond, then, we find the voltage on the upper wire has reached out to a distance of 300 meters and is just ready to begin affecting the electrons in the second 300 meter section of the line. Much the same thing is true along the lower line. We see the voltage pulse has also reached out there to affect the electrons in that line, and at the end of one microsecond has been able to travel a distance of 300 meters along that line.

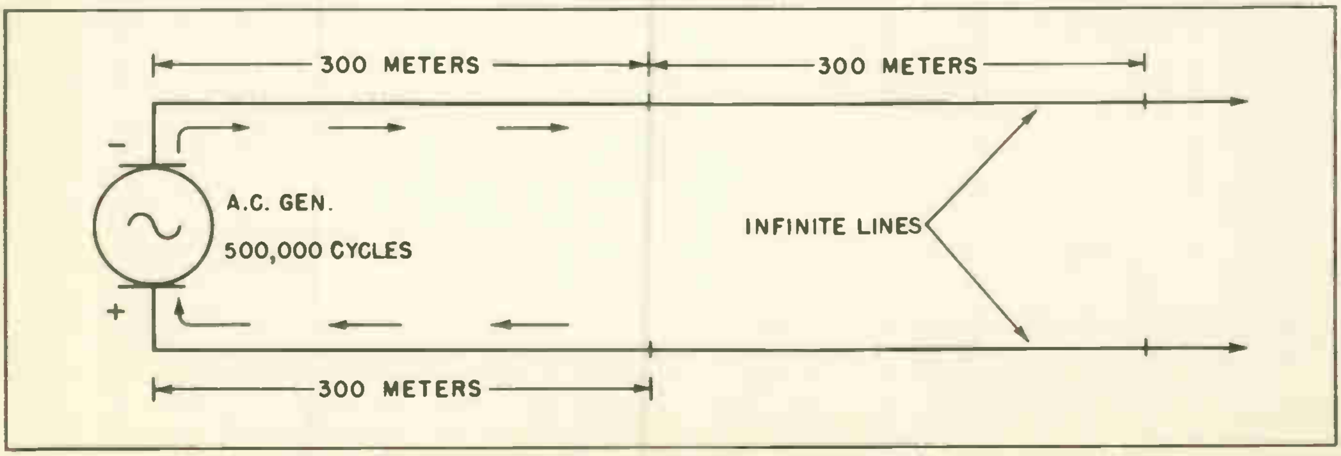

Fig.10. Current in an Infinite Line During the First Half-Cycle When the Source is a 500,000-Cycle A-C Generator.

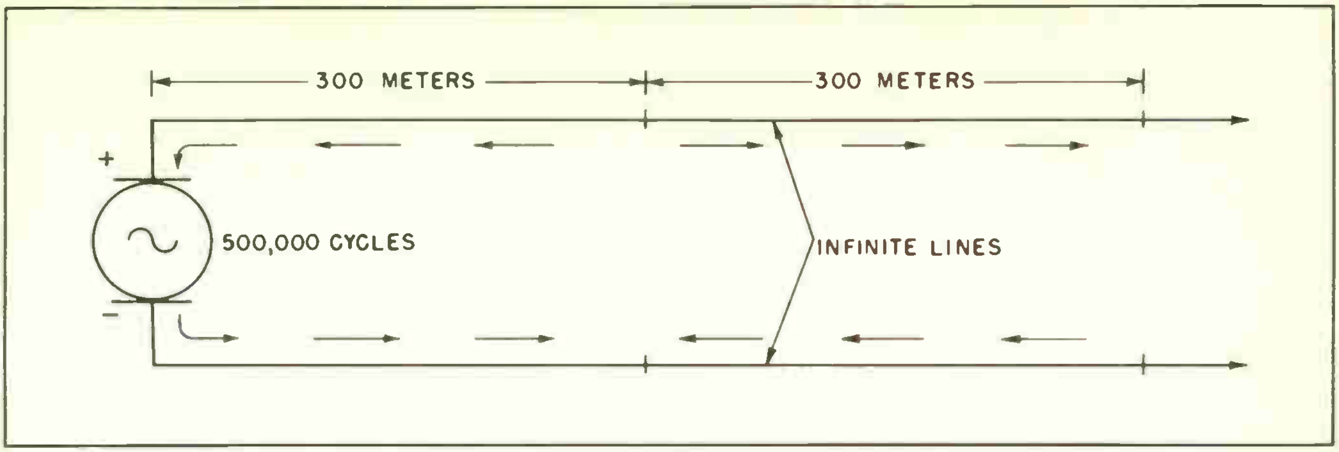

Fig.11. Current Distribution During the Second Half-Cycle Where the Source is a 500,000-Cycle A-C Generator.

It is just ready to begin affecting the electrons in the second section of the line.

Now at the end of the first microsecond the voltage at the terminals of the generator will reverse itself. Instead of the polarity of the upper terminal being negative it will now be positive; and we find the voltage at the lower terminal will be negative instead of positive. (See Fig. 11.)

This reversal in the polarity at the terminals of the alternator will cause the current to reverse in the lines which are connected to the terminal. Thus we find the current in the wire of the two lines will begin flowing in the opposite direction. (See Fig. 11.) There is nothing unusual about this, we have gone over this situation many times in our course.

But what about the voltage and the current out there in the second 300 meter section of the line? That section will know nothing about the reversal of the voltage at the generator until it is notified of it another microsecond later. In the meantime the section of the line which consists of the second 300 meter section is still under the influence of the voltage which existed when the polarity of the generator was as shown in Fig. 10. Thus, during the second microsecond we find the current in the second 300 meter section flowing in the same direction as it flowed in the first 300 meter section during the first microsecond.

Now we find that during the second microsecond the current in the first 300 meter section of the line will be flowing in one direction, while the current in the second 300 meter section will be flowing in the opposite direction. This is as shown in Fig. 11.

At the end of the second microsecond the polarity at the alternator will again reverse itself. The current in the conductors

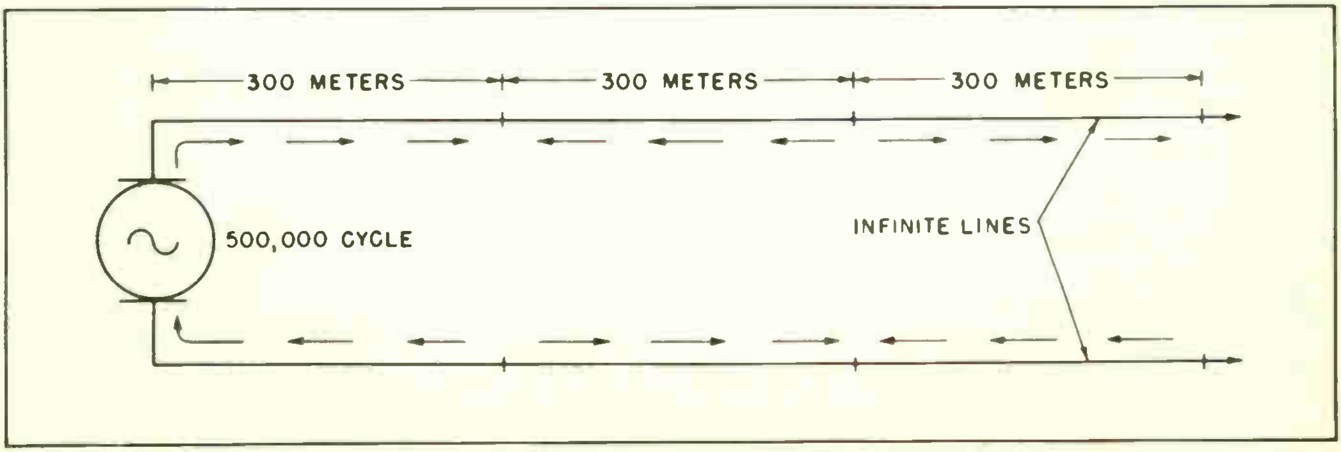

Fig.12. Current Distribution During the Third Half-Cycle Using a 500,000-Cycle Source.

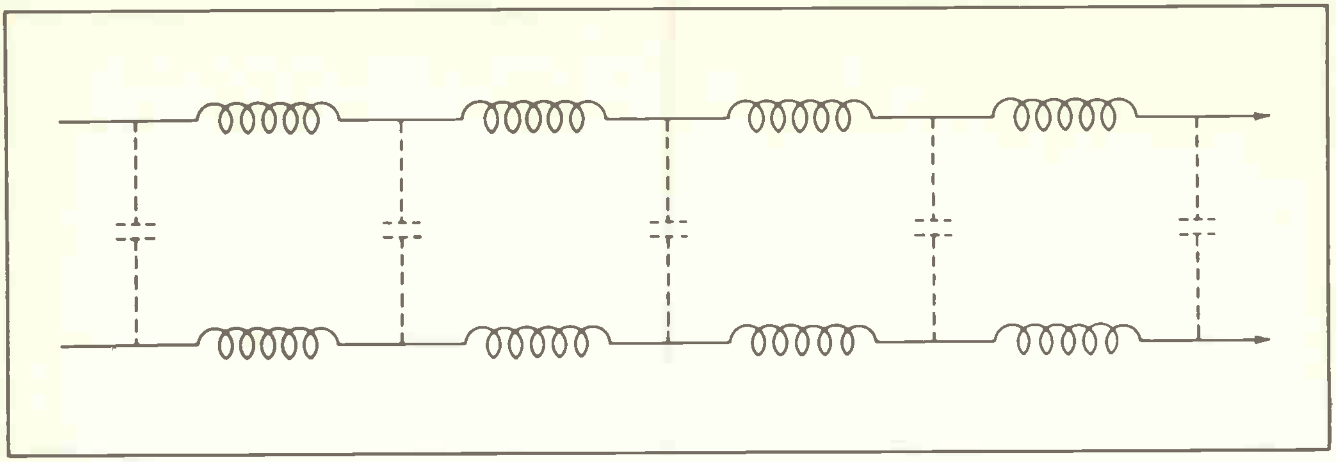

Fig. 13.

immediately adjacent to the generator will again start flowing in the same direction as during the first microsecond. This means that during the third microsecond the current in the first three 300-meter sections of the line will be flowing as shown in Fig. 12. Here we find the current in the first 300-meter section flowing in one direction, that in the second 300-meter section flowing in the opposite direction, and the current in the third 300-meter section flowing in the same direction as in the first.

As time passes and the voltage effects from the generator reaches out further and further we will find that in each 300-meter section of the line the current will be flowing in the opposite direction to the current in the adjacent 300-meter section. This condition will exist as far out on the line as the voltage is capable of reaching. Theoretically the voltage may get weaker and weaker as it becomes attenuated by the constants of the line, but is capable of reaching out to an infinite distance. Actually, of course, under practical conditions the signal would eventually become so weak as to become worthless.

Section 4. **CHARACTERISTIC IMPEDANCE**

We have mentioned the matter of *characteristic impedance* many times. Whenever we have mentioned it before we have always told you that we would defer an explanation of it until later in the course. Now we will discuss it in detail so you will understand what is meant by the term.

It is only fair to mention that characteristic impedance is also widely known as *surge impedance*. It makes no difference which term is used, both refer to the same thing. Surge impedance is the term which has been most used for many years. But characteristic impedance seems to be the more accurate and more descriptive from a technical viewpoint.

Let us go back and consider the situation of the A-C generator in Figs. 9, 10, 11 and 12. When that generator "looks" into a circuit consisting of two parallel wires it "sees" a rather complex system of impedance. It "sees", of course, the customary resistance which is inherent in any electrical conductor. But in addition to the resistance it also "sees" the capacity which exists between the conductors and the inductance which is also an inherent part of the conductor.

The existing capacity in the circuit will remain reasonably constant for all frequencies, but such will not be true of the resistance and the inductance. The resistance will change at the higher frequencies due to the peculiar phenomenon known as "skin effect". The "skin effect" has a tendency to force the current to flow at the higher frequencies more and more on the surface of the conductor.

Because of this, the inner portion of the conductor is used less and less. In one respect this is practically the same as reducing the cross-sectional area of the conductor as the frequency increases. If the current does not use the inner portion of the conductor such inner portion serves little function as a conductor. Since this is the same as reducing the cross-sectional area it has the effect of raising the resistance at the higher frequencies. Because the current tends to flow more and more on the surface of the conductor at high frequencies there are fewer linkages of the magnetic fluxes which result in a slight decrease in the inductance. This is the reason we say the resistance and the inductance changes slightly with the increase in frequency.

But to get back to our consideration of the peculiar electrical property we call characteristic impedance. The A-C generator will "look" into the line and see a complex impedance composed of the distributed inductance, the distributed capacitance and the resistance of the conductors. Ignoring the resistance for the moment the circuit "seen" by the generator could be diagrammed as shown in Fig. 13. There would be a continuous series of inductances and an endless group of capacitances.

Now such a line will have a rather peculiar property. If we were to take a mile long section of such line we would have a certain amount of inductance. The exact amount of inductance would depend upon the size of the conductors and the distance apart, etc. The same length of line would also have a certain amount of capacitance. Here again the exact amount would depend upon several factors.

We could set up a ratio of that inductance and that capacitance in this manner:

$$\frac{L}{C}$$

If we knew the exact values of the inductance and the capacitance the ratio would become a very real number, a definite figure.

For the moment we are not particularly concerned with the exact amount. We are merely content to say that for any existing condition of a pair of parallel conductors there would be some definite ratio of the inductance to the capacitance.

Now the interesting thing is that if we were to actually determine the ratio of the inductance to the capacitance in a line one mile long, then went on to determine the ratio of the inductance to the capacitance of a one-half mile length of the line we would discover the ratio to be exactly the same.

This might be surprising at first, but if we stop to think about it for a moment it will not be as surprising as we first thought. If we measure the inductance of the line for one-half mile we will find it to be just one-half the inductance of one mile; furthermore, if we measure the capacitance for one-half mile we will also find it to be just one-half the capacitance of the mile-long length. Since both the inductance and the capacitance have been reduced by one-half the ratio between them still remains the same.

We could carry this experiment still further. We could measure the inductance and the capacitance for any given distance; one-quarter mile, five-hundred feet, a hundred feet, twenty-five feet, or any other distance. We would find that changing the length of the line would change the inductance and the capacitance of the line, but it would not change the ratio between them. As one is increased the other is increased, as one is decreased the other is decreased.

From all this it follows that we can take a short portion of any transmission line and study it. What we find to be happening

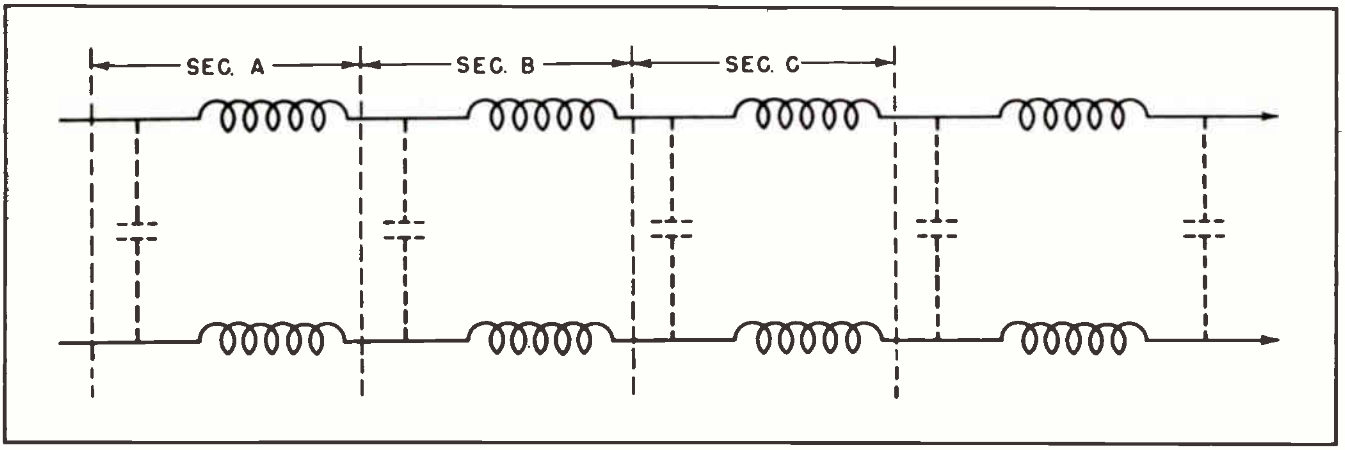

Fig. 14.

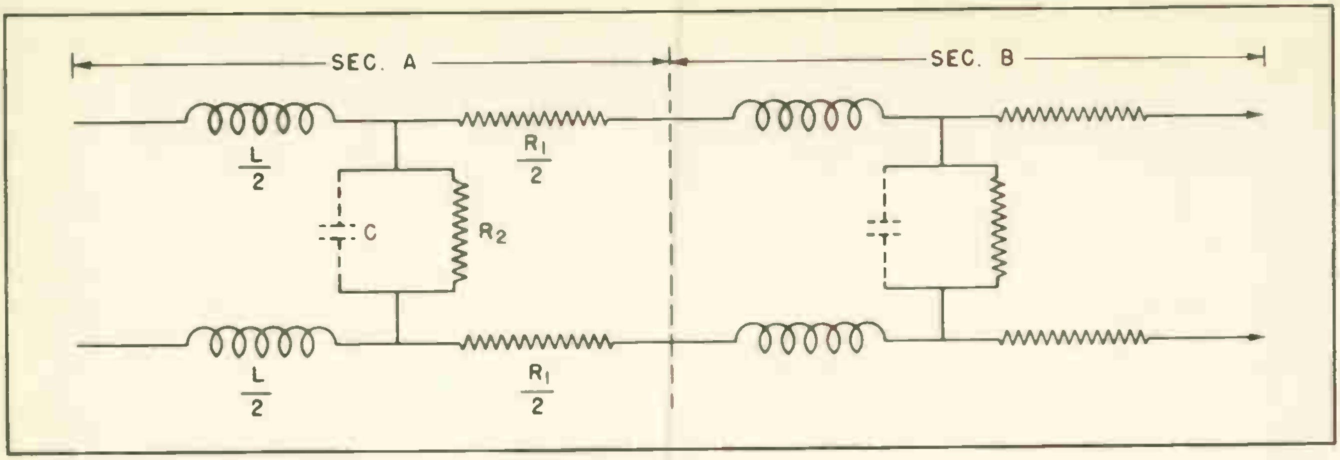

Fig. 15.

there is essentially what we will find happening in all parts of the same circuit. If we take the long line shown in Fig. 13 and divide it up into shorter sections as shown in Fig. 14 it will become easier for us to study the line. More than this, whatever we learn about the shorter line will be equally applicable to the longer one.

Thus far in our consideration of the long line we have mentioned only the capacitance between the two conductors and the inductance of the conductors themselves. But, as in all other conductors, we must take into consideration the resistance of the conductors.

Strangely enough we now find that we must take into consideration *two* kinds of resistance. It is only natural that we must consider the resistance of the metal of the conductors. But it is not so easily understood that we must also take into consideration the resistance of the dielectric between the two conductors. The truth is, however, that we must do so.

You will remember that in one of our earliest lessons we told you that every conductor had a certain amount of *resistance*, yet on the other hand every insulator had a certain amount of *conductance*. Actually every type of matter is an electrical conductor to some extent, but some materials are much better conductors than others. We consider those materials which readily pass electrons to be good conductors, or merely *conductors*. On the other hand those materials which do not readily pass electrons are considered to be *insulators*.

All this may seem elementary to you at this stage of your training, but we want to impress these truths upon you so you can more readily understand the other things we want to tell you in this lesson.

You will also recall from your earlier lessons that several elements enter into the amount of resistance any material will present to the passage of electrons. One of these is the kind of material. But another important element is the *cross-sectional area* of the material. In the case of the insulation, or dielectric, between the conductors of a long line the material may be so highly resistive to the passage of electrons that it is considered a good insulator; nevertheless the cross-sectional area of the path between the two conductors is quite large. This means that even though a small area of the material might have a resistance of many million ohms a much larger cross-sectional area would have a much lower resistance.

The main point to remember is that we have two types of resistance to consider when trying to determine the characteristic impedance of a line.

What all this means is: we must now redraw our circuit in Fig. 14 so as to include the various resistances which are a definite part of the circuit. The circuit as redrawn would look like the one in Fig. 15.

In Fig. 15 we see a resistance in series with each of the inductances. This is only natural, since each of the wires contains some resistance, and since the resistance and inductance is contained in the same locations it is, of necessity, in series with each other.

We also see a resistance in parallel with each of the capacitances. Following our explanation of the resistance which exists between the lines this should now appear right and proper to you.

You will note that the inductance in Fig. 15 is shown as:

$$\frac{L}{2}$$

You may wonder why this should be. The reason is that regardless of what length we use as a section of the line the inductance in either line will amount to only half the inductance in the section. The reason is that each section will have a certain amount of inductance; and since each of the lines are equal to the other, each of them will contain the same amount of inductance. Therefore, each of the lines will contain only one-half the inductance for any given length of the section. The same reasoning applies to the series resistance. Each line would contain that amount of inductance and that amount of resistance even though the other line was not near. But since in a line such as we are discussing the two lines are always close together we always think of them as a unit. Therefore, for any unit length each wire will contain only one-half the inductance and one-half the resistance for that unit of length.

But in the case of the capacitance the situation is slightly different. The capacity is *between* the two lines, not a part of either. Furthermore, the resistance of the dielectric is also between the two conductors and not a part of either one. This means that for any unit length of the line the capacity between the lines will amount to a certain amount, and the same will be true of the resistance of the dielectric.

All this being true it is possible for us to show all the inductance in each section in only one of the lines and the series resistance in only one of the lines. This has been done in Fig. 16. By arranging the inductance and the resistance in this manner it becomes easier to work out the impedance for any unit length of the line.

You will probably have already noticed that there are two kinds of impedances present in each unit length of the line as shown in Figs. 15 and 16. There is the series impedance composed of the inductance and the resistance shown as R_1. In Fig. 17 we have shown these two circuit elements as Z_1.

In Figs. 15 and 16 there is shown another impedance consisting of the capacitance between the lines and the resistance which exists between the lines. This is shown as C and R_2. In Fig. 17 this capacitance and resistance is combined to form impedance Z_2.

Here we also find two kinds of impedance, one a series impedance and the other a parallel impedance. We are not going to show you all the calculations which are necessary to develop the formula for characteristic impedance, but any of the advanced texts on communication engineering will show you that it will turn out to be:

$$Z_o = \sqrt{Z_1 Z_2}$$

where the symbol Z_o is used to represent characteristic impedance.

Now suppose we connect the generator we used back in Figs. 10, 11 and 12 to the transmission lines we have developed in

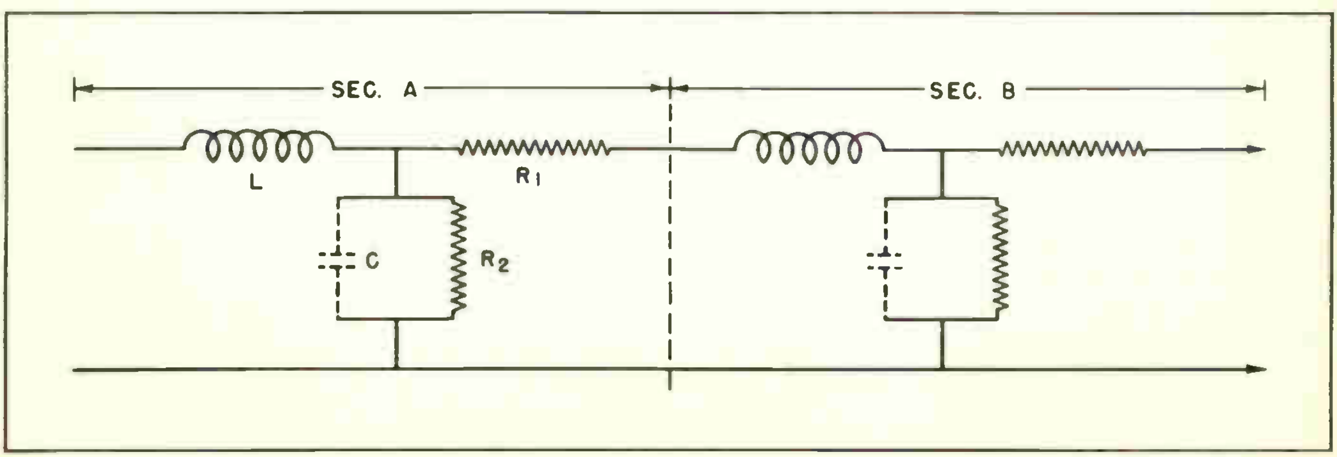

Fig. 16.

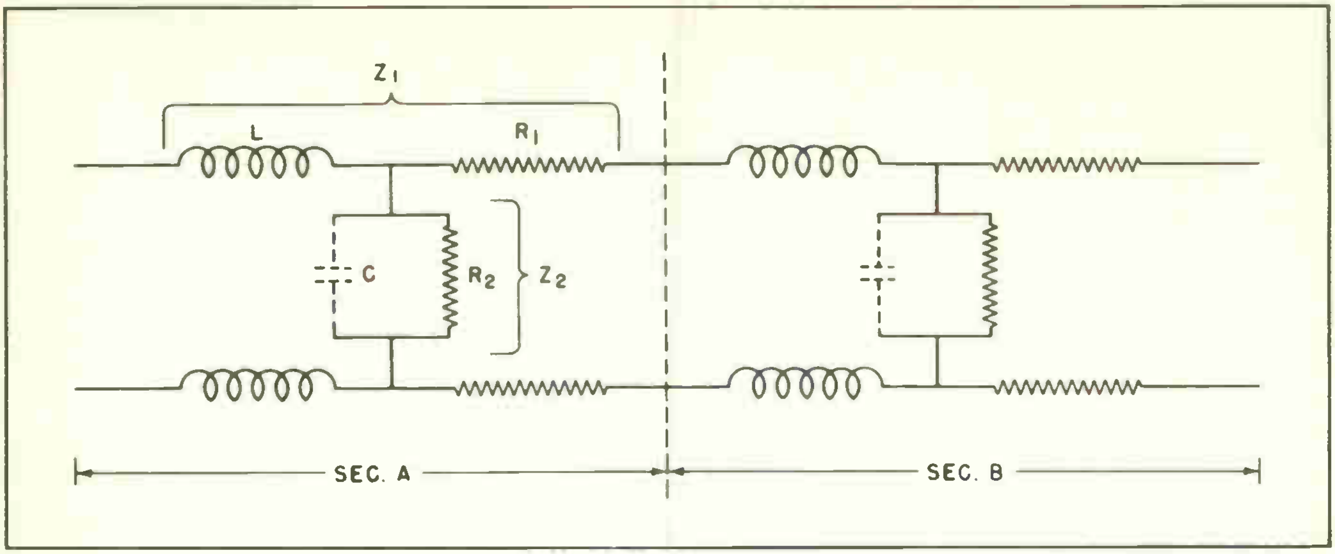

Fig.17. The Composition of the Two Types of Impedance Found in a Transmission Line.

Figs. 16 and 17. At the terminals of the generator there will be a certain amount of current flowing. We can designate that current as *I*. The exact value is of little importance at the moment. This is shown in Fig.18.

The generator will also develop a certain amount of voltage. Here again the exact amount is of little importance at the moment.

As soon as either the current or the voltage gets away from the generator both

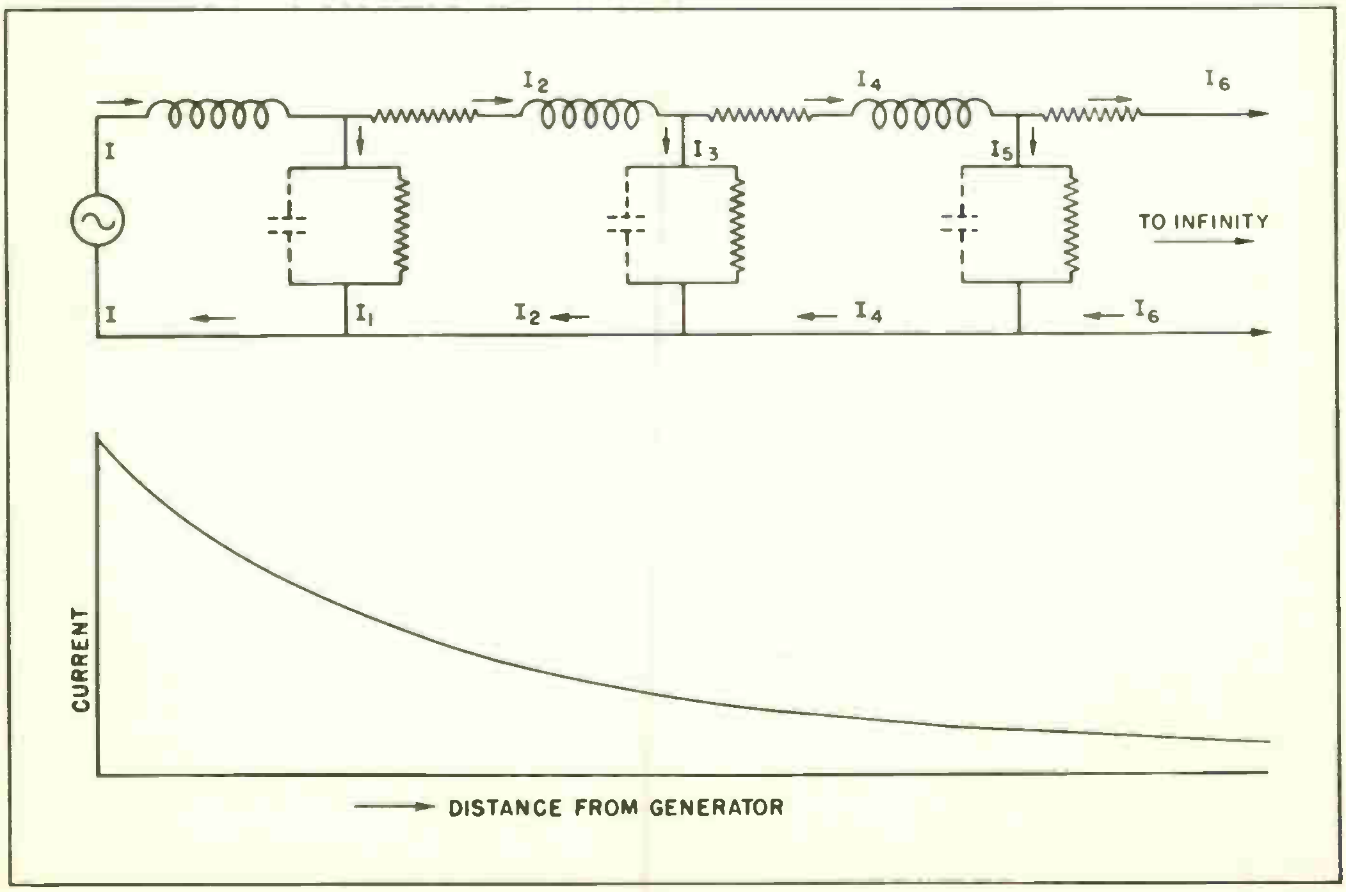

Fig.18. The Current Distribution in an Infinitely Long Transmission Line.

are going to start diminishing. As the current flows through the resistance it will create a voltage drop, thus reducing the voltage. Further than this we will find part of the current being diverted from its path down the transmission line and will pass, instead to the other line through the leakage resistance and through the capacitance which exists between the lines.

We see the current I in Fig. 18 leaving the generator. Part of the current is diverted. This is shown as I_1. The balance of the current continues on down the line as I_2.

I_2 is equal to $I - I_1$.

graph immediately below the circuit diagram in Fig. 18 shows the magnitude of the current and the voltage growing progressively smaller as the line extends farther toward infinity.

The graph in Fig. 18 shows the gradual diminuition of the voltage and the current somewhat more accurately than does the diagram itself. The decline of the voltage and current is gradual because the capacitance, inductance and resistance in the circuit is distributed rather than being lumped as shown in the diagram.

While the diagram in Fig. 18 is designed primarily to show the decline of the current

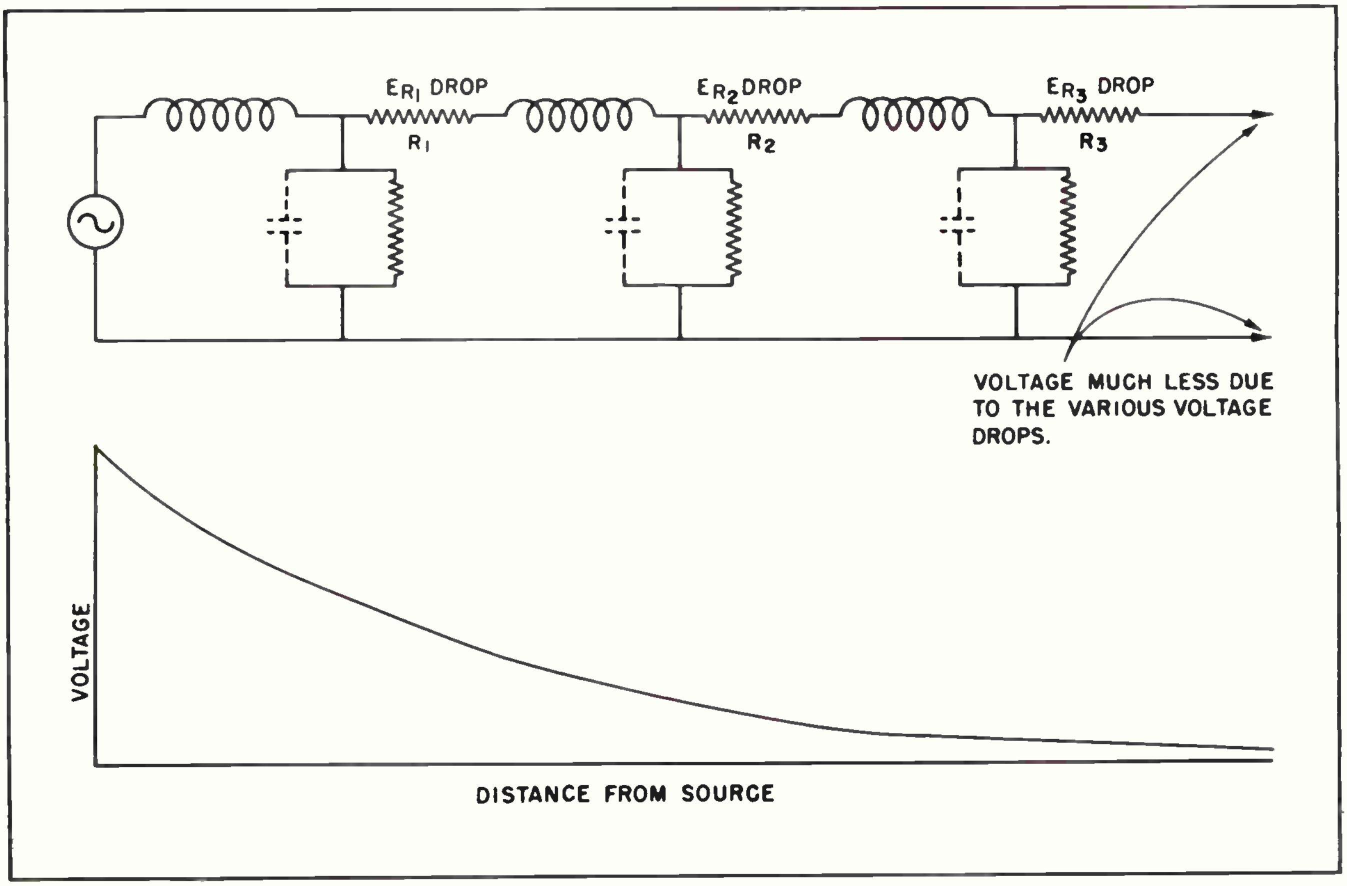

Fig.19. The Voltage Distribution in an Infinitely Long Transmission Line.

A little later we find some more of the current being diverted. This is shown as I_3. The balance continues on down the line as I_4.

As the line stretches out further and further the magnitude of the current becomes less and less. As the current decreases we find the voltage also being reduced as we get farther and farther from the generator. The as the line becomes longer and longer, the truth is that the voltage will decline in the same manner. A similar diagram designed to show the drop of the voltage is shown in Fig. 19. There we see that the voltage also declines as the distance increases from the source.

One thing should be made clear before we go any further. In our diagrams we have shown only a few sections of the line. These sections can be referred to as "unit lengths". The units of length can be whatever one cares to make them. They can be an inch, a foot, a yard, a meter, a mile or some greater distance. Everything we have discussed will continue to hold good regardless of what unit of length might be chosen.

The main point you should understand is that despite the fact we have shown only a few unit lengths of the line the real truth is there will be many such unit lengths.

Now let's turn to our line of infinite length for a few moments. Such a line is an imaginary one that continues into the distance endlessly. In such a line a voltage and current wave-front which leaves the generator would theoretically continue on forever. Such a thing could happen only in a line of infinite length because a line which has some definite length would have some change in the characteristics of the line at the point where the line ended.

This can be better understood if we consider the load to be either an inductance or a capacitance. In either event the characteristic of the load would most likely be different from the characteristics of the line. Either the inductance of the load would be greater or less than that of the line, or the capacitance of the line would be greater or less than that of the line. It is very unlikely that it would be exactly the same.

Now if we consider inductances and capacitances to be elastic devices, which they are, they will return to the line most of the energy which is fed to them. This means that if our transmission line is ended in some kind of a load such as an inductance or a capacitance some of the energy fed the load is going to be reflected back into the line and will disturb the conditions we have been setting up there to be described.

But, if our line continues on indefinitely there will be no such disturbances or reflections, and the conditions we have been describing will be true.

Now if we have a line which contains no reflected energy it follows that it must be devoid of inductive or capacitive loads. From this we can infer that in an infinite line the load is *entirely resistive*. This brings us to another truism. Any line which has an impedance which contains only resistance will have a current and a voltage which are always in phase with each other. In effect what this means from a practical standpoint is that such line, having only resistance, will have an impedance which is *independent of frequency*. Neither raising the frequency, nor lowering it, will have any effect on the impedance of the line, because a change in frequency affects a line only when it can affect either capacity or inductance. Since this line is wholely resistive no change in the frequency of the signal will affect the impedance.

From all this one conclusion stands out so prominently it almost seems self-evident. This is that the impedance at any given point in the line will be equal to the ratio of the voltage to the current, because, by Ohm's Law, the resistance of any circuit is equal to the ratio of the voltage and current. Thus, the impedance at any point is equal to: $\frac{E}{I}$

Or, this can be said in another manner. The ratio of the voltage to the current at any point on the line is equal to the impedance of the line.

To make this a little more clear suppose we use some actual examples of the voltage and the current relationship in such a line. Suppose, by actual measurement, the voltage in a line somewhere near a generator is 75 volts while the current at that point is 0.25 amperes. By applying Ohm's Law to this example the resistance, or impedance, of the line at that location is equal to the voltage divided by the current. Thus, dividing the 75 volts by the 0.25 amperes gives us an impedance of 300 ohms; it gives us this impedance for the simple reason that 0.25 amperes will divide into 75 volts exactly 300 times.

We can pursue this same example a little further. Suppose that we measure that same signal at some greater distance along the line. It is entirely understandable that somewhere along the line the effect of the line resistance will reduce the voltage in half, or to 37.5 volts. A measurement of the current at that location will show that it also has been reduced by half, or to a value of 0.125 amperes. We can divide the 0.125 amperes into the 37.5 exactly 300 times.

We can apply this line of reasoning to any other part of the line, at any location. If we measure the voltage and the current at a point halfway between the first point of measurement

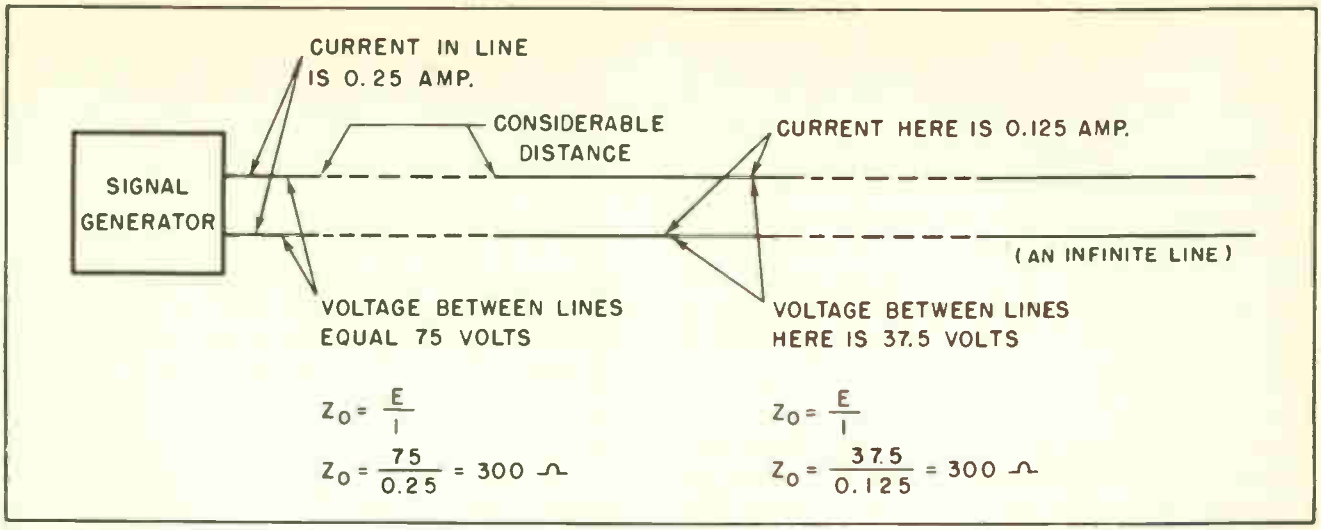

Fig. 20. Impedance of infinite line is equal to ratio of voltage to current, and is the same for all parts of line.

and the second point of measurement; and again divide the current into the voltage, we will find the impedance at that point is still the same -- it is still 300 ohms. See figure 20.

Or we can go on further down the line until we come to a spot where the voltage has again been reduced in half to only 18.75 volts. The distance here will be about twice as far from the second point of measurement as it was from the first point of measurement to the second, but this is only an incidental fact and has nothing to do with the impedance. If we were to measure the current flowing at the location where the voltage has been reduced to 18.75 volts we would find the current flowing at that location would amount to 0.0625 amperes. But when we use ordinary arithmetic to divide the 0.0625 amperes into the 18.75 volts we find the impedance at that location is still 300 ohms.

This line of reasoning, and this manner of applying the rules of electricity could be followed indefinitely, but regardless of how far we go we find the same conditions existing. Wherever we go along the line we find the voltage present, and we also find a current. Further than this, we will find that the ratio between them will remain constant, the impedance will remain unchanged, it will always be 300 ohms.

This conclusion points up this truth: the impedance of an infinite line is the same at all points along the line.

This is the impedance we call the characteristic impedance of the line. For any given length of the line that characteristic impedance will remain the same, will remain unchanged. The characteristic impedance is, as its name implies, a characteristic of the physical construction of the line. Changing the frequency applied to the line will not change the impedance of the line; neither will changing the voltage affect the impedance. The impedance is determined by the physical construction of the line, the size of the conductors, the distance between them, and the material used as insulation.

Characteristic impedance is usually designated by the symbol Z_0.

In the foregoing examples we have deliberately used relatively high values of voltage and of current. We did this so we would have values we could work with more easily. But the same principles apply to actual operations when the voltages are very low, on the order of tiny fractions of a volt, and the current is also very small. If we were to use voltage and current values in these examples of the order commonly found in antenna lead-ins, and in similar places, we would have to devote so much attention to the handling of the figures we would have little left for studying the principles we have been discussing.

Section 5. REFLECTIONS

When dealing with any form of wave propagation, whether the wave-form energy is light, heat, electromagnetic, electrical, electrostatic, or hydraulic, we find many points of similarity among them. The physical laws governing the propagation of wave-form energy can always be applied, and the medium through which the wave-forms move has little bearing on the general, underlying principles.

One of the important laws governing such wave-form propagation has to do with the action which occurs when the waves pass from one medium to another, or when they pass from one composition of a medium to another composition of the same medium. Invariably changes will occur in the form of the waves when any such passing is attempted.

Were we to take a long tube and speak through it the sound would travel to the other end without great difficulty. There are a number of places where this has been put to practical use. Most of us know that we can send our voices to much greater distances with less effort when we talk through a tube or pipe. In the earlier days such speaking tubes were quite commonplace. Many apartment houses and other large buildings installed them so a person in one of the upper apartments in a distant part of the building could talk with someone at the front entrance or at some other location within the building. In the pipe or tube we have what amounts to a column of a medium; in this instance the medium is air. We have a column of air.

The use of such tubes often disclosed echoes. Bends in the tube would sometimes create echoes. Sometimes humidity or changes in the temperature of the air within the tube would also cause echoes. Any change of any kind in the dimensions or shape of the tube, or in the condition of the air within the tube, could create echoes. Of course, not all such echoes were objectionable, especially if they were weak, but the echoes would often be present just the same.

Fogs over open water, or over large flat land areas, often create echoes. This is the reason we sometimes hear echoes in a fog which are not audible at other times. The variation in the humidity of the air causes the sound waves to be reflected, reflections which are not normally present.

An even better illustration, one with which more people are familiar, is that of sunlight falling upon water. If the water is clear the sunlight, or a part of it, will penetrate the water and make stones and pebbles on the bottom of the still water clearly visible. But we also know that not all the sunlight is able to penetrate the water. If we are able to place ourselves in the correct position we will find a large percentage of the sunlight is actually

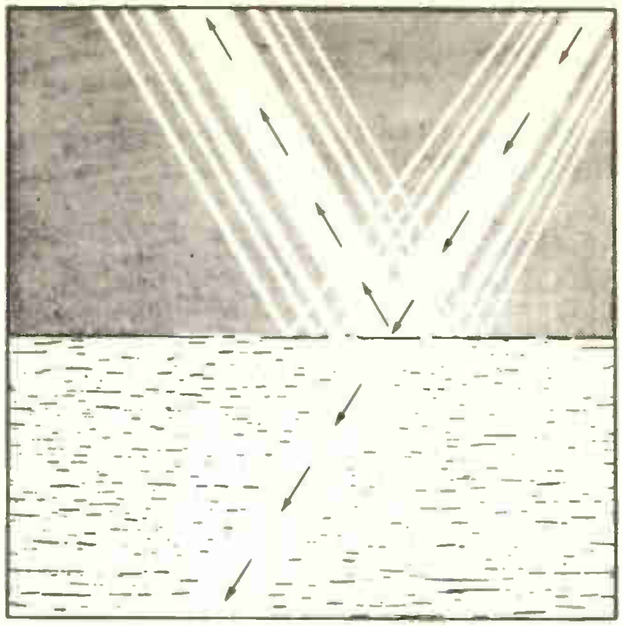

Fig. 21. When beam of light passes from one medium to another part of wave-motion energy in light is reflected.

reflected from the surface of the water. From this it is not hard to deduce that while part of the sunlight penetrates the water and illuminates objects in the water, not all of it does so. This effect is well known to most of us. but the principle is effectively illustrated in figure 21.

So long as the sunlight travels through a medium where there is no abrupt change in its composition none of the light will be reflected. But when it enters a different medium, or a different concentration of the same medium, part of the light will be reflected.

Probably the best known, yet little understood, example of light being reflected by a different concentration of the same medium is that of the mirages which are fairly common in desert areas. The air near the surface of the ground becomes so highly heated and expanded it has a much lower density than the air a short distance above. When light strikes this layer of thin air, which has a different density, some of the light is reflected. When light from distant objects, or scenes, strike such superheated layers of air, mirages are sometimes created. Mirages often result from a double reflection, the first reflection taking place several hundred, or several thousand, feet in the air where a layer of cold air overlays heated air. The second reflection occurs just above the ground where a layer of warm air overlays the very hot air just above the ground.

A variation of the conditions which make such mirages possible is often encountered when driving along the highway in the summertime. Sometimes the light from the sky will be reflected from superheated layers of air just above the roadway. Often the highway will appear covered with water. As you continue to drive, however, the water seems to disappear.

Light is a form of wave motion. Its reflection is brought about whenever the waves of light encounter a different medium through which it is traveling. An example of that occurs when the sunlight strikes water as described before. But the wave motion of light can also be reflected when the light strikes any change in the medium itself through which it is traveling. The mirages we have just mentioned are examples of that.

The action of electrical wave motion when it is traveling along a conductor is very much the same as that of light when it is traveling through air. Previous explanations have shown how electrical impulses could be sent great distances without changing the wave-form were it possible to construct an infinite line, (line without end) along which such impulses could be sent. The wave-form of the wave motion would not be changed because in such an infinite line it would never encounter any changes in the medium through which the waves were traveling; and since they encounter no change in their medium of travel they do not encounter any reflections from other waves which have preceded them.

It should be carefully noted right here that we are talking about the wave-form of the wave motion, the shape of the waves, their frequency, their relative amplitude, and such like. The shape of the waves which would pass any given point in such a hypothetical, infinite line would be just the same as when the waves left their point of origin. This does not mean there would be no change in the absolute amplitude--the strength--of the wave motion. There would be a diminishing in the strength as the waves moved to ever greater distances. But the shape of the waves would always remain the same.

This is important because electrical wave motion is often some kind of signal. This is true when used to send some form of intelligence from place to place. When such change occurs in the shape of the electrical waves so generated the manner of the intelligence transmitted is also changed in some way. When a man shapes his mouth and vocal cords in the manner necessary to form the letter S, the creation of that sound disturbs the surrounding air and sets in motion a series of air waves. When these air-waves strike a microphone they act to set up therein another type of wave motion, this time electrical wave-motion. But the general shape of the electrical wave motion is identical with the shape of the air-waves created by the man's voice.

If those electrical wave-forms are then applied to some kind of sound reproducing device such as a pair of headphones or a loudspeaker the sound of the letter S will be reproduced by again setting up air-waves having the same identical shape and wave-form as the original air-waves created by the man's voice.

However, if something happens somewhere along the line to change the form of those waves, either during the time they are in the form of electrical waves or during the time they are in the form of air waves, the sound of the letter S will not be reproduced. The sound that comes out of the sound reproducer will be something else. It might be F, or Z or C or something else, but it will not be S. If we want to reproduce the original sound, or the original something else, we can permit no change in the form of the electrical waves which carry the intelligence.

As we progress with our studies we find the problem of reproducing wave-forms, both electrical and in the air, assuming increasing importance. We mention the matter of wave-forms again at this time merely because we are presently dealing with the transmission lines over which electrical waves are so often passed, and are at the moment dealing with the reflections which so often occur in those lines. Reflections of any kind tend to distort or disturb the original shape of wave-forms. This is the reason we strive so hard to reduce reflections, and why it is necessary to first understand the nature of those reflections before they can be corrected.

Another form of reflections affecting electrical signals which has come rather prominently to the attention of the general public during recent months is that which occasionally affects the reflection of radar beams and sometimes tends to create false or spurious images on the screen of the radar scope. It is fairly well known that reflections of the radar signal occur when the signal strikes a cloud. When the radar beam, a form of wave-motion, strikes the cloud it passes from one density of a medium of travel to another density of the

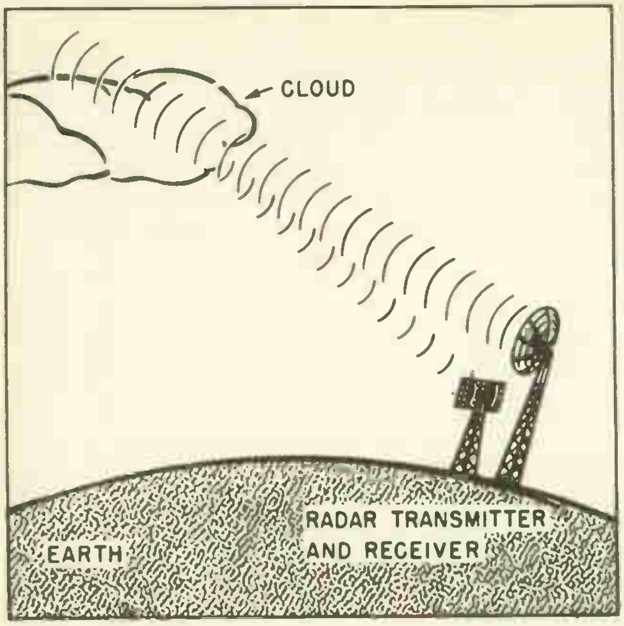

Fig. 22. Radar beams are form of wave-motion energy. Some of wave-motion energy is reflected when beam strikes cloud.

same medium of travel. Most of the wave-motion energy of the signal will continue along the path in the direction it has been following, but a small portion of the wave-motion will be reflected and can be picked up by the radar receiver and will appear on the screen of the radar scope.

It is not so well known that when a radar beam strikes a column of heated air, or a compact body of cold air, or some other change in the characteristic of the air, that reflections will also occur. But such is indeed true. Skilled radar operators are aware of these things, and soon become so skilled they readily recognize the pattern of the reflections from such things.

The fact that such things can affect radar operations has come to public knowledge in recent months in connection with the periodic reports of the so-called *flying saucers*. There have been proven instances of strange bodies being tracked by radar, reports of such tracking having originated in many widely separated areas. The official explanation of such instances has invariably been that natural phenomena were responsible for them. There has been no explanation of how experienced radar operators could have been so badly fooled, but there the matter rests at this time.

The important thing for us, however, is that whenever a wave of any kind traveling in any given direction through some medium of travel strikes any change in that medium some of the energy in that wave will be reflected. One of the best known examples of that reflection is the movement of a wave on the surface of a body of water. Such wave, once created, will move away from the source of the disturbance that created it. The wave will move continuously at a given rate of speed. If that wave strikes a post in the water, small waves will reform at the post and move in a direction opposite to that of the original direction of travel. If the original wave strikes the shore of the body of water other waves will be reflected back from the shore, such reflected waves moving in the opposite direction to that of the original wave. Figure 23 illustrates such action better

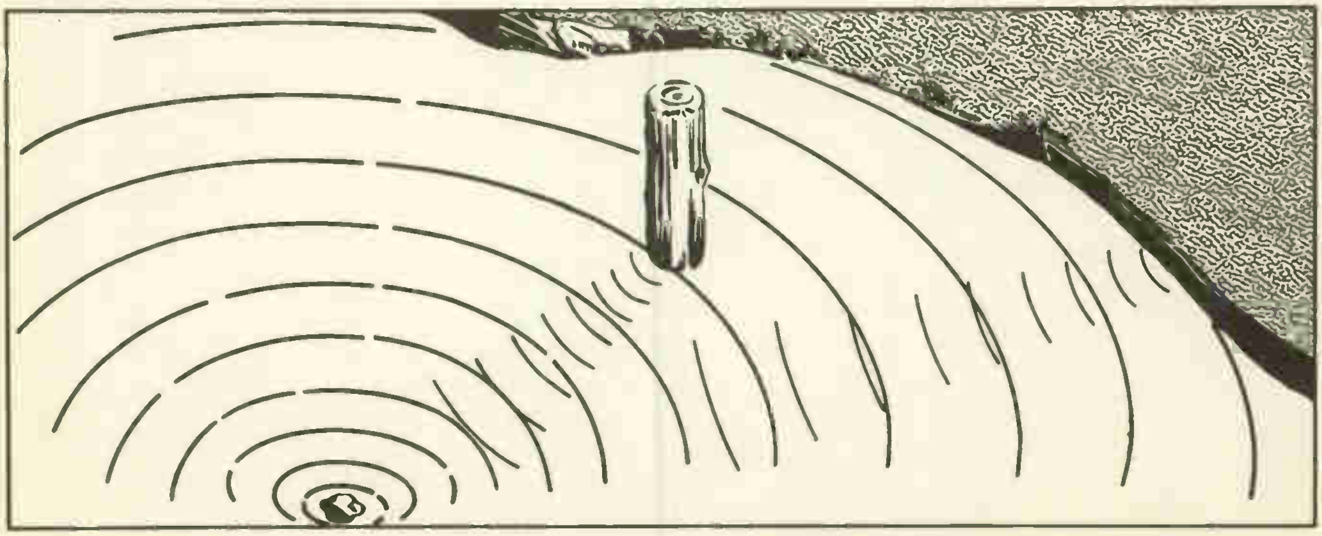

Fig. 23. Waves on body of water are form of wave-motion energy. Part of wave-motion energy reflected when waves strike obstruction, or change in medium of travel.

than words alone.

To get back to our study of transmission lines, and the problems we must face when working with them, it is readily understandable that we never construct infinite lines. In the first place such construction would be literally impossible because everything man has yet made is limited in some manner by size, it just would not be possible to construct any kind of line that would be so long it would have no end. In the second place there would be no use for such a line even if it could be constructed.

But the study of imaginary infinite lines has a very definite value. It prepares us for the problems we must face when dealing with practical lines, and provides us with a basis through which it will be possible to solve transmission line problems as they arise.

Section 6. IMPEDANCE MATCHING

Some of the things mentioned on the preceding page may seem a trifle intangible, to have little application to the practical side of television servicing, to mean little to the ordinary man in the repair shop or out on installation work. Yet those things about which we have been talking form a necessary background to make it possible for you to understand some of the other things which are very important for a television man to know.

Television men are constantly faced with the problem of matching the impedance of some source with that of a load, and probably matching the impedance of either the source or the load to the transmission line. There are also many other places where it is necessary to match impedances, such as that of matching the output impedance of a power tube with that of a loudspeaker. The problem of impedance is almost invariably tied up in some manner with that of the transmission line. Yet the characteristic impedance of a line is such an intangible thing it is always difficult to explain, and is sometimes almost impossible to understand. It is only by knowing the full background of the electrical action surrounding the operation of such lines that one can even hope to approach some degree of understanding.

From the things we have been telling you some idea of the pattern we have been discussing must now be forming before you. One of the things which must now be standing out before you clearly is that a transmission line consists of a pair of conductors. Such transmission line, with its pair of conductors, will have a characteristic impedance. That characteristic impedance will have properties which appear to consist solely of pure resistance.

The value of the characteristic impedance of that transmission line cannot be measured with an ohmmeter. Neither will a 100-foot length of the line have more impedance--or less impedance--than a length only 10 feet long. The value of the impedance of the line is not dependent upon its length. On the contrary, the value of the impedance is characteristic of that particular line, a characteristic which is determined by the size of the wire used in its construction, and the distance between the two conductors. In other words, upon the physical construction of the line itself.

The existence of such a line, a line which does have a definite characteristic impedance but which impedance is not affected by its length, brings up a problem. This is the problem of terminating such a line. Unless the line is infinitely long it must be terminated somewhere. But the very fact of the termination brings up the problem that such termination unavoidably brings about a change in the character of the line at its point of termination. And any change in the character of a transmission line will automatically create reflections of the signal waves passing along the line--reflections which are reflected back toward the source, and are definitely undesirable. The presence of such reflections will mix with the outgoing waves and create distortions in the original signal.

One thing stands out in connection with the use of transmission lines. This is the fact that if we are to use such lines they must be terminated. So, if we are to use them it is necessary to devise some method of terminating them so as to avoid the creation of undesirable reflections.

Experience and experiment has shown there is a way in which transmission lines can be terminated without introducing unwanted reflections. This can be done by terminating the line in a resistance which is equal in value to the characteristic impedance of the line.

The reason for this can be explained in this manner: When an electrical signal in the form of electrical wave-motion travels down a transmission line the impedance it encounters there is solely resistive. The value of that resistive impedance is determined by the characteristics of the line itself. There will be no change in the character of the wave-motion

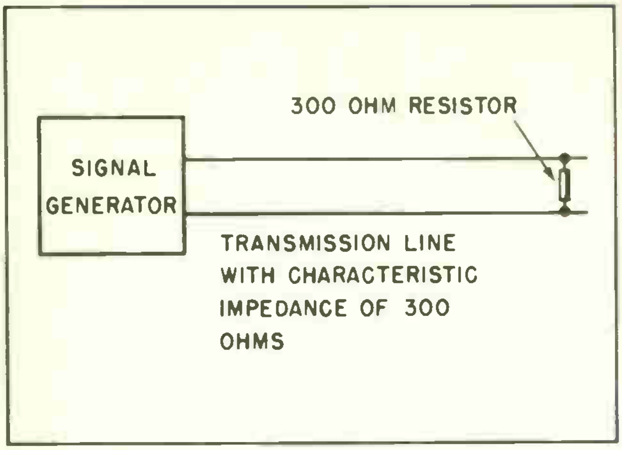

Fig. 24. When transmission line is terminated in resistance equal to characteristic impedance of line any wave-motion signal on line will have its energy absorbed in the resistance so none will be reflected.

signal so long as there is no change in the impedance, or resistance, of the line. If, at the end of the line, an ordinary resistor equal in value to the characteristic impedance of the line is connected across the line, such resistance will look to the wave-motion signal just like the characteristic impedance of the line, all the energy of the wave-motion will be absorbed, and none of the wave-motion energy of the signal will be reflected.

Thus it becomes practically possible to terminate the line without creating unwanted reflections.

In figure 24 we see a 300-ohm transmission line being fed a signal from a signal generator. There will be no reflections in such a line if the line is terminated with a 300-ohm resistor as shown in the diagram.

Something of the importance of knowing the characteristic impedance of a line can now be better understood. Unless the line is properly terminated reflections and distortion will be created in the line. But the line cannot be properly terminated unless its characteristic impedance is known.

There is something else which should be kept in mind about this matter of impedance, and impedance matching. It goes beyond the importance of terminating the transmission line in a resistance which is equal to the characteristic impedance of the line itself. The line, at best, is merely a transmission medium. It transmits a signal in the form of electrical wave-motion from some source to some load. It is important that the impedance of the line be matched to the impedance of the source--vitally important. Just as important as it is to make sure the impedance of the line does not change throughout its length.

We have pointed out how any change in the impedance of the line will set up unwanted and undesirable reflections. But if the characteristic impedance of the line does not match the impedance of the source there will be a *mismatch* between them. Such mismatch amounts to a change in the character of the path along which the wave-motion signal passes, and distortion can occur at that point. This means that we must watch the matching of the impedance of the source to the impedance of the line because such matching is just as important as maintaining a transmission line which has no changing characteristics along its length.

One place where we use transmission lines in television work is to bring the signal picked up by the antenna from that location to the television receiver in the home. The antenna itself has an impedance of its own. The impedance of the antenna is dependent upon its physical characteristics, and such impedance will be discussed in much greater detail when we take up the subject of antennas. The important thing at this time is that the antenna does have a characteristic impedance of its own.

In television work it is very essential that the impedance of the antenna be matched to the impedance of the transmission line which takes the signal to the receiver. Since all antennas do not have the same impedance this means that a line must be selected which has a given impedance if that line is to work properly with the antenna which has been selected. Fortunately, several popular antennas have an impedance of approximately 300 ohms. If such antenna is connected to a lead-in transmission line having a similar characteristic impedance the match between the two components will be good, the maximum amount of the signal will be transferred from the antenna to the line, and there will be a minimum of distorting reflections. From all this it follows that if an antenna is used which has an impedance of approximately 300 ohms it should be connected to a transmission line which also has an impedance of approximately 300 ohms; but if an antenna is used which has an impedance of 72 ohms it should be coupled with a transmission line which also has an impedance of 72 ohms. Of course, if some other antenna, such as a rhombic, is used which has an entirely different impedance from either of these, then a line having a similar matching impedance should be coupled to it. It is possible to couple an antenna having one characteristic impedance to a line which has a different impedance by using an impedance coupling transformer. But that is another matter, one that will be discussed in another lesson. They should not be coupled directly without a matching transformer.

It has been mentioned before that the characteristic impedance of a line depends upon its physical characteristics. It depends upon the size of the wire, upon the distance between the conductors, and upon the type of insulation used between them.

The distance between the conductors affects the capacitance which exists between them. The size of the conductors affects the inductance present in any given length of the conductor.

The closer the lines are to each other the greater will be the capacitance which exists between them. The larger the size of the conductor the lower will be the inductance of the conductor.

The characteristic impedance of any line is equal to the square root of the ratio between the inductance and the capacitance for any given length. This can be written in formula form in this manner:

$$Z_o = \sqrt{\frac{L}{C}}$$

when Z_o is used to represent the characteristic impedance.

From this it follows that anything that tends to increase the inductance or reduce the capacitance will automatically increase the characteristic impedance of the line. On the other hand, anything that tends to reduce the inductance or increase the capacitance will reduce the characteristic impedance of the line.

Since placing the conductors closer together will increase the capacitance between them this means that the closer the conductors are together the lower will be the characteristic of the line. In like manner, increasing the size of the conductors also reduces the inductance; so, increasing the size of the conductors also tends to reduce the characteristic impedance of the line. This is shown in figures 25 and 26.

On the other hand, moving the conductors farther apart reduces the capacitance between

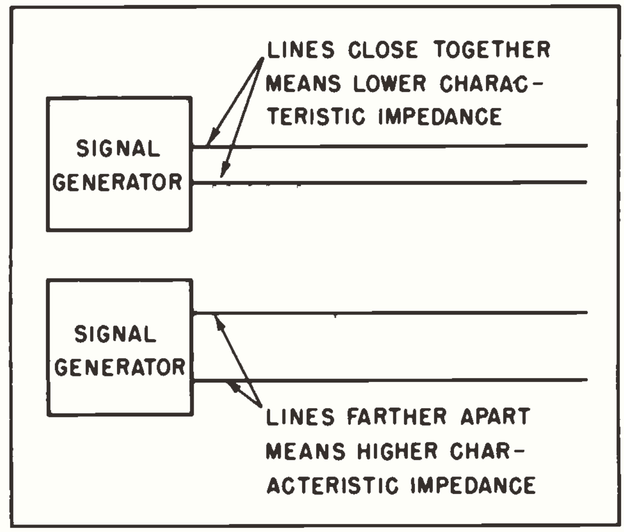

Fig. 25. Distance between conductors of a transmission line has bearing on characteristic impedance of the line.

the conductors, thus increasing the characteristic impedance of the line. Further, reducing the size of the conductor will increase its inductance, and this, in turn, will increase the characteristic impedance of the line.

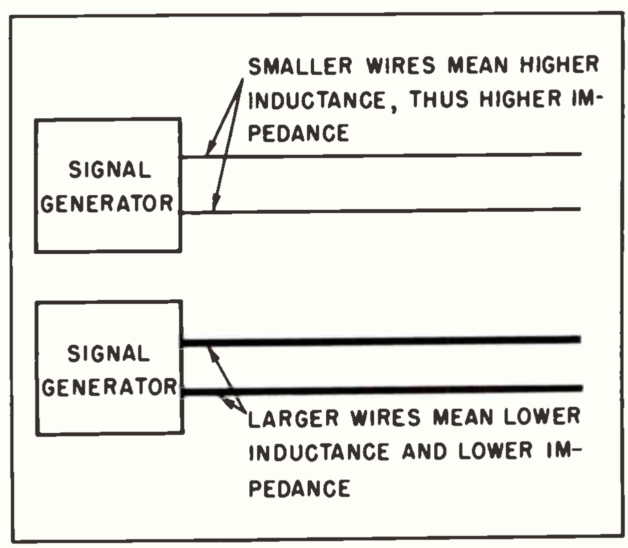

Fig. 26. Size of wires in transmission line has effect on inductance in conductors, and this, in turn affects characteristic impedance.

This all adds up to this; large conductors spaced closely together will have a low characteristic impedance. But small conductors spaced widely apart will have a high impedance.

The matter of the material from which the insulation is made enters into consideration because various materials have different dielectric constants. Thus, the material of the insulation will affect the capacitance between the conductors in a manner similar to the distance between them.

Normally the inductance of any given length of conductor will be very much greater than the capacitance which exists between the two conductors. This means the characteristic impedance will be from several ohms up to several hundred ohms. It will rarely be less than 1 ohm.

Section 7. ATTENUATION CONSTANT.

In addition to the characteristic impedance of a line, another element of a transmission line assumes importance. This is the *attenuation constant* of the line.

We showed you in figures 17 and 18 that the voltage and the current gradually decrease as they travel along the line. The amount of this line attenuation depends upon several factors. Among those factors are the kind of wire used in the line, and its size. It can be shown that for any given kind of transmission line there will be a certain amount of attenuation per length of the line.

This attenuation is called the attenuation constant of the line. The attenuation constant is largely responsible for the losses which occur in the line.

It has become the custom and practice among manufacturers of transmission lines to measure the attenuation of their lines in the number of decibels of such attenuation per hundred feet of length. The use of decibels for such measurement is much more practical than trying to measure the attenuation in terms of volts, amperes or watts, because decibels take into consideration the logarithmic (a mathematical) nature of such attenuation.

Section 8. COMMERCIAL TRANSMISSION LINES

There are a number of types of transmission lines which have been used from time to time during the history of radio, television and other methods of communication. But in general they tend to fall within a relatively few general types. At least, there are relatively few types in general use at this time.

In the earlier days of radio work and experimentation the twisted pair had rather wide acceptance. This was especially true among radio amateurs. Probably the best reason for such use was that an ordinary lamp cord could be used for that purpose and served surprisingly well.

A twisted pair is just about what its name suggests--nothing more than two wires insulated from each other, then twisted around each other in the form of a long spiral.

Twisted pair transmission lines have a characteristic impedance ranging from about 40 ohms to about 150 ohms. A commonly used type had an impedance of about 70 to 75 ohms, and was favored because it provided an excellent impedance match with a half-wave dipole antenna. A typical dipole antenna has an impedance of about 72 ohms, thus a twisted pair matched that impedance very nicely.

The twisted pair can be used in television work, but rarely is. The dielectric loss in a twisted pair is considerably higher than in other easily obtainable lines, and the characteristic impedance of the line does not readily match that of the more popular types of antennas, nor does it provide a well balanced impedance match to the input of many television receivers.

Two-wire parallel transmission lines have long been used by both amateurs and by the radio industry to connect transmitters and their antennas. Such types have proven highly efficient, and readily adaptable to varying conditions of operations. With the arrival of television the two-wire parallel transmission lines have been standardized, and are widely used.

Two wires encased in a plastic ribbon have proven to be very popular with television service men. Several manufacturers make that type of line. Probably the most prominent of all is the American Phenolic Company of Chicago. They manufacture a variety of twin-lines for use under many kinds of conditions, and having characteristic impedances to match almost any condition of operation.

Part of the popularity of the twin-line is its flexibility, but equally important is its cost. It is probably the least expensive kind of transmission line now in general use. Further than this, the twin-line has a low attenuation constant and can be obtained in almost any value of impedance from 75 ohms to 300 ohms. Several examples of the twin-conductor transmission lines manufactured by American Phenolic are shown in figure 1. Still others are shown in figure 27.

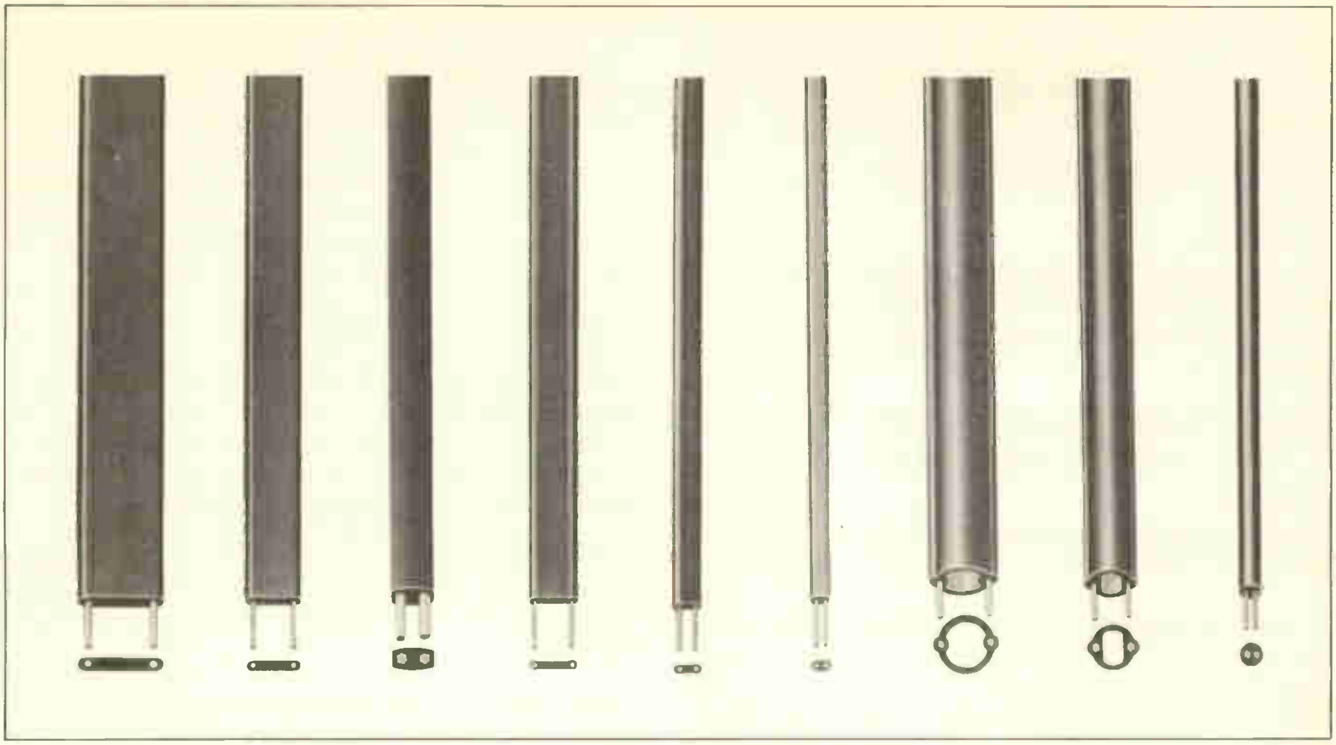

Fig. 27. Types of twin-conductor transmission line. Distance between conductors and dielectric between them affects impedance.
(Courtesy American Phenolic Company.)

Photographs of the several types of twin-conductor transmission lines shown in figure 27 shows very graphically how the characteristic impedance of each conductor is actually built into the line through the arrangement of the conductors. In some of the lines the conductors are close together. From our previous studies such a line is known to have a lower characteristic impedance. Others of the lines have the conductors more widely spaced. Spacing the conductors wider apart gives the line a higher impedance.

Notice the illustrations of the tubular lines. Such lines are more expensive than the flat kinds. But notice how the method of manufacture maintains the conductors equal distance apart, yet does so without interposing the dielectric material between the conductors. Such transmission lines have a very low line loss and can be used to advantage where the line is long. In fringe areas where the signal is likely to be weak, or where it is necessary to bring the signal from a high antenna on the roof of a high building to a receiver in the basement or one of the lower floors, the tubular twin-conductor line is very useful. It is considerably more expensive, however, than the flat, twin-conductor.

The 300-ohm twin-conduotor line has a spacing of about 3/8 inch between the parallel conductors. This makes it easy to work with, and adds to its popularity. It is convenient for matching the standard 300-ohm input impedance of most standard television receivers to the 300-ohm impedance of the more popular types of antennas. The two impedances can be matched by using this line and without having to resort to impedance matching transformers.

Probably the most efficient of all transmission lines is the co-axial cable. Where high standards of operation, and high quality, are more important than the cost of the cable the co-axial line is always the choice. But both the original cost and the matter of impedance matching makes the co-axial transmission line more expensive than most other types.

Figure 28 shows very clearly the appearance of a co-axial cable. Several types are shown there, including one example of a shielded pair. We have described a co-axial cable previously, but will do so here again. A co-axial cable consists of two conductors which both have the same common center. To make such a construction possible one conductor is placed

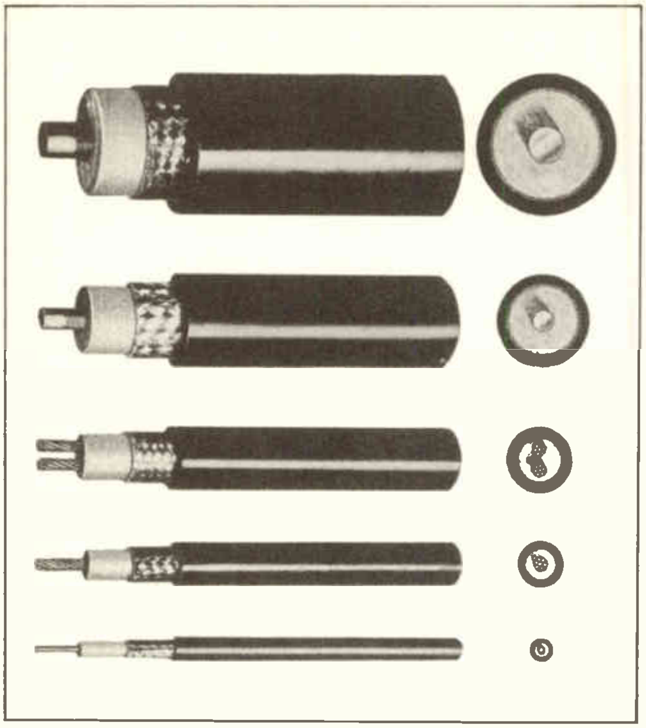

Fig. 28. Types of co-axial cables. The cable in middle position is twisted pair.
(Courtesy American Phenolic Company.)

inside the other, one being simply a wire while the outer one is in tubular form. Quite often the outer conductor is a woven braid, but some are in the form of metal tubes. These latter are not used in television service work so there is no point in discussing them at this time.

In operation the outer conductor of a co-axial cable is often grounded. When so used it acts as a shield for the inner conductor. This arrangement has some very definite advantages for certain kinds of work, and for use in certain locations. Where there is a high noise level which could disturb the operation of a television receiver, and it is desirable to avoid picking up any more of that noise than is absolutely necessary, the signal can be brought from the antenna to the receiver by using a co-axial cable as the transmission line. Practically no noise will be picked up in such a line.

It is a very common practice to use co-axial cables in areas which have a high noise level. Factory districts where many kinds and types of electrical equipment are in steady use is one example og such location. The portable electric hand tools which are used so widely in modern production work are serious sources of electrical noise. The brushes which ride on the commutators of such motors have a tendency to spark badly, and the sparks create noise.

Areas around medical and dental offices have been locations of high noise levels in the past. Much of the equipment used by doctors and dentists has been the source of radio and television interference. But the FCC has devoted much attention to such sources of noise during recent years, and they have succeeded in eliminating much of it.

The co-axial line has several outstanding advantages. It has a very low attenuation constant. Thus there is very low loss of the signal between the antenna and the input to the receiver. Its attenuation constant is less than one-half a decibel per hundred feet of length. This makes it useful where it is necessary to bring in a signal from a high antenna where the signal might be rather weak, or to run the line from a high building with the antenna on the roof to a receiver in the lower part of the building.

One drawback of the co-axial cable is that most such cables do not readily match the impedances of the more popular types of antennas, nor do they readily match the input of many commercial receivers. The characteristic impedance of co-axial cables which are commonly available run from as low as 10 ohms to a maximum of about 100 ohms. Several such cables are now being made with an impedance in the neighborhood of 73 ohms, which can be readily matched to simple dipole antennas.

The middle cable shown in the illustration in figure 28 is a shielded pair. A shielded pair is not a co-axial cable, but it does possess some of the advantages of a co-axial cable. Shielded pair cables are made with characteristic impedances ranging from 50 ohms up to 300 ohms. One which recently came on the market has an impedance of 300 ohms, is ruggedly constructed, and is highly effective in reducing noise pick-up from ignition systems, motors, neon signs and other sources to a minimum. The shielded pair costs about twice as much as a co-axial cable with similar characteristics.

The shielded pair has the disadvantage that it has a much higher attenuation constant, thus cannot be used for such long runs as the co-axial cable. Its attenuation constant, however, is somewhat lower than that of a twisted pair, and can be used for runs up to about 100 feet.

Given here is a table showing a comparison of the various characteristics of the more popular types of transmission lines. Given in the table are the characteristic impedances of each type of line, the attenuation constant, and the maximum length of the run for which each type can be used.

PROPERTIES OF TRANSMISSION LINES

Type of line	Characteristic impedance, ohms.	Attenuation Decibels per 100 feet.	Maximum length
Co-axial	10 - 100	0.4	400 feet
Two-wire, parallel	75 - 300	1.2	150 feet
Shielded Pair	50 - 300	1.5 to 3.0	120 feet
Twisted Pair	40 - 150	4.0	50 feet

NOTES FOR REFERENCE

The characteristic impedance of a transmission line is a peculiar electrical property which depends upon the physical characteristics of the line itself.

The characteristic impedance of a line can be considered to be purely resistive.

If a transmission line is terminated in a load which has a resistance equal to the characteristic impedance of the line itself none of the energy transmitted by the line will be reflected back into the line from the load.

There are two commonly used formulas by which the characteristic impedance of a line can be calculated. The first, which takes into consideration the two types of impedance found in a transmission line, is:

$$Z_0 = \sqrt{Z_1 Z_2}$$

The other formula for finding the characteristic impedance of a transmission line takes into consideration only the inductance and the capacitance per unit length of the line. It is:

$$Z_0 = \sqrt{\frac{L}{C}}$$

A careful study of the two formulas will show that each takes into consideration the physical construction of the line. The second ignores the resistance.

Reflection of wave-motion energy occurs when the waves move from one medium to another, or into a different concentartion of the same medium.

The losses due to the resistance in a transmission line is the basis of the *attenuation constant* of the line.

NOTES

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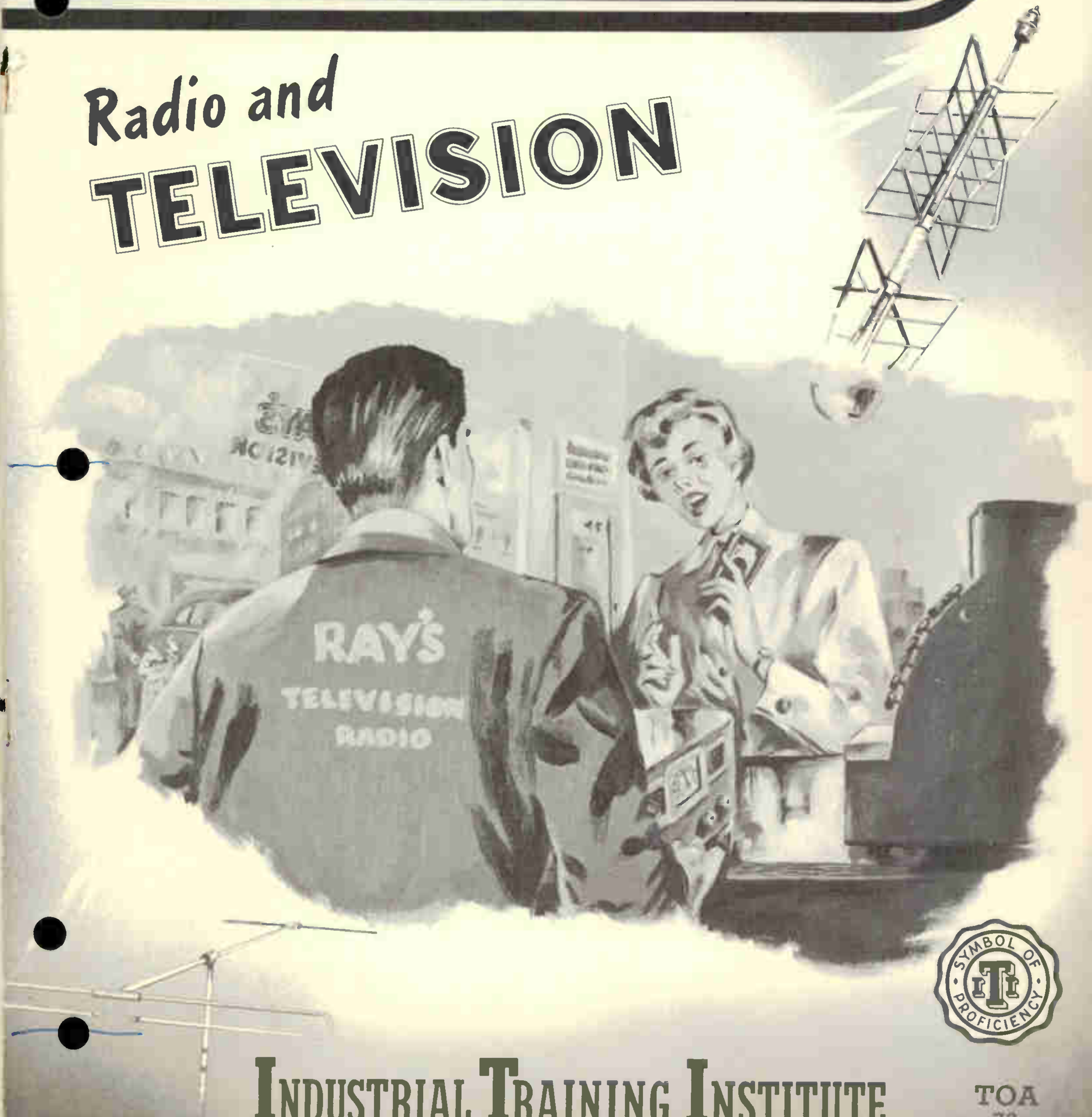

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RADIO TELEVISION

VERY HIGH FREQUENCIES

Contents: Introduction - Effect of Increasing Frequency - Standing Waves - Current Loops and Current Nodes - Action of a Quarter-Wave Line - Practical Applications of the Quarter-Wave Line - Lecher Wires - High Frequency Oscillators - Skin Effect - Notes for Reference.

Section 1. INTRODUCTION

When reduced to their basic fundamentals all electric currents and voltages follow the basic rules and regulations explained to you in the early lessons of this course. This means there are certain basic physical laws which govern the behavior of currents and voltages in all kinds of circuits.

Because of a number of circumstances, very high frequency alternating currents and voltages often appear to violate those basic rules. It is to clear up such *apparent* discrepancies that we will devote our attention in this lesson. Present day television operating frequencies have already ventured into the very high frequencies, and as additional progress is made in television it is inescapable that the operating frequencies will be higher and higher.

Now, despite the fact that A-C currents and voltages at the high frequencies actually do obey the same physical laws as the lower frequencies, it is unquestionably true that in many ways they *appear* to ignore the basic laws, or to operate under laws of their own. Most often this appearance is brought about by reason of the fact that many things which can be ignored at the low frequencies become of controlling importance at the higher frequencies. Because an action may be of negligible importance at low frequencies does not mean that it does not exist. In most cases it does exist, but in many instances some circuit element may be of very little importance at the low frequencies. But the same circuit element can assume more and more importance as the frequency increases until at the higher frequencies it is the most important element of all.

The relationship between frequency and wave-length is often responsible for the apparent difference between the operation at low frequency and the operation at high frequency. As the frequency is increased, the wave-length becomes shorter. Where the wave-length may be measured in miles, or even in thousands of miles, at the low frequencies it is measured in meters, feet, inches, or even in centimeters and millimeters at the very high frequencies. Where the resistance of the conductor necessary to cover one wave-length where the wave-length is long may be of great importance, the resistance of a conductor necessary to cover

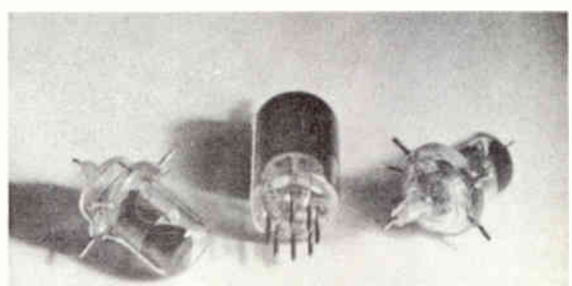

Fig.1. Appearance of Special Types of High Frequency Tubes.

one wave-length where the wave-length is short may be almost negligible. Thus we can see that while in some cases that which is negligible at low frequencies may become important at high frequencies, the converse is also true. That is, what may be highly important at low frequencies may become almost negligible at very high frequencies.

It is not our intention to delve into the subject of very high frequencies in an exhaustive manner in this lesson. Many books have been written on the subject of Ultra High Frequencies and the Very High Frequencies. It is obviously impossible to include everything we would like for you to know about this subject in this one lesson. In fact, we could never hope to be able to teach you everything about the higher frequencies without resorting to the use of much higher mathematics than we expect you to know. Nevertheless, we are trying to teach you the most important things you need to know about the higher frequencies. Furthermore, if you absorb and understand everything we try to teach you in this lesson it will make it much easier for you to pick up one of the more advanced text books on the subject and be able to understand it.

Even more important than anything else is the background knowledge it will give you, so you will be better able to learn and understand the new things about the subject -- new things which are being constantly developed and passed along to the service technicians. Without a basic understanding of the names, the terms and the actions which take place at the higher frequencies you would find it extremely hard to even understand much of the language which is used to describe the action of the newer circuits and the newer equipment as it is developed by the research laboratories and passed along by them to the trade.

Section 2. EFFECT OF INCREASING FREQUENCY

So that we may obtain a concrete picture of some of the things that take place as the frequencies are increased, and so that we may begin to understand and appreciate the need for different types of circuits elements, we will start with an ordinary Hartley oscillator and see just what happens to it as we raise the frequency higher and higher.

In Fig. 2 we have an ordinary Hartley oscillator circuit. There is nothing

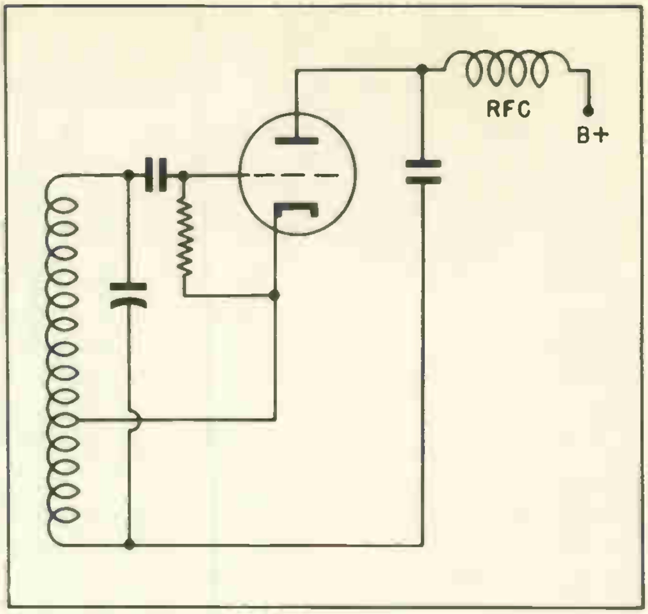

Fig. 2. A Conventional Oscillator.

particularly unusual about this circuit. It is one which you have encountered many times in your studies and in your experiments. It is used for many purposes, and is generally highly regarded by all radio men.

Now we know from our earlier studies that the fundamental formula for resonance, that is for resonant frequency, is:

$$F_r = \frac{1}{2\pi\sqrt{LC}}$$

where L is used to represent henries.
C is used to represent farads.

This formula tells us, and our previous studies and experiments emphasizes the truth of it, that we can increase the resonant frequency by reducing the amount of the inductance or by reducing the amount of the capacitance. When this is applied to the case of an oscillator circuit we already know that we can increase the output frequency of the oscillator by reducing either the inductance of the coil in the "tank" circuit, or by reducing the capacity of the capacitor. We also know that we can increase the frequency even higher by reducing the value of both the inductance and the capacitance.

In Fig. 3 we have redrawn the circuit of the oscillator in Fig. 2. At *A* in Fig. 3 the circuit is quite similar to that in Fig. 2. But at *B* in Fig. 3 we find the inductance coil in the tank circuit much smaller. From this we can deduce that the frequency of the circuit at *B* is much higher than is that of the circuit at *A*. And, of course, such a deduction would be correct.

If the capacity of the capacitor in that circuit is also reduced quite radically, the output frequency of the oscillator would be even higher.

But there is a practical limit to how high a frequency can be attained by such a conventional oscillator. As the coil is made smaller and smaller it becomes necessary to examine more and more closely the matter of the "Q" of the circuit. You will recall from your previous studies that the "Q" of a circuit is the ratio of the inductance of the circuit to the resistance in the circuit.

When we have a true coil composed of many turns of wire wound around a common center we can obtain a relatively high inductance without radically increasing the resistance.

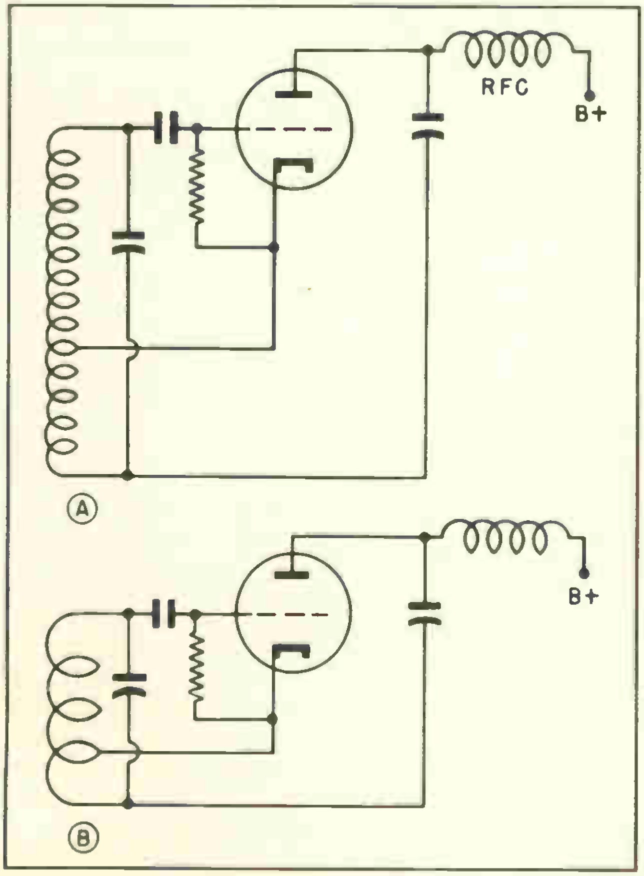

Fig.3. Increasing the Frequency by Reducing the Size of the Components of an Oscillator.

This is because the magnetic lines of force surrounding each portion of the wire will link through many turns of the coil. But as the coil is made smaller and smaller, the inductance drops quite rapidly. Of course, the resistance drops also, but the resistance does not drop nearly so fast as the inductance. Whereas, the inductance increases roughly equal to the square of the number of turns, and thus decreases roughly as the square root of the number of turns, the resistance will increase or decrease in direct proportion to the number of turns.

What this all adds up to is that as the size of the coil becomes smaller and smaller the "Q" of the circuit will become much smaller.

It is true, of course, as we told you in an earlier lesson, that the "Q" of a coil can be increased by reducing the number of turns on the coil, then inserting a powdered iron core to increase the inductance with respect to the amount of the resistance. This acts to increase the inductance without increasing the resistance, thus raising the "Q". But there are definite practical limits to the usefulness of the powdered iron core. They are highly useful in the range from the Broadcast Band up to a little higher than 100 megacycles. But as the frequencies are increased still higher it becomes impossible to use the powdered iron core. To obtain the higher frequencies it is imperative that the inductance be decreased, and in order to decrease it we must do everything possible to make the coil smaller.

As a matter of fact, there is a practical limit to the frequency which can be attained by the conventional oscillator, such as the Hartley. The place is eventually reached when there is just simply no more capacity to be removed, and no more inductance. The Hartley oscillator is useful up to about 200 megacycles, and some modifications of it can be used to slightly higher frequencies. But from there on up it is necessary to generate the frequencies in some other manner.

Section 3. STANDING WAVES

In the preceding sections we have touched upon the limitations of the ordinary oscillator at the higher frequencies. We have tried to emphasize the necessity of generating the frequencies which are being used more and more widely. But in order to generate these higher frequencies we must resort to new and different types of circuits. Furthermore, we must put to use an entirely new kind of electrical phenomenon we have not yet mentioned. This new phenomenon is called "Standing Waves".

Before explaining how *standing waves* can be used to generate the higher frequencies that are needed for many kinds of work, it is first necessary to explain to you just what we mean by "standing waves", and what they are.

Before trying to explain standing waves, we should first repeat a brief summary of the action of an infinite transmission line. You will recall from our study of transmission lines that if we could create an infinite transmission line -- a line without end -- we could feed a signal into one end of the line and the signal would continue indefinitely down the line. The signal would become progressively weaker, yet it would continue indefinitely.

We also told you that we could obtain the *effect* of an infinite transmission line by terminating the line in a resistance which is equal to the characteristic impedance of the line. If the line is terminated in a resistance equal to the characteristic impedance of the line, the signal will be absorbed by the load and will not be reflected. This will occur because the resistance of the load will look to the signal just like the impedance of the line. Since the appearance is the same in either case, the signal will be absorbed and none will be reflected.

You were also told that any change in the electrical characteristics of the line would cause a part of the signal to be reflected back toward the source. This results from the fact that an electrical signal fed into such a line is a form of wave-form energy, and whenever any kind of wave-form energy, whether electrical, electromagnetic, light or heat, finds a change of any kind in the character of the medium through which it is passing, it has a tendency to reflect part of the signal back toward the source. This was gone into in considerable detail in a previous lesson and it is not our intention to go into it too deeply again at this time.

The important point at the moment for you to understand is that while the voltage and the current is becoming progressively weaker as they get further and further from the source, as shown in the graph of Fig. 4, this decline in strength is a gradual thing. It results from the resistance and other electrical losses in the line. You should note carefully that if measured with a meter there is no rising or falling of the voltage or the current in such a line.

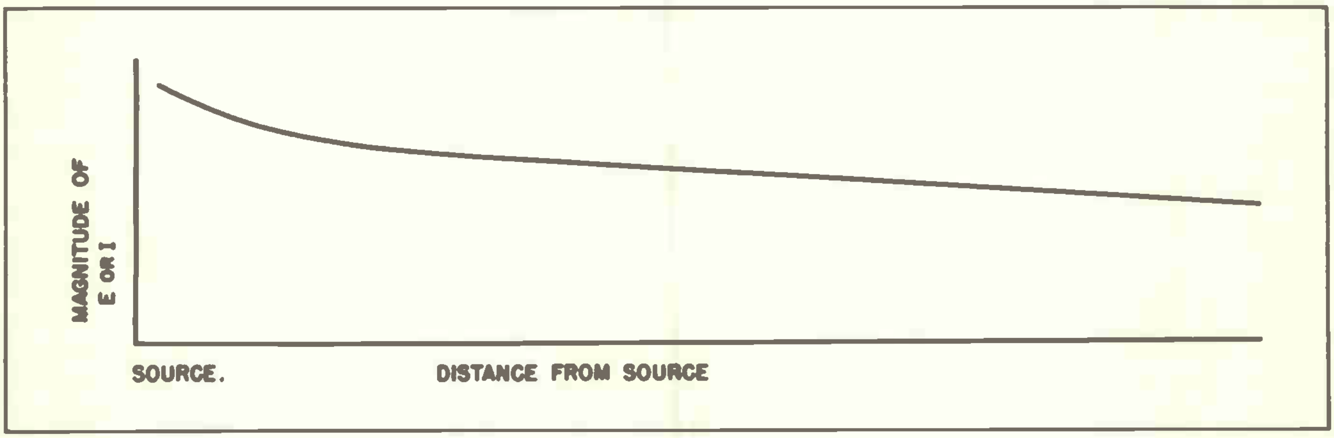

Fig. 4.

The voltage and the current would be equally distributed all along the path of an infinite line, or in a line which is terminated in the characteristic of the line.

But suppose we were to feed a very high frequency signal into a line of some definite length -- say, 1000 feet as in Fig. 5. The line might be even shorter. It could be 500 feet, or 100 feet, or almost any other length that happened to be convenient.

Here we find the signal going down the line in the same manner as was described in our lesson on transmission lines. That is, the signal would feed into the line and

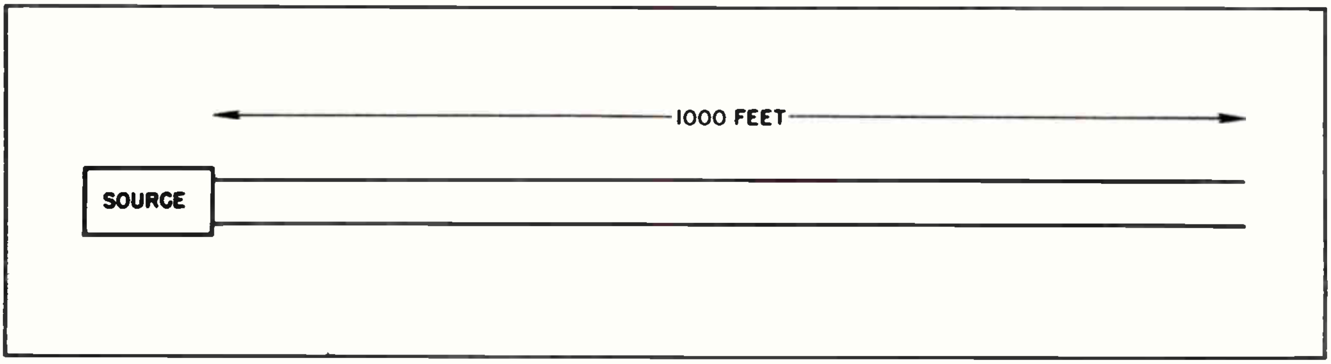

Fig.5. An Open-Circuited Transmission Line.

start down it. In all truth, the signal would continue down the line until it reached the end.

Now here is where we find something new. When the current of the signal reaches the end of the line it will find a definite break in the character of the line. The line is *not* infinite, neither is it terminated in a resistance equal to the characteristic impedance of the line. Instead, the line just stops. That is all there is to it.

Remember, the signal that starts down the transmission line is in the form of wave-form energy. The current rises, falls, reverses, etc., characteristically an example of wave-form energy. The distribution of the current waves could be graphed as shown in Fig. 6. While the current in the wave above the line flows in one direction and the current below the line flows in the opposite direction, the waves themselves travel progressively along the line. If you have trouble visualizing the waves as being distinct from the movement of the electrons, it would be well to go back to your first lesson and review the remarks on wave motion contained there.

The action of the current waves in the transmission line is quite similar to the waves on a body of still water. The dropping of a stone in a body of still water will cause a succession of waves to move away from the source of the disturbance. The actual drops of water on the surface of the pool will move up and down but will move little, or none at all, in the direction of the wave-motion. Yet the waves themselves will continue to spread out for great distances. Thus, there is a distinction between the waves and the particles of water which form the waves.

Much the same thing is true in the transmission line. The flow of current may be in either direction at any point within the line, but the waves will be traveling constantly away from the source.

When the waves strike the end of the transmission line, as shown by the graph in Fig. 6, they find a definite change in the character of their medium of travel.

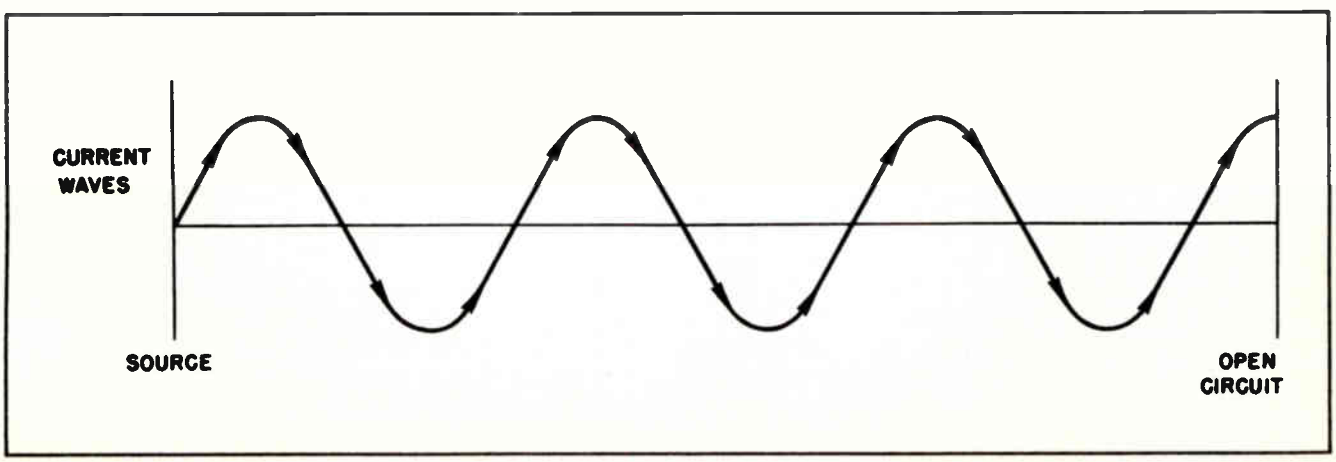

Fig.6. How the Waves of a Signal Move from the Source to the End of the Line.

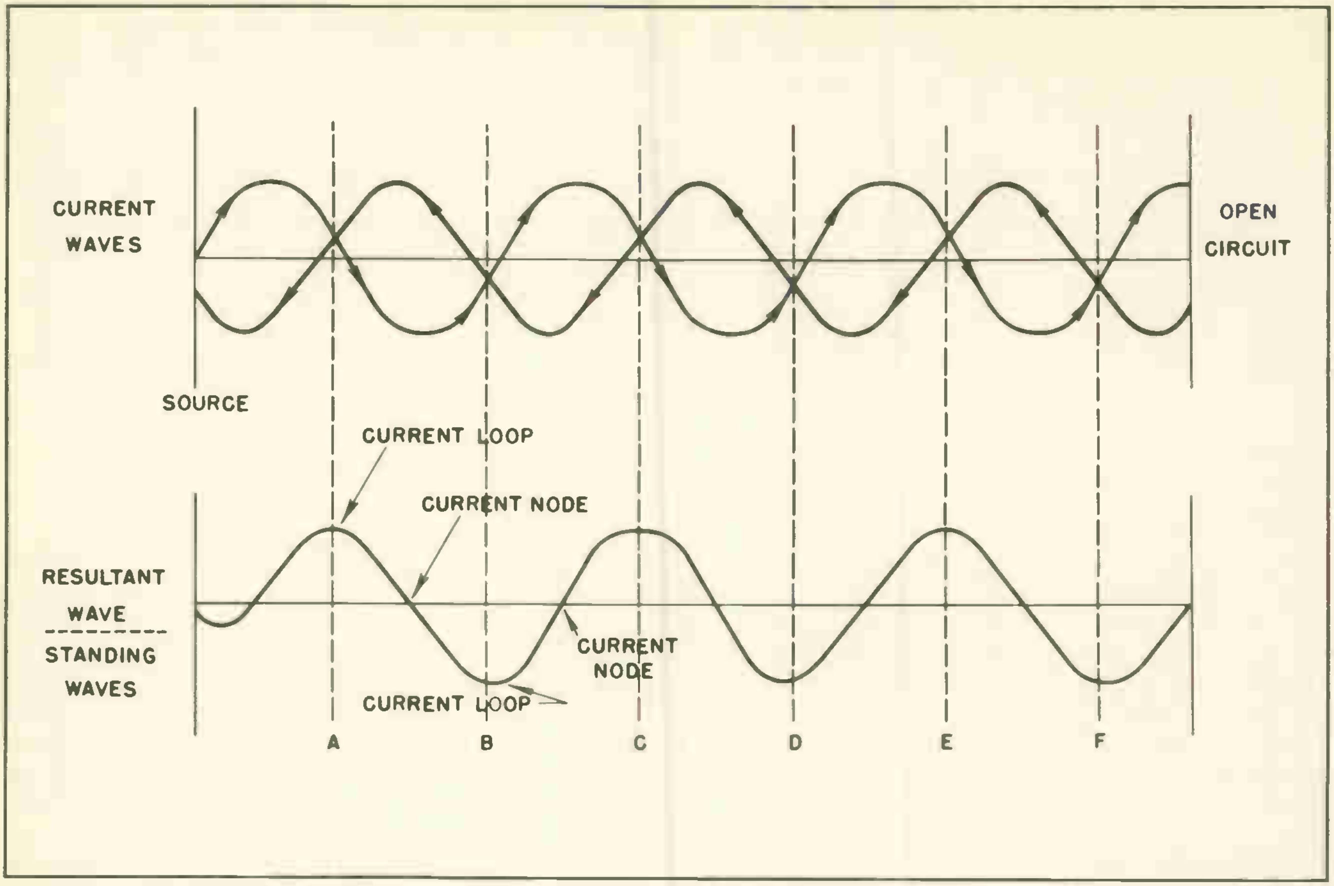

Fig.7. How the Waves are Reflected by the Open End of the Line. Note the Resultant Wave at the Bottom which does not Move.

Whenever waves of any kind, strike any change in the medium through which they travel, there is a tendency for part of the wave-energy to be reflected toward the source. If the medium through which the waves are traveling is ended, *all* the wave-motion energy that is present there will be *reflected*.

In our present case the current waves reach the end of the transmission line and find no means for them to continue their travel. Following the physical laws which governs wave-motion travel, all the energy which is present there will be reflected. Since the wave-motion which strikes the end of the line is traveling in one direction, the wave-motion which leaves the end and starts back toward the source will travel in the opposite direction. This is elementary, yet it is important.

Since the wave-motion which reaches the end of the transmission line is above the axis line of the graph, the wave-motion which starts moving in the opposite direction must be graphed below the line. This is shown in Fig. 7.

Here is the feature about this situation which is important. The outgoing waves and the reflected waves combine to form what are called "standing waves". These standing waves are nothing more nor less than the resultant waves created by the combination of these two groups of waves. The resultant wave will be as shown in the bottom graph of Fig. 7.

Since these resultant waves, or "standing waves", are composed of the outgoing waves combined with the reflected waves, they will be moving neither away from the source nor toward the source. They will not be moving at all. They will stand still. It is because of this that they are given the name "standing waves".

Section 4. CURRENT LOOPS AND CURRENT NODES

The resultant wave of current in a transmission line where there are standing waves is indicated by the resultant graph at the bottom part of Fig. 7. Since the resultant wave is composed of the two signal waves,

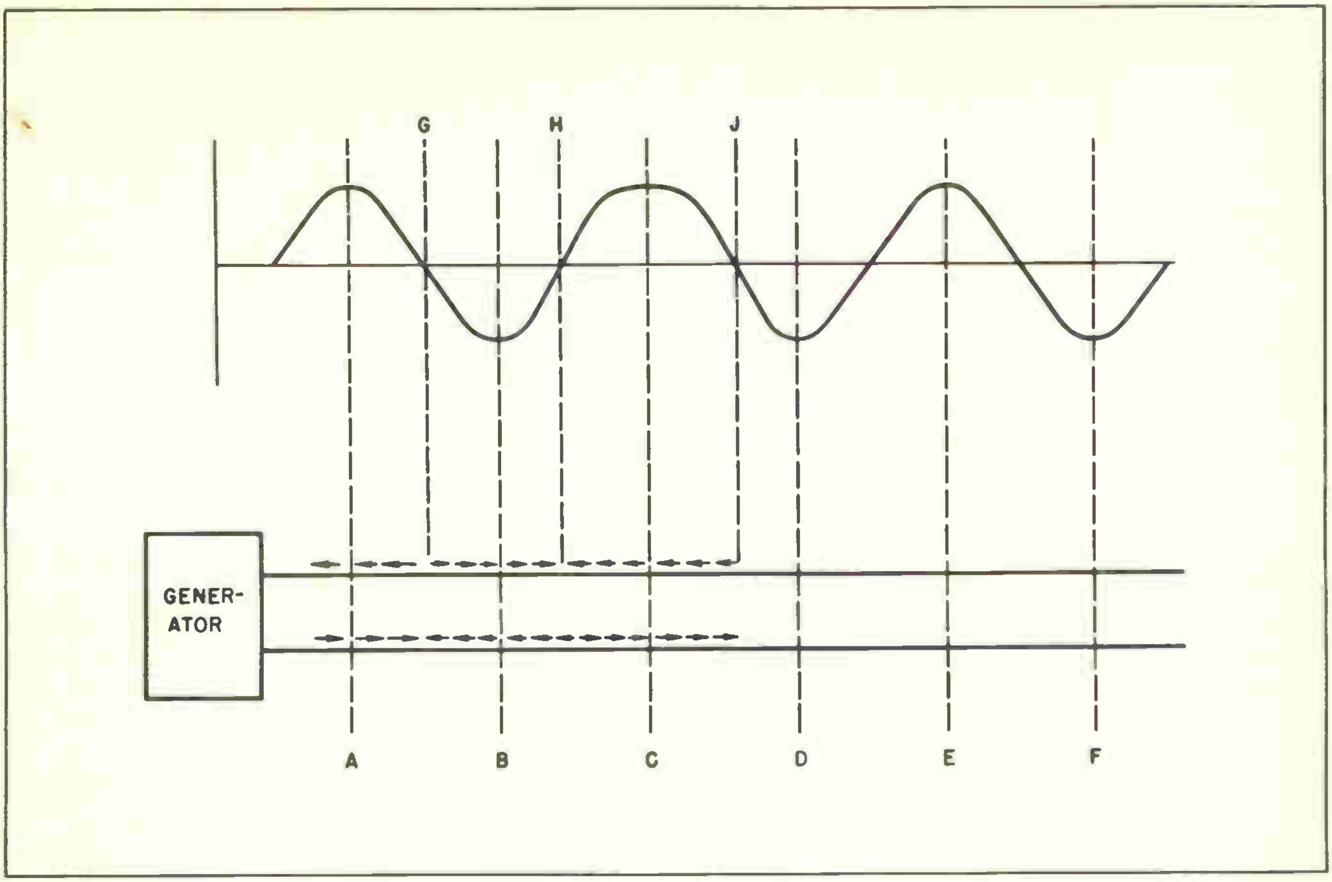

Fig.8. Current in the Line.

one moving from the generator toward the end of the line and the other moving from the end of the line toward the generator, the resultant wave itself does not move in either direction. But this does not mean there is no movement of electrons within the conductor of the transmission line. Actually there is a constant movement.

At the points where the graph is cut by the dotted lines in the lower part of Fig. 7 we find the maximum amounts of current. At the point in the transmission line which would be cut by line *A* there would be a maximum movement of electrons in one direction. At the point where dotted line *B* cuts the transmission line there would be another maximum movement of the electrons. But here the movement would be in the opposite direction.

Fig. 8 diagrams the movement of electrons in the conductors of the transmission line at one instant of time. Taking the upper line in Fig. 8 for a moment, we find the electron moving in one direction of the line at point *A* and in the opposite direction at point *B*. Further than this, we find the electrons at point *C* moving in the same direction as at point *A*.

We call the points of maximum current in the line current *loops*.

It is interesting that we find the current flowing in one direction at each of the current loops at one instant, then an instant later -- depending upon the frequency of the signal -- we find the current flowing in the opposite direction. In this respect there is little difference from the situation we find in any circuit containing alternating current. But we do run into a most interesting situation if we move our observation of the line just a little distance in either direction from the current *loops*.

If we were to examine the transmission linear points *G*, *H* or *J*, we would be unable to discover any current at all. This means there would be no current flowing at those locations at any time. These last mentioned spots are called current *nodes*.

This means we can set up a transmission line of some definite length, the exact length is not particularly important. We can connect a signal generator of some kind to one end, the exact frequency is not greatly important, but for the sake of convenience should be fairly high, 30 megacycles or higher. The opposite end of the transmission should be left open, that is, not connected to anything nor be connected together.

The signal we feed into the line will travel to the opposite end, there it will find a change in the characteristic of the line and a major portion of the signal will be bounced back toward the source. The reflected signal will mix with the original signal. At some points the two signals will exactly cancel each other. Here we find no current at any time, and for that reason we call such a location a *node*. At other places along the line the current in the reflected signal will aid the current in the original signal. At these points we find the two signals reinforcing each other. This results in a signal stronger than normal. Thus, within a short stretch of the line we will find a large current flowing back and forth. Such portions of the line are called the current *loops*.

Now consider this interesting and intriguing situation, these loops and nodes remain stationary on the line, they move in neither direction, either toward the source nor away from it. They do not move, provided there is no change in the signal frequency or in the circuit elements.

Meter measurements can be taken along the line. Heavy current flow is readily apparent at certain places along the line. These are loops. No perceptible current at all will be found at other places along the line. These are the current nodes.

You can provide yourself with almost endless hours of experimentation by creating a high-frequency generator and feeding the output of the generator into an extended pair of evenly spaced conductor wires which extend some distance from the generator. The distance such a line should extend will depend upon the frequency of the generator. At 30 megacycles the line should extend not less than 60 feet, and it would be better to extend it 100 feet or more. Such a line is called a *Lecher Wire* system.

If a frequency of 100 megacycles can be generated, some interesting experiments can be conducted with a line 20 or so feet long. At still higher frequencies, the line can be even shorter.

Now we will refer back to Fig. 7 for a moment. We find that the current which is flowing immediately away from the open end of the line at the right is exactly equal to the current which is flowing toward the open end. Since one current is flowing in one direction and the other current is flowing in the opposite direction, it means that the resultant current at that point is zero. This will always be true.

The current at the end of the open line is always zero. No matter where the open end of the line happens to be with respect to the outgoing wave, the resultant current at the end of the line will always be zero.

Now we come to another interesting fact: Although the current is zero at the end of the line, the *voltage* will be maximum. The voltage will be maximum because of the infinite resistance between the lines at that location.

The voltage will also vary along the transmission line between the generator and the open end. As is to be expected, such voltage will be sinusoidal in character. Since the voltage is at a maximum at the end of the line where the current is minimum, and since the voltage varies along the line in a sinusoidal manner, it will probably come as no surprise to you that the *voltage* between the two wires of the conductor will *always be maximum where the current is minimum and will always be minimum where the current is maximum.* Such is indeed the truth.

Instead of there being a constant impedance along a transmission line as in the case of an infinite line, or in that of a properly terminated line, we find a radical difference in the impedance at various points along the line where standing waves are present. To better understand just why this should be so, suppose we pause for a moment to analyze the situation we find here.

We have long known that the impedance in an A-C circuit is equivalent to the ratio of the voltage to the current. This is expressed by our well known formula:

$$Z \text{ (impedance)} = \frac{E \text{ (voltage)}}{\text{(current)}}$$

Using this formula, it is easily possible to calculate the impedance at any point along the transmission line. At the current nodes the voltage will be very high, while the current will be very low. This means:

$$\frac{\text{High voltage}}{\text{Low current}} = \text{Large impedance}$$

At the locations of the current loops, the opposition condition will be present. There we find a low voltage and a high current. A low voltage and a high current can be diagrammed as:

$$\frac{\text{Low voltage}}{\text{High current}} = \text{Low impedance}$$

We can even carry this a little further and say that the impedance along the line will vary as the voltage, although not necessarily proportionately. Wherever the voltage is high the impedance will be high, and where the voltage is low the impedance will be low. This all seems rather self-evident, but it is so important it is certainly worth explaining in detail.

Before leaving this immediate subject, it should be emphasized that standing waves will always be present in a line which is not properly terminated in its characteristic impedance; and we can say the converse, the only time standing waves will be present in a line, is when the line is not properly terminated.

Section 5. ACTION OF A QUARTER-WAVE LINE

If, instead of having a line several times longer than the wave-length of the input signal, we shorten the transmission line until it is only one-fourth as long as one wave-length, we come across some more interesting conditions.

In Fig. 9 we show a transmission line which is 1/4 wave-length long. It also has a graph which shows the current and voltage distribution along the line. At the bottom of the illustration is another graph which shows the impedance at various points along the line, the impedance being lowest at a location nearest the source and becoming increasingly higher as the line moves further from the source.

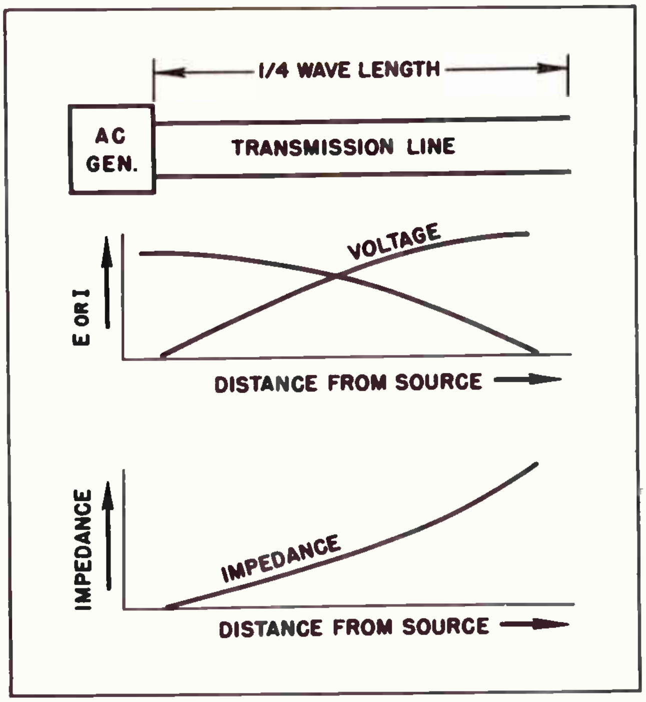

Fig. 9. Current, Voltage and Impedance Distribution Along a Quarter-Wave Line.

Note that the impedance rises in much the same manner as does the voltage, but the rise is not identical. The voltage tends to rise more sharply, then gradually flatten out toward the maximum. The impedance, on the other hand, does not rise quite so steeply immediately after moving away from the source, but tends to rise somewhat more steeply a little later.

The conditions which exist on a transmission line that is only one-quarter wavelength long follow the same rules which exist in the case of a longer line. The signal from the generator enters the line and starts traveling away from the source at the speed of light. The signal strikes the open end of the line and is immediately reflected back toward the source. The resultant of the two signals is such that the current will be minimum at the end of the line (this results from the fact that the same amount of current leaves the end as reaches there, and since the current is opposite in direction, the currents will cancel.) Since the line is only a quarter-wave-length long the out-bound signal and the reflected signal will combine to create a current loop exactly at the point where the line is joined to the source.

You will note another condition here. The impedance of the line at the point where

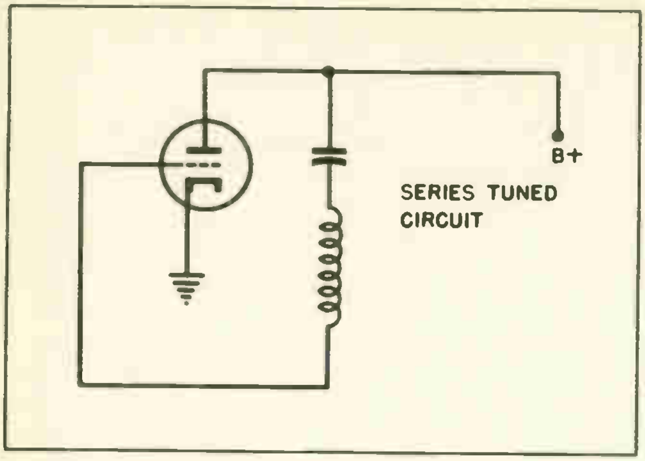

Fig.10. Operating a Vacuum Tube into a Series-Tuned Circuit.

the line is joined to the source will be at its minimum value. This can be said in another way: The source will look into a line whose impedance is at its minimum value at the point where the source is connected to the line.

You will no doubt note the similarity here to the situation of a source looking into a series-tuned line. The similarity is shown somewhat more clearly in Figs. 10 and 11. In Fig. 10 we are feeding a vacuum tube into a series-tuned circuit while in Fig. 11 the tube is feeding into an open-circuited quarter-wave transmission line (which has characteristics similar to a series-tuned circuit).

It is not the general practice to feed a vacuum tube into a load consisting of a series-tuned circuit. The reason, of course, is that the series-tuned circuit has a low impedance while the vacuum tube circuit is normally a high impedance one. This means that feeding a vacuum tube into a quarter-wave, open-circuited transmission line would not provide ideal results.

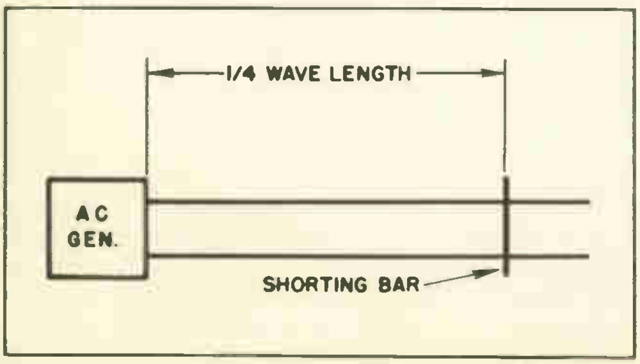

Fig.12. A Quarter-Wave Line.

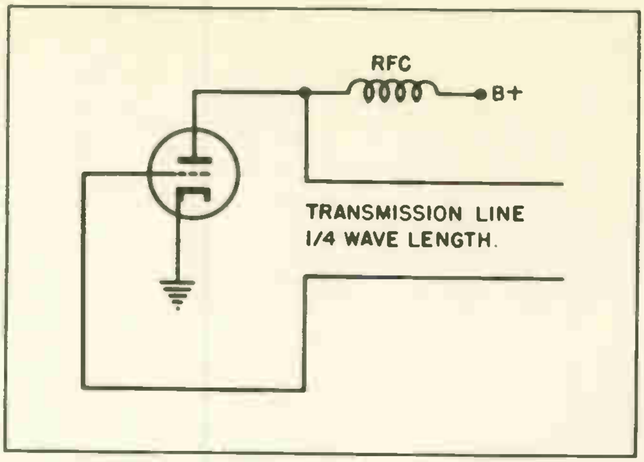

Fig.11. Operating a Vacuum Tube into an Open-Circuited Line.

It so happens, however, that we can short-circuit the line at the far end and create somewhat different characteristics on the line.

A short circuit would look like that in Fig. 12. There we find the shorting bar placed across the line exactly one quarter-length from the source. The current, the voltage and the impedance distribution along the line where the end of the line is short-circuited is somewhat different than is the case where the line is left open.

Fig. 13 shows the relationship of current, the voltage and the impedance along the transmission line. One of the most important features is that now the impedance at the point near the source of the signal is quite high instead of being quite low as in the case of the open-circuited transmission line. In this respect, the source of the signal would look into a line which has a characteristic quite similar to that presented by a parallel tuned circuit.

The similarity between a short-circuited quarter-length transmission line and a conventional parallel-tuned resonant circuit is shown in Fig. 14. To the high impedance tube they both look the same.

Now we are getting somewhere. Whereas we were rapidly reaching the limitations of our conventional oscillators, we now find we have a new method of creating circuit elements which have similar features to those possessed by the more familiar types of oscillator circuits, but which do not have the same limitations.

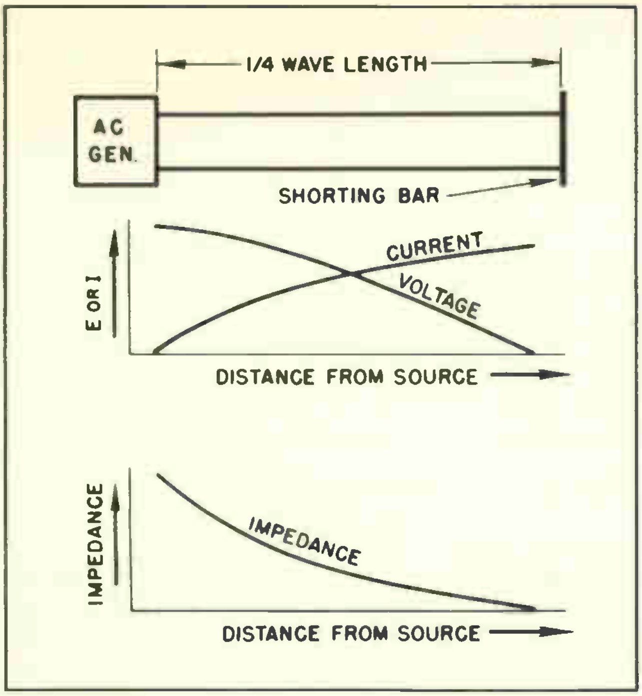

Fig. 13. The Voltage, Current and Impedance Distribution Along a Short-Circuited Quarter-Wave Line.

Section 6. PRACTICAL APPLICATIONS OF THE QUARTER-WAVE LINE

It is nothing new to us at this time that a coil which has a certain amount of inductance will resonate at some definite frequency with a capacitor which contains a certain definite amount of capacity. We have gone over this so many times it should be thoroughly familiar.

Therefore, when we place an inductance and a capacitor in an oscillator circuit, that oscillator will begin generating alternating voltages at a frequency which will cause these two circuit elements to resonate. Much the same thing is true when an oscillator tube is connected to a quarter-wave short-circuited transmission line. The circuit will resonate at the frequency of which the length of the transmission line is a quarter wave-length long.

To change the frequency of such an oscillator, it is merely necessary to change the length of the transmission line.

But the short lengths of transmission lines are used for many other purposes at the very high frequencies than has been suggested here. Many chapters could be written on such uses.

Section 7. LECHER WIRES

We have mentioned Lecher Wires before in this lesson, and it is well that we take a little additional space to study the characteristics of such a circuit a little more in detail. As the frequency increases in a circuit which happens to be under study for any reason, it often becomes convenient to use a pair of Lecher wires for such study.

Essentially a Lecher wire system is nothing more than a pair of parallel wires which are connected at one end to an A-C voltage source of some kind. Since it is understandable that a frequency which is to be studied on a Lecher wire system must have a relatively short wave-length, it follows as a natural consequence that the use of Lecher wires is usually reserved for the study of very high frequencies. Since only vacuum tube oscillator circuits are capable of creating such high frequencies, it also naturally follows that the signal which is fed into a Lecher wire system, therefore, must originate in a vacuum tube oscillator.

All this may seem an elementary form of reasoning. But it is better that there be no possibility of misunderstanding.

One of the principal advantages of Lecher wires is in the ability to use such a cir-

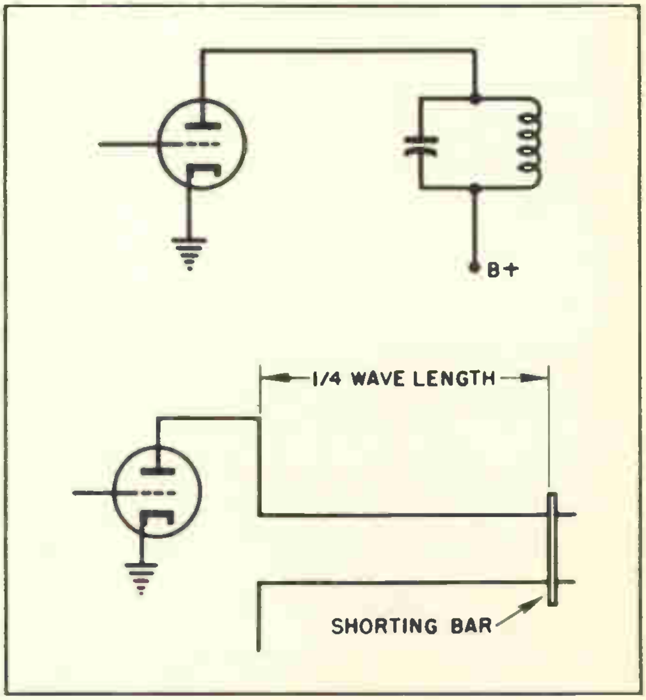

Fig. 14. Comparison of a Conventional Anode Load with One Composed of a Quarter-Wave Line.

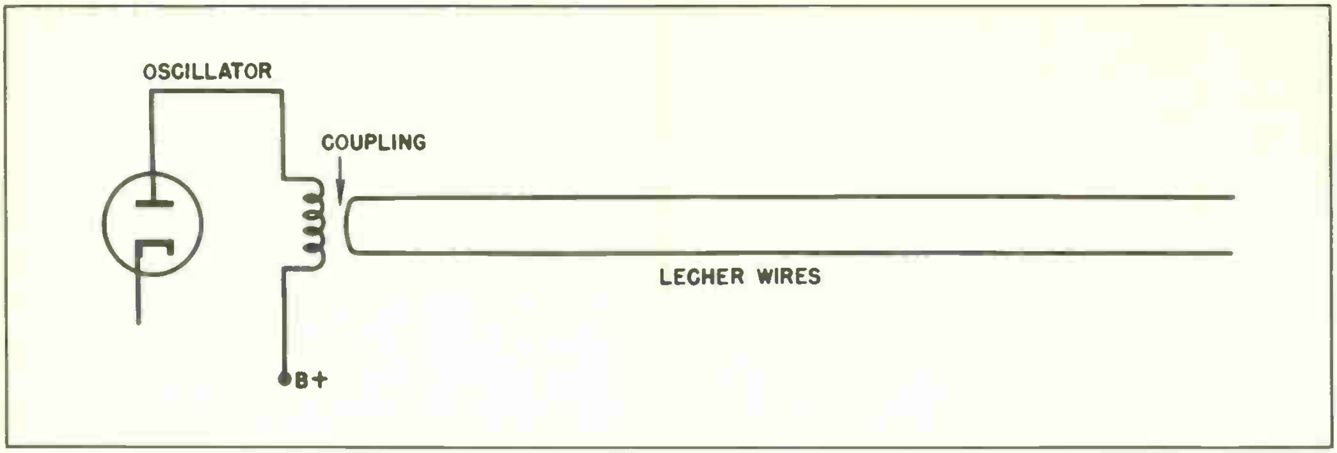

Fig. 15. Coupling an Oscillator to a Lecher Wire System.

cuit to actually measure the physical length of the wave-length of a signal under study. A Lecher wire system is set up much as shown in Fig. 15. The two ends of the Lecher wire system is connected to a loop at one end. This loop is then used as the secondary of a high-frequency transformer so that R-F energy can be fed to the line from an R-F oscillator. The vacuum tube is a component in some kind of a high-frequency oscillator, the output of the oscillator appearing in the anode circuit of the tube. This output signal is then coupled to the Lecher wires in the manner already described.

Since the Lecher wire system is essentially a short transmission line, the electrical and physical laws which govern the action of a transmission line will also control in the action of the Lecher wire system. The signal fed into the end of the line will travel down the line to the open end, then it will be reflected back. As in the case in any transmission line where there is a strong reflected signal, we will now find standing waves present along the Lecher wire system.

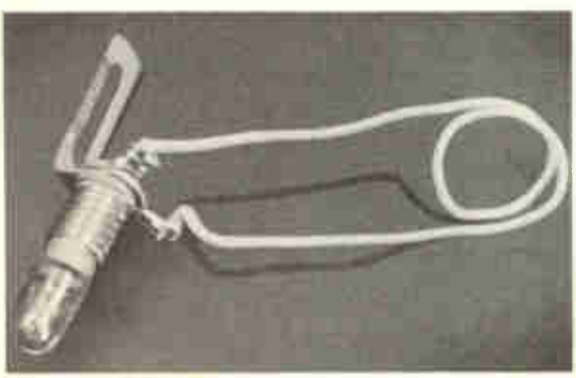

Fig. 16. A Test Lamp Used for Testing a Lecher Wire System.

For good study conditions the Lecher wire system should use wires which are at least as long as the longest wave-length which is to be studied. It is usually better from a practical standpoint to make the line somewhat longer even than that. The greater the length, within the limitations of the surroundings, the better is the opportunity to study the standing waves and the other electrical characteristics which will be found there.

When the oscillator signal is fed into the end of the Lecher wire system, standing waves will immediately form along the wires. The current loops can be readily detected by using a little test lamp arranged similarly to that shown in Fig. 16. The loop in the wire connected to the test lamp can be held close to one of the wires of the Lecher system, see Fig. 17, then moved along the wire. When the coil of the test lamp approaches a current loop of a standing wave on the Lecher wire, the lamp will begin to glow. When the lamp is glowing at its brightest it is a sign that the peak of the current loop on the Lecher wire has been reached.

If you actually perform one of these experiments you should use a little care the first time, so you do not risk burning out your test lamp bulb. The results of burning out a bulb are not too serious, however; such lamp bulbs are not very expensive.

By moving the test lamp along the Lecher wire system, two current loops are soon

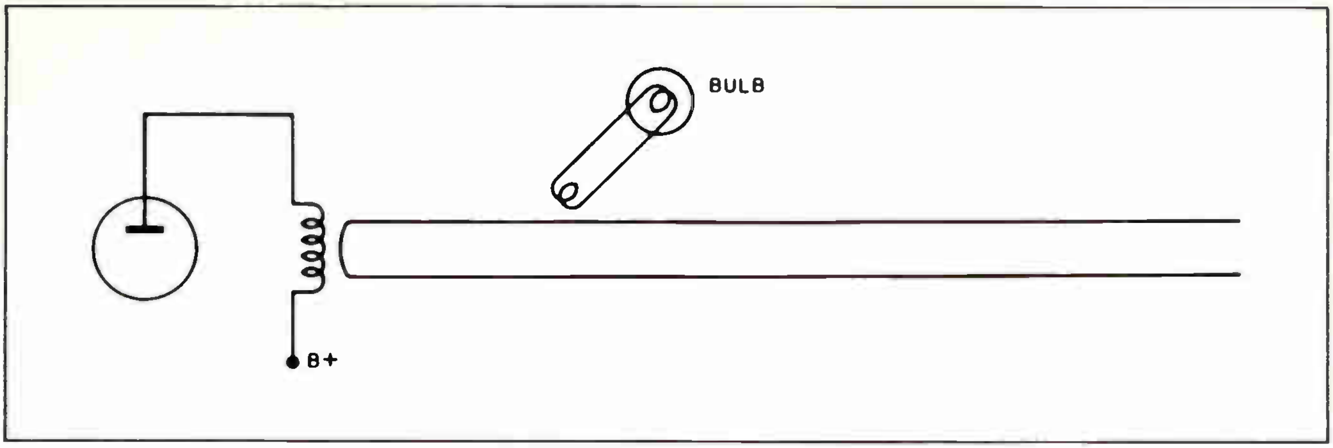

Fig. 17. Testing a Lecher Wire System with a Test Lamp.

located. These two loops can then be marked in some manner. See Fig. 18.

Once these two current loops are located they can be measured in any manner that is convenient. The measurement can be made with a tape measure, a carpenter's folding rule, a steel tape, or anything else that happens to be handy. The important thing is that this distance is equal to *one-half* the wave-length of the frequency under study.

Thus it can be seen that it is readily possible to actually measure the wave-length of a high-frequency signal by means of the Lecher wire system and some common, ordinary measuring stick. As important as anything else, such measurements are reasonably accurate.

Another method of measuring the wave-length of high-frequency signals is to place an ordinary fluorescent lamp between the two Lecher wires. At the points where the voltage is maximum, the fluorescent lamp will glow brilliantly. By placing several such fluorescent lamps end to end between the two wires it will be readily possible to locate several such spots of maximum voltage, providing, of course, the line is sufficiently long and the frequency is high enough to make the wave-lengths shorter than the Lecher wires. If you set up such an experiment you can use old fluorescent lamps which have been discarded as no longer being of any value. They will work in such an experiment just as well as a new lamp.

Section 8. HIGH FREQUENCY OSCILLATORS

It is interesting to learn that the principal of the Lecher wire system, and that of transmission lines, can be applied to oscillator circuits and used to generate frequencies considerably higher than can be generated by a conventional oscillator circuit. It has been hinted previously that 200 megacycles is just about the top limit of the frequency that can be generated by using conventional vacuum tubes and conventional circuits. It is true, of course, that special tubes have been designed which make it possible to continue to use conventional circuit design to generate frequencies slightly higher than 200 megacycles. But generally speaking, that is getting close to the top limit.

You have probably guessed, however, that frequencies far higher than 200 megacycles are in common use. In radar work it is regular practice to operate at frequencies which range from 20 times 200 megacycles to above a hundred times that frequency. There are a number of methods by which such frequencies can be generated. Most of such things are far outside the scope of this course. But no harm can come from mentioning some of the special types of tubes which have been designed, by which it is possible to regularly generate such frequencies and to keep them under as rigid a control as we normally keep the much lower radio frequencies.

A vacuum tube was developed during World War II which was called the "lighthouse" tube. It received its name from the outer appearance of the tube. In many respects the appearance of the tube is quite similar to the old time lighthouses, large at the bottom, then gradually becoming smaller near the top. The tube becomes progressively smaller through a series of steps. Instead of the connections from the outer circuit

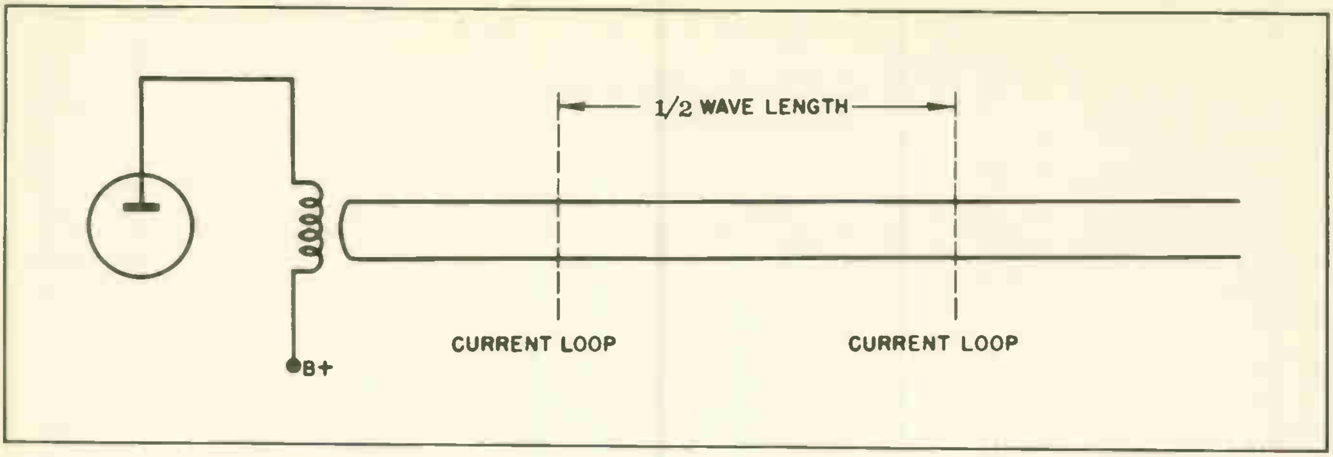

Fig. 18. Using a Lecher Wire System to Measure the Wave-Length of a High-Frequency Signal.

being made to the inside of the tube in the normal manner, they are made to metal flanges which are a part of the "set-backs" in the tube. Such tubes work with good stability up to approximately 1000 megacycles. Since its original introduction, the "lighthouse" tube has been adopted for many uses.

But the limitations of the lighthouse tube prevents it being used at the extreme frequencies commonly used in radar work. To make it practical to operate at those extremely high frequencies it became necessary to develop entirely new types of tubes, tubes that operate on entirely different principles from any that have yet been mentioned in this course.

One such tube was developed by a group of engineers and scientists on the west coast shortly before the outbreak of World War II. It was called the *Klystron*. Instead of depending upon the action of a grid to control the passage of the electrons through the tube, an entirely new method of control was brought into existence. Through the action of a variety of "cavities" the electrons given off by the cathode are bunched into successive waves within the tube.

These successive waves which strike the anode are able to create frequencies far higher than is possible by ordinary conventional circuits. Since the total period of a cycle at such high frequencies is often shorter than the time needed for an electron to pass from the cathode to the anode, it often happens that several groups, or waves, of electrons are moving from the cathode to the anode at the same time. It is due to this ability of the tube that it becomes possible to generate frequencies whose cycle period is shorter than the transit time within the tube. The bunching of the electrons is accomplished by specially constructed "cavities" in the wall of the tube. By adjusting the size or depth of the cavities, it is possible to control the frequency of the generated output.

There is another type of specially constructed high frequency tube which is called the *Magnetron*. The magnetron operates on still a different principle from that of the Klystron. In the magnetron the action of the electrons is brought under the influence of a powerful magnet. The action of the magnet is such that the electrons are given an oscillating movement within the tube itself during the time the electrons are passing from the cathode to the anode.

Since it is not within the scope of this lesson, or of this course, to go into a technical explanation of a magnetron, we will leave it pretty much alone. A comprehensive understanding of the action of either the Klystron or the Magnetron would fill several lessons. In fact, an entire book could be devoted to these two tubes without exhausting their possibilities. It is doubtful if you will soon encounter either of these tubes in television work. But as the commercial television frequencies are raised into the higher parts of the spectrum there is a strong possibility you may encounter one or the other of them eventually.

We believe that you should learn of the existence of these tubes if you are not already aware of them. This is true even though we make no attempt to go into the technical details concerning them. The reason is that every time radio and television men get to talking about the higher frequencies, one or the other of these tubes always seem to pop into the conversation.

But despite the fact you may not soon be using Klystrons, Magnetrons or the Lighthouse tube, it is almost certain that before long you will encounter high frequency oscillator circuits which seem to bear no resemblance to the more conventional types of such circuits. In Fig. 19 we have drawn the diagram of such a circuit, then shown you a diagram of a corresponding conventional oscillator.

Note that in the tuned circuit using the Lecher wires as the tuning unit, the Lecher wires are shorted at the end opposite the tube. You recall from your earlier theory on the action of a transmission line that when the tube looks into an open-circuited line the impedance at the tube will be low, but when it looks into a short-circuited line the impedance at the tube will be high -- it will be similar to that seen when looking at a parallel tuned circuit.

One difference between the tuned line shown in Fig. 19 and those you studied earlier, is that the opposite end of the line in Fig. 19 is completely shorted, and the B-plus is applied at that point. Then the desired length of the line is adjusted by shorting out the line somewhere between the end of the line and where it is connected to the tube. This method of shorting out the line makes it possible to adjust the frequency of the output by merely moving the shorting bar to the correct location -- and thus the frequency -- that is desired. If the part of the shorting bar that rests on the two wires has a sharp edge, the sharpness of the frequency can be kept within rigid limits.

It is possible to use concentric lines in the same manner as parallel lines to control the frequency of a high frequency oscillator. As a matter of fact, the concentric line is used fairly often in some of the more advanced design television receivers. They are used to control the frequency of the oscillator on the higher frequency channels.

The frequency adjustment on such oscillators can be made at the factory, then the entire oscillator is sealed. Some of the so-called "printed circuits" also employ this principle on the high frequency channels.

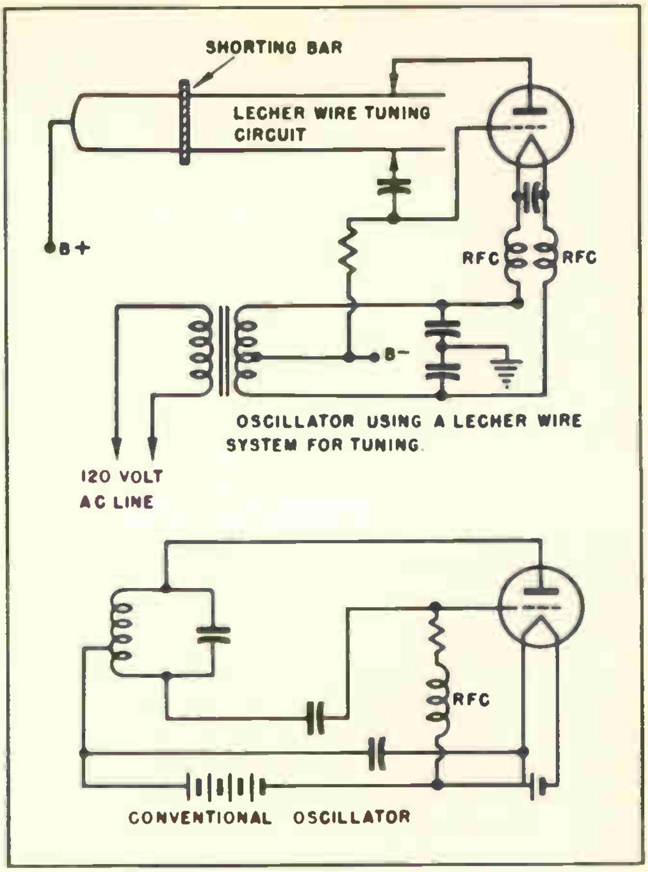

Fig. 19. Comparing a Conventional Oscillator with One Using a Quarter-Wave Line as the Tuning Element.

Section 9. SKIN EFFECT

Another electrical peculiarity that is encountered in high frequency work is known as "Skin Effect". "Skin effect" is the name given to the peculiar habit of high frequency currents to travel on, or along, the outer surface of a conductor rather than in the entire cross-sectional area as is the case with direct current and low frequency A-C.

You are already thoroughly familiar with the fact that the cross-sectional area of a conductor is an important factor in the conductance or resistance of a conductor. As in Fig. 20, for example, we can determine the cross-sectional area by measuring the diameter, then computing the area of the cross-section in the same manner the area of any circle is computed. Since, in D-C work the current moves in all parts of the cross-section at the same time, the total area of the cross-section is directly proportional to the ability of the conductor to carry current. The larger the cross-

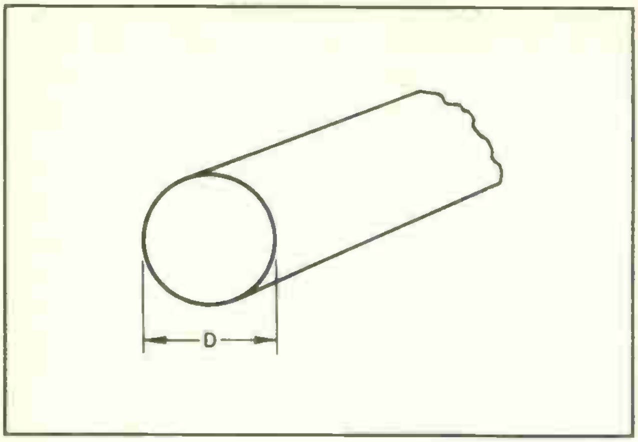

Fig. 20.

section, the more current can be handled by a given conductor.

But with A-C we have a somewhat different situation. Here we have the matter of inductance to consider. Getting down to the basic fundamentals we can understand that whenever or wherever an electron moves we will find an electromagnetic field set up around that electron. The more electrons that move the stronger will be the field.

Now in the case of a conductor we have a large number of electrons all flowing in the same direction together at the same time. We already know that when a large group of electrons start to move through a conductor they will instantly build up an electromagnetic field around that conductor. During the time the *field is building up* it will act to induce a voltage in the conductor that tries to oppose the movement of the current. All of this is old stuff to you by this time, but we want to repeat it again to make certain it is clearly in your mind.

In a conductor where there is direct current flowing, the original movement of the electrons which compose the current will be such that there will be a momentary opposition built up against that flow of current. But this opposition will be momentary only. After the current has built up to a steady flow, the opposition will cease.

Under most conditions we consider the opposition created by inductance to be uniform through the cross-section of the conductor. By this we mean that we usually consider the opposition to be as great in one part of the conductor as in the other. But this assumption is not true, even though it is true that we can usually consider it to be so. The opposition exerted on any particular electron which composes the flow of current depends upon the strength of the magnetic field that is built up around it.

Suppose we consider the illustration in Fig. 21 as being an enlarged cross-section of a piece of conductor. Within the cut cross-section we have tried to represent a number of electrons. Around the electrons we have drawn dotted circles to represent the expanding magnetic lines of force as the electrons start to move through the conductor.

In Fig. 22 we have gone a step further and tried to show how the lines of force surrounding each individual electron cuts across and affects the other neighboring electrons. It should be understood, of course, that while we have been able to show only a very few electrons, there are actually billions of such electrons present in the cross-section of even the smallest conductor.

The important point to understand is this: The electrons in the center of the conductor will be cut by more lines of force than the electrons nearer the surface of the conductor. This is because many of the magnetic lines of force of the electrons near the surface will extend out into the space which surrounds the conductor. The net result is that the electrons near the center of the conductor are more affected by the self-inductance which is always present in a wire than are the conductors near the surface.

It has already been explained to you that even a straight piece of wire contains a certain amount of inductance. We have also

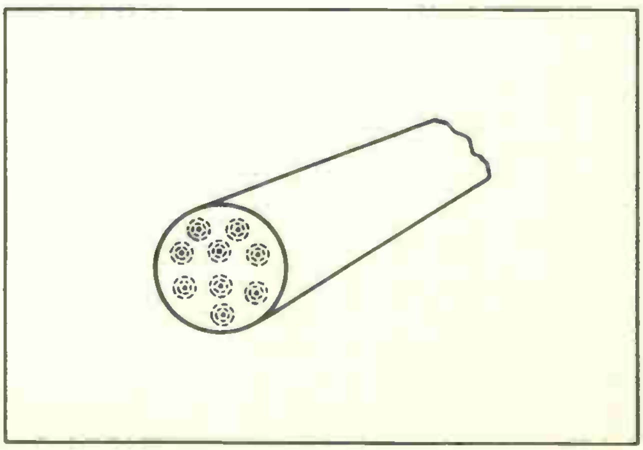

Fig. 21.

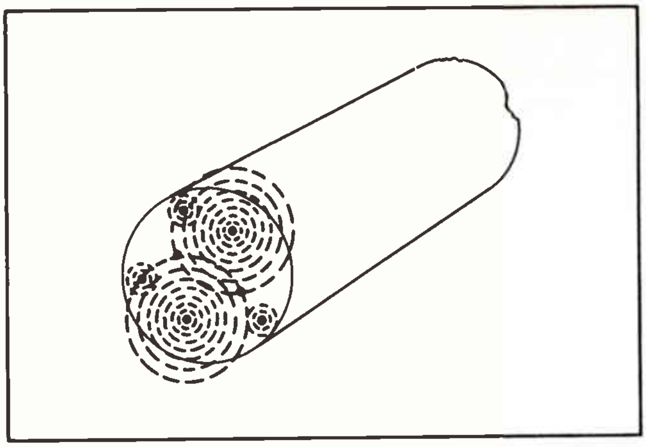

Fig. 22.

explained that while the inductance is always present as an inherent part of the conductor, the inductance is so small that at low frequencies we do not normally have to take it into consideration. All this is true.

But we have also explained to you that while the reactance created in a piece of conductor by the inductance may be so negligible that it can be ignored at 1 megacycle, the reactance can easily become so high at 100 megacycles that it is an important element in a circuit.

And so it is also true of the inside of the conductor itself. While each moving electron sets up electromagnetic lines of force, and these lines of force act upon adjacent electrons and affect them, such action is so negligible at low frequencies they are of no importance and can be ignored. But as the frequency is increased, this condition no longer exists. The effect upon the electrons in the center of the conductor becomes so pronounced that at the very high frequencies the reactance is so great at the center of the conductor that no electrons can move. This means that as the frequency is increased higher and higher there will be less and less current flowing in the center of the conductor.

To put this in other words, as the frequency is increased, the tendency is for more and more of the current to flow at, or near the surface of the conductor. Since the current tends to flow nearer the outer surface, or skin, of the conductor, this property has been given the general designation, "skin effect". This is the reason why it is necessary to use conductors which are so much larger when the frequency is high than is necessary when the frequency is low, or the current is D-C.

To overcome the problems created by skin effect, a special kind of wire has been developed called "Litz" wire. Litz wire is composed of a large number of very fine wires woven together into a strand. Sometimes each strand is insulated from each other. The theory behind the use of such wire is that each strand is a separate conductor. This means that a much larger current can be carried by the many strands of fine wire than can be carried by a single wire which has the same overall dimension of the grouped Litz wires.

Litz wire was proven to be useful for many purposes. But it is not used as widely in television work as it was once used in radio work. Many of the high frequency components in a television receiver need to be rigidly mounted so there can be no physical movement. This means the components themselves must be strong. The combination of this need and that imposed by the skin effect has been to build many of the high frequency conductors of very heavy wire.

The peculiar properties of skin effect requires that high frequency vacuum tubes be constructed somewhat differently than those which are to be used only at the low frequencies. The lead wires from outside the tube to the tube elements must be much larger if the tube is to be used in high frequency work than would be permissible for low frequency work.

Because of the tendency of high frequency currents to travel on the surface of the conductors instead of inside the conductors, it becomes important to make the conductance of the outer surface of the conductor as high as possible. The manufacturers of some of the finer television receivers use conductors which have a coating of silver because silver is a better conductor than copper. Many of the high frequency conductors used in radar equipment are made of silver, or are coated with silver, for the same reason. Many of the switch contacts, wave guides, and other kinds of conductors used in radar work are plated with silver for the same reason.

(over)

NOTES FOR REFERENCE

Although all electric currents and voltage obey the same rules, those at very high frequencies *seem* to act differently in many ways than is true of direct current or low frequency A-C.

The usefulness of conventional oscillators becomes limited as the frequency increases.

At very high frequencies the conventional oscillator using coils and capacitors is useless.

Whenever wave-form energy strikes a change of any kind in the character of the medium through which it is passing, a part of the energy will be reflected back toward the source.

Reflected wave-motion of any kind travels at the same speed as the original wave.

The energy of a reflected wave will combine with the original wave to form a resultant.

The resultant will not move in either direction; it remains motionless. Such a motionless wave in a transmission line carrying high frequency electrical energy creates what we call "standing waves".

There will be no standing waves in a transmission line that is properly terminated.

Standing waves will always be present in any transmission line that is not properly terminated.

When standing waves are present in a transmission line the voltage will always be high between the lines where the current is low, but it will be low where the current is high.

If a transmission line is open-circuited at the end, the current will be minimum at the end.

The voltage will always be maximum at the end of an open-circuited transmission line.

When a signal source looks into a transmission line whose opposite end is open-circuited, the source will be looking into a low impedance.

When a signal source looks into a line whose opposite end is short-circuited, the source will be looking into a high impedance.

To a signal source, an open-circuited transmission line looks like a series-tuned circuit.

To the source, a short-circuited line looks like a parallel-tuned circuit.

"Skin-effect" is a peculiar electrical property which tends to cause the current to flow on the surface of a conductor at high frequencies rather than to use the entire cross-section of the conductor.

At very high frequencies the conductors are sometimes plated with silver so as to provide better electrical paths for the current.

A special type of stranded wire called "Litz" wire is also used for some kinds of high frequency circuits.

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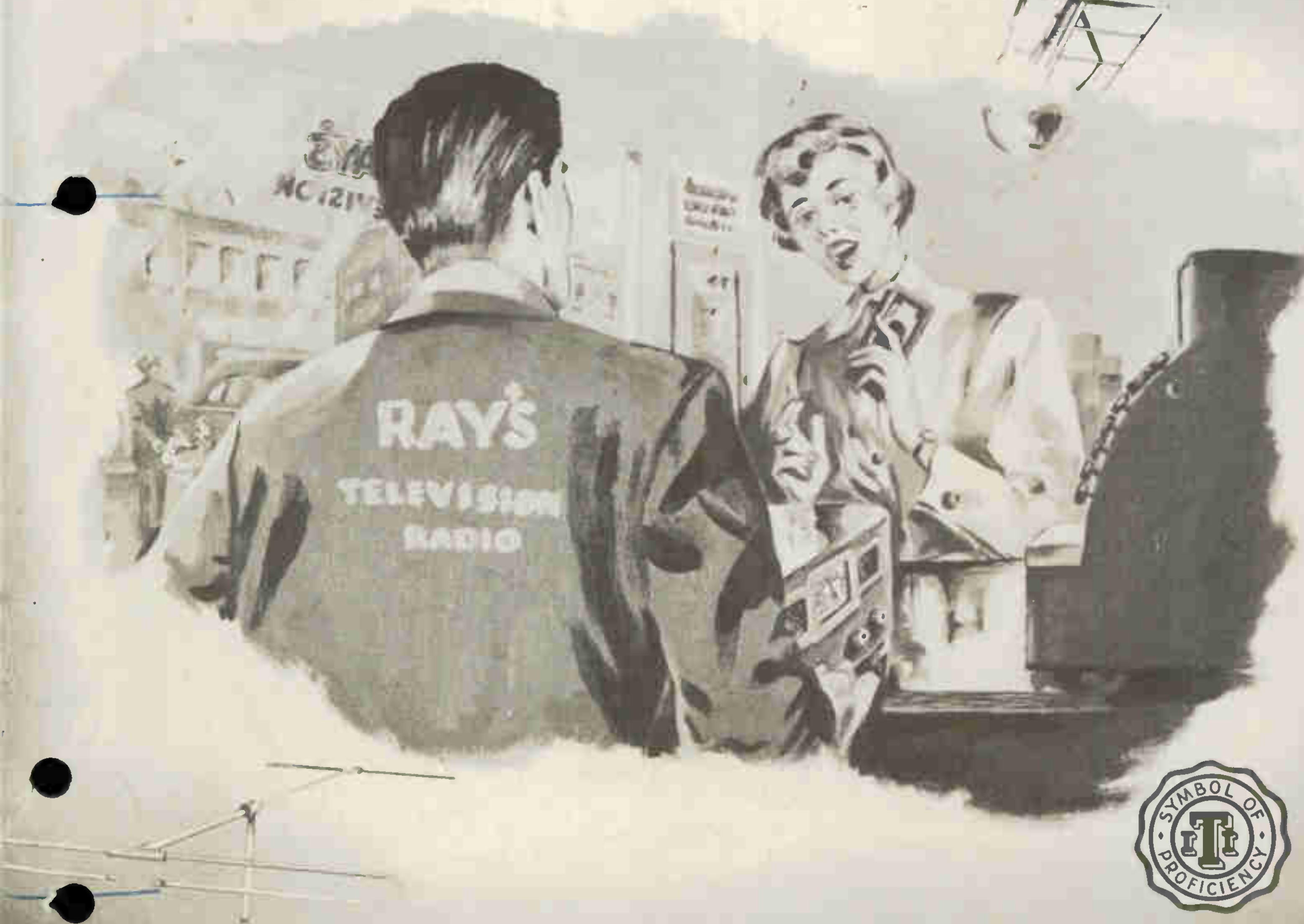

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TECHNICAL TRAINING SERVICE

REVISED 1957

ANTENNAS

Contents: Introduction - Electrical Fundamentals - Antenna Radiation - Properties of Antenna Systems - The Action in an Antenna - Polarization of the Radiated Waves - Distance of Travel - Location of Antennas - Reflected Signals - Receiving Radiated Energy - Dipole Antennas - The Folded Dipole - Directional Arrays - Reflector Elements - Director Elements - Stacked Arrays - Conical Antennas - Commercial Antennas - Multi-Channel Reception - Comparison of Various Types of Antennas - Impedance Transformers - Resonant and Non-Resonant Lines - Notes for Reference.

Section 1. INTRODUCTION

To a person whose experience has been limited to radio servicing, or to the use of radio receivers which are limited to the reception of Broadcast programs, the need for a good knowledge of antennas may seem comparatively unnecessary. Since there are so many types of commercially constructed antennas for use with television receivers it would also seem that the selection of a usable one would be merely a matter of selecting the least expensive, or the most attractive antenna, orpossibly accepting the one handled by the most personable salesman.

The part played by the antenna in a television system is so vital to the proper performance of the receiver that it is almost impossible to over-estimate its importance.

Some twenty or more years ago, most owners of radio receivers had an outside antenna for reception of the radio signal. As improvements were made in the sensitivity and selectivity of receivers, the need for the outside antenna gradually decreased until in recent years few radio receivers in metropolitan districts use an outside antenna at all. Nearly all modern radio receivers have a loop antenna incorporated as a part of the receiver. For most purposes the built-in antenna is entirely adequate.

We find the needs of the television receiver, however, to be somewhat different from the needs of the home radio receiver. A television receiver must have an outside antenna for every installation except those which are quite close to the transmitter.

There are many types of television antennas on the market. Most of them are

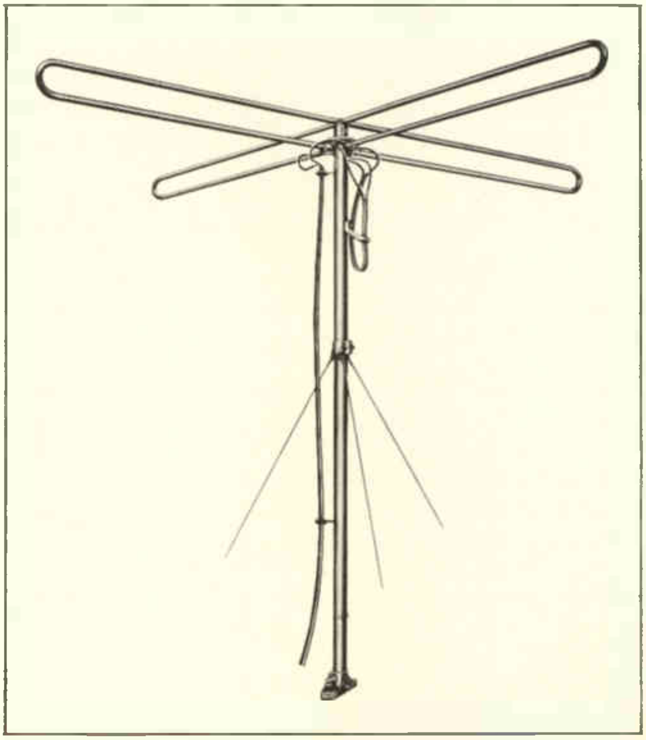

Fig.1. Folded Dipole Double Doublet Antenna. (Courtesy American Phenolic Co.)

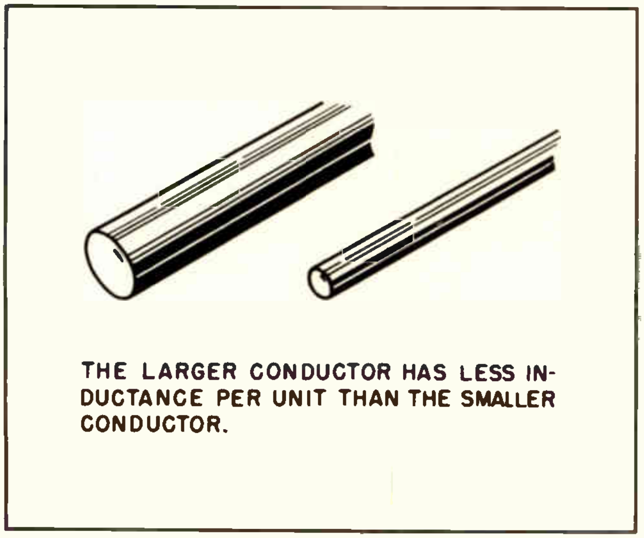

Fig. 2.

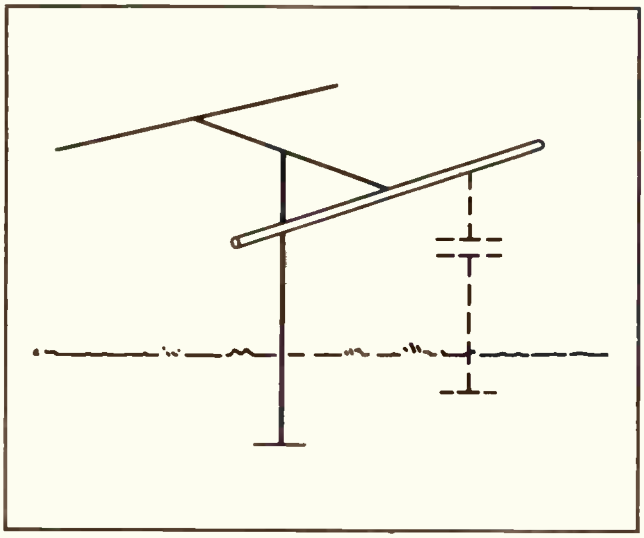

Fig. 3.

good, and all are useful in some installations. But it should be clearly understood that no antenna yet put on the market is good for all installations. The reasons why this is true is one of the purposes of this lesson.

Several manufacturers build television antennas which are ideal for use in metropolitan areas where there are several transmitting stations. These antennas do a remarkably good job of picking up signals from all the local television transmitting stations, and bring the signal into the receiver strong and clear. Yet these same antennas might be almost worthless if the receiver is located some 70 to 100 miles from the transmitter.

It might be thought, then, that an antenna which could be used to pick up a signal at the longer distances of 65, 75 or 100 miles from the transmitter, and do a reasonably good job of it, could also do a satisfactory job for a receiver located near the transmitter. In some cases the same antenna might be able to do the job, but such would not necessarily be true for all cases. An antenna which could pick up a single station at a distance might be almost useless for picking up several stations located in a metropolitan area. The reasons why these things are true will be taken up point by point in this lesson, and discussed in detail.

Section 2. ELECTRICAL FUNDAMENTALS

It may seem a bit strange that we should take up your time at this stage of your course to discuss electrical fundamentals. Nevertheless, we think it wise to do so. There are a number of things which you learned about the action of electricity in electrical circuits that may have slipped your mind during the progress of your studies. Some of them you have not used recently in your studies. Some were mentioned only sketchily at the time they were first discussed; in some cases we thought it wiser to postpone a detailed discussion until the need for such knowledge was deemed important.

Let us first consider the effect of the physical dimensions of a conductor on the inductance of the conductor. It has been stated repeatedly that every conductor contains a certain amount of inductance.

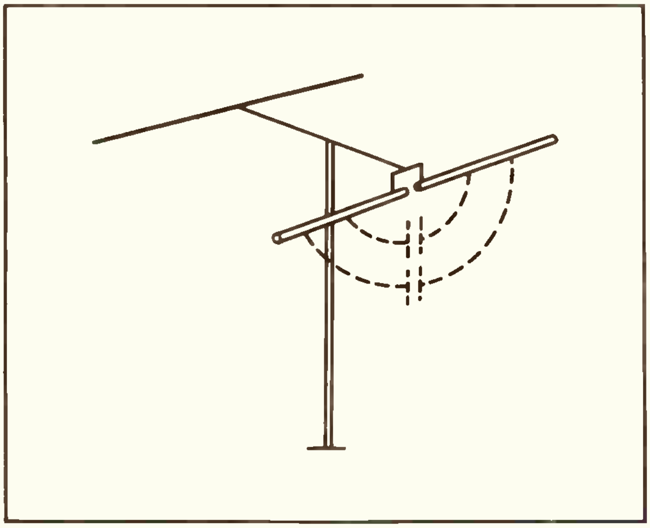

Fig. 4.

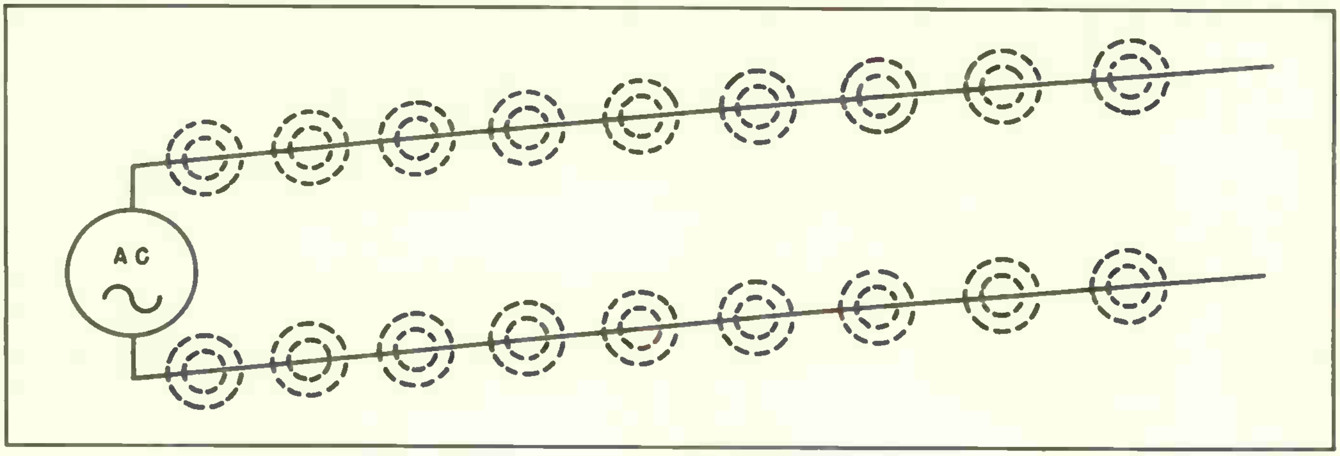

Fig. 5.

Such inductance will affect the flow of high frequency alternating current through the conductor.

It has also been mentioned that the larger the cross-section of a conductor the lower would be the inductance for any given length. In this respect the effect of cross-sectional area on inductance is somewhat similar to that of its effect on resistance. It should be mentioned, however, that the difference is not proportional, nor inversely proportional. In the case of resistance, a conductor which has twice the cross-sectional area has just half the resistance. In the case of inductance, a conductor which has twice the cross-section has *less* inductance than the smaller conductor, but the value of inductance is not necessarily half that of the smaller one. This is shown graphically in Fig. 2.

Another electrical property worth keeping in mind when working with antennas is that of capacity. The capacity between the antenna element and the ground must always be considered and kept in mind. This is the condition shown in Fig. 3. But in addition to the capacity between the antenna and the ground we must also consider that which exists between the various parts of the antenna itself. This last condition is shown in Fig. 4.

The size of the conductor also figures in the amount of capacity which exists under any particular condition. If the cross-section of the conductor is large there will be more capacity present than if the conducting material is small. This all makes clear sense, of course, yet it is something we are often prone to forget. From all this it can be seen that the size of the conducting material from which the antenna is constructed has a considerable influence on the operating characteristics of the antenna itself.

In addition to the physical construction of the antenna there are other things which must be considered in working with antennas. Some of these other things can also be considered to be electrical fundamentals, and all have been covered in previous lessons. But even they should be touched upon briefly again before we get into the actual consideration of antenna construction and operation.

Whenever electrical current flows in an electrical conductor there will always be certain conditions present in the space which surrounds the conductor. If we feed an alternating current into a pair of conducting wires, such as a transmission line,

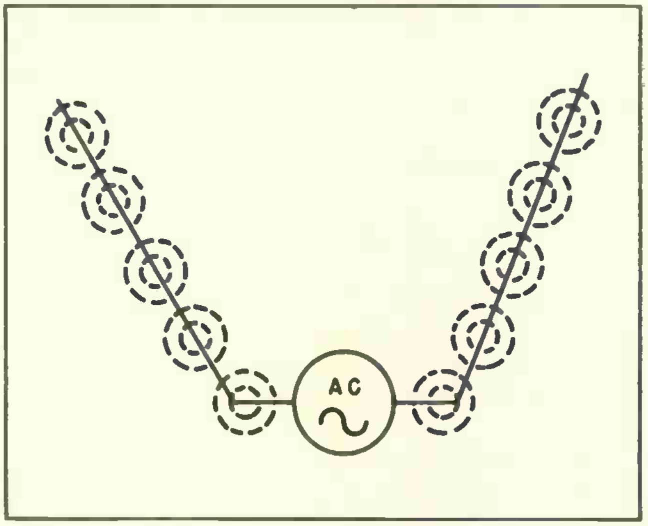

Fig. 6.

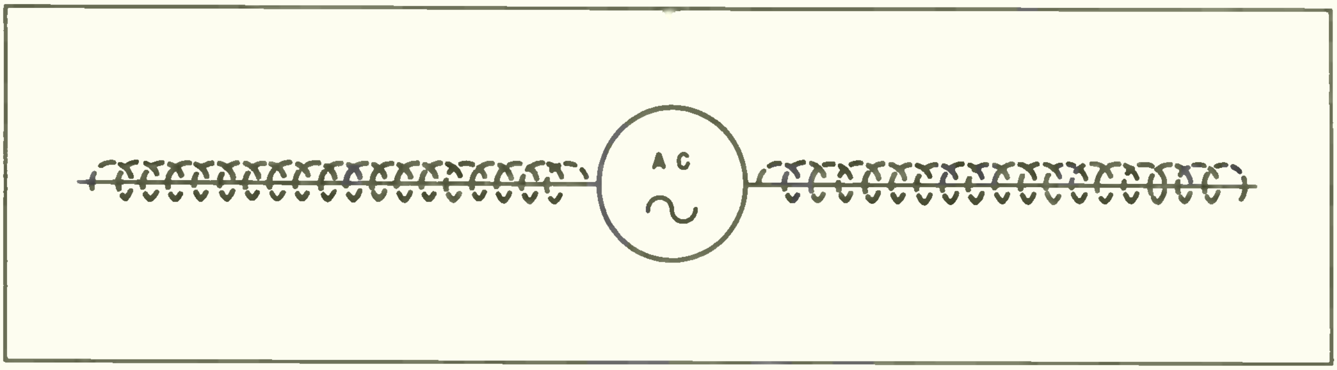

Fig.7.

we instantly set up magnetic fields around that conductor. Such a situation is shown in a graphical manner in Fig. 5. And, of course, such a situation is nothing new to us; we have encountered it many times in our studies.

Instead of having the two wires go out in a parallel manner as shown in Fig. 5, they could go out in different directions as shown in Fig. 6. They could even go out in opposite directions as shown in Fig. 7. The important point is that regardless of how the lines go out from the source of the signal, the magnetic lines will surround the wires of the conductors in the same manner as is true in any other kind of conductor.

What we have said here has been directed toward the magnetic field which surrounds a conductor which is carrying an electrical current. We have chosen to treat the magnetic condition which is present under such circumstances because it is something with which you are more familiar at the moment. But there is another electrical element present -- one that we have not discussed so extensively as that of magnetism. We refer to the *electric field* which is also present whenever there are voltage differences present.

The matter of electric fields was discussed in Lesson TBA, the lesson on VACUUM TUBES, in somewhat more detail than in most other lessons. If you have forgotten the effect of electrostatic fields, we suggest that you go back and read over that lesson again before proceeding with this one.

The essential points which you should keep in mind during the study of this lesson is that whenever two electrical conductors are so charged that an electrical potential difference is maintained between them, there will be an electric field between the conductors. The electric field will be present whether there is any current flowing through the conductors or not. The mere presence of the voltage difference between the two conductors is enough to set up the existence of the electric field. You will recall that this is the same thing which we so often find present within vacuum tubes -- in fact it is one of the conditions which makes vacuum tubes useful.

In Fig. 8 we have tried to represent the existence of the electric field by means of an arrowed line which contains a capacitor. This may not be the best method of representing the condition which actually exists but it should bring the point home to you reasonably well. The main thing is that if a voltage difference exists between the two lines, an electric field will also be present. Furthermore, the electric field will be present regardless of the presence of any current, thus the electric field will be present whether there is an electro-

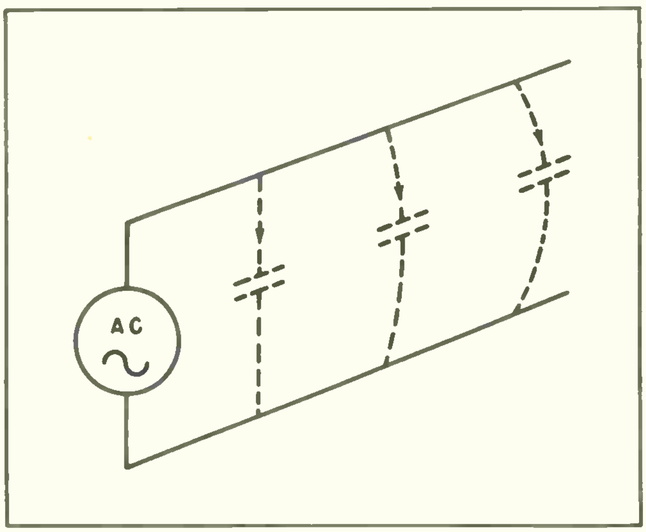

Fig.8.

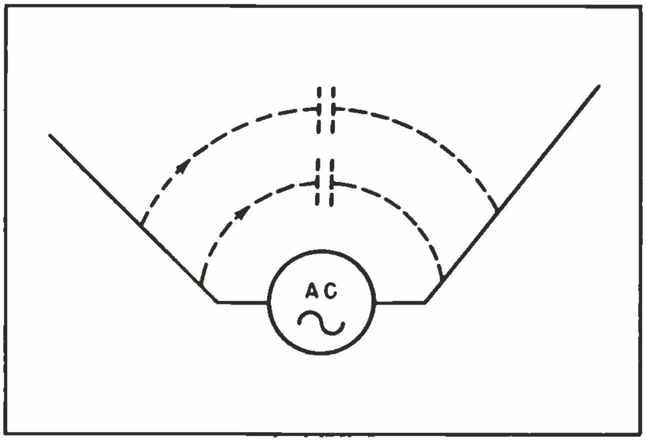

Fig. 9.

magnetic field present or not. The condition would still be present even though the lines were not parallel. The lines could diverge as in Fig. 9, or even go out in opposite directions as in Fig. 10. Yet in either situation there would still be an electric field between the two conductors.

Now we come to another electrical fundamental which you have come across a number of times in your studies, but we want to mention it again before seriously getting into a discussion of antenna properties. Whenever electrical current flows through a conductor that current will create a magnetic field. During the time that magnetic field is *moving* it will create an electrical voltage in a conductor or an electric field in space.

Equally important -- whenever an electric field is *moving* in space it will create a magnetic field.

Note carefully these two statements -- they are very important to a full understanding of antenna principles: A moving magnetic field will create an electric field; and a moving electric field will create a magnetic field. And these conditions will be true regardless of whether the magnetic field and the electric field are held close to a moving current in a conductor or are present in free space.

Section 3. ANTENNA RADIATION

Before tackling the complexities of a receiving antenna we will first discuss briefly the conditions under which a transmitting antenna operates. It is somewhat easier to explain and to understand the operation of a transmitting antenna. Then when the operating principles of the transmitting antenna are understood we will apply those same principles to the receiving antenna, and proceed from there.

The principles which govern the radiation of energy from an antenna are based on the physical law that a moving electric field creates a magnetic field, and that a moving magnetic field creates an electric field. Although we earlier thought of the situation of a magnetic field producing an electric field as usually taking place in a conductor, the fact is that the laws of field generation continue to hold true when the fields are present in free space and not connected with a conductor at all. The same thing is true of an electric field generating a magnetic field.

When the two fields are radiated in free space they will always be electrically in phase with each other. This means that as the electric field rises, the magnetic field will rise and that as one falls, the other will fall.

But despite the fact both fields are in phase with each other, it should be noted that they are so located *physically* that they are at right angles to each other. As an example of this, suppose we have a pair of fields moving outward through space. One of the fields will be rising and falling in a horizontal plane while the other will be rising and falling in a vertical plane. Thus, while they rise and fall in phase with

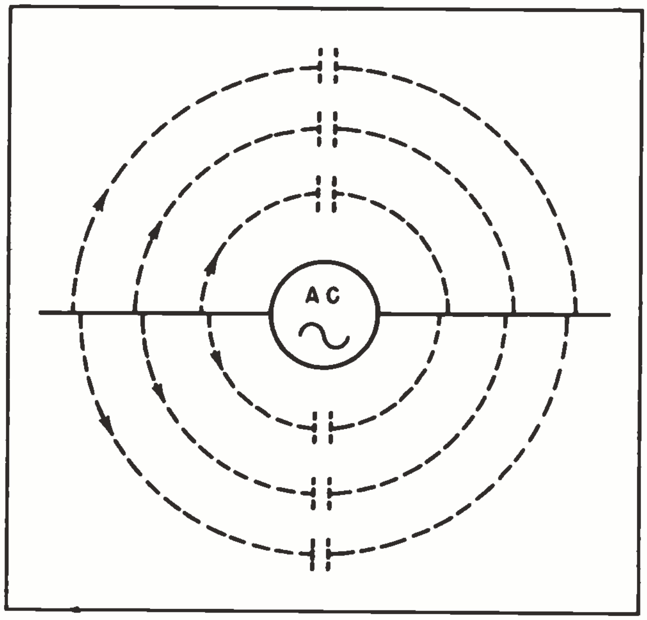

Fig. 10.

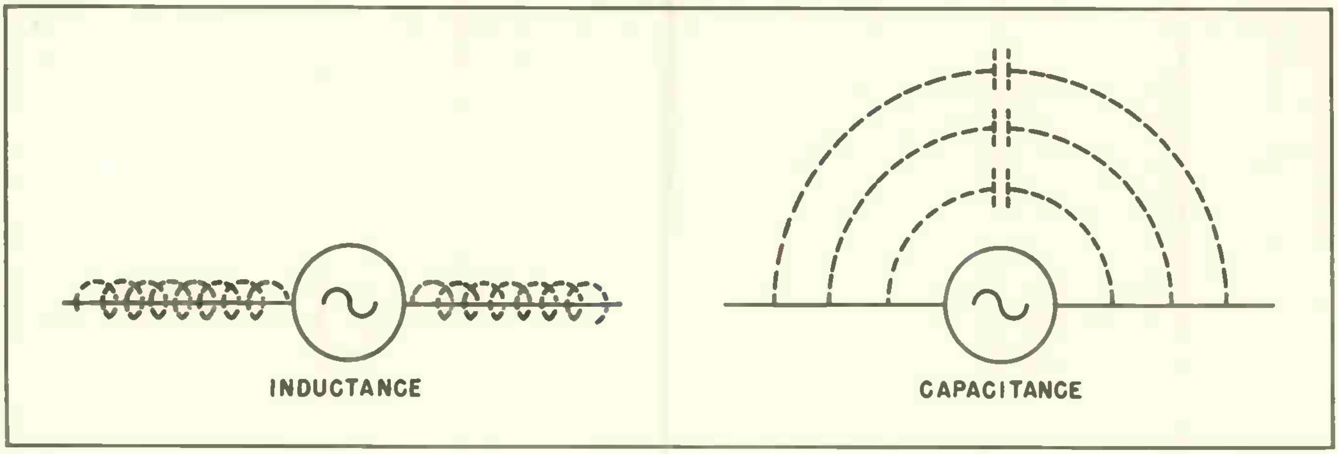

Fig. 11. The Inductance and Capacitance which is Always Present in a Dipole.

each other, they do so in places which are perpendicular to each other. This is the basis for the oft-quoted statement that the electric and magnetic fields in a radio wave are at right angles to each other and also at right angles to the direction of travel. This will be explained a little more in detail further along in this lesson.

When the action of an antenna is reduced to its basic fundamentals we come up against the fact that all antennas, whether transmitting or receiving, are resonant circuits. They are tuned to resonate at some particular frequency. This means that each antenna system possesses the tuned circuit properties of inductance and capacitance.

The inductance of an antenna is provided and determined by the length of the conductor which serves as the antenna. The capacity is provided by the actual capacity which always exists between the various parts of the antenna. Fig. 11 indicates the properties of inductance and capacitance which are always present in and around the conductor which is used as an antenna.

Section 4. PROPERTIES OF ANTENNA SYSTEMS

Since we have said that an antenna is a resonant circuit, and since all resonant circuits contain inductance and capacitance, let us now turn our attention to the physical and electrical properties of an actual antenna system. For the purpose of illustration and discussion we will first examine the case of a simple dipole antenna. A dipole antenna, as its name suggests, is an antenna composed of two poles, or two arms. Usually such an antenna consists of two metal rods extending at angles 180° apart, and supported in the center by some insulating material. The general appearance of such a dipole antenna is shown in Fig. 12.

It would seem evident that if the antenna is a resonant circuit its physical size must bear some relationship to the frequency to which it is resonant. Such is, indeed, the truth. The frequency to which a simple dipole antenna will resonate is determined by the physical length of the metal rods. When each rod is cut to 1/4th the wave-length of a frequency the antenna will resonate at that frequency.

As a practical example, suppose we want to build an antenna that will resonate at a frequency of 50 megacycles. The total length of the antenna consisting of the *two* rods must be one-half wave-length long,

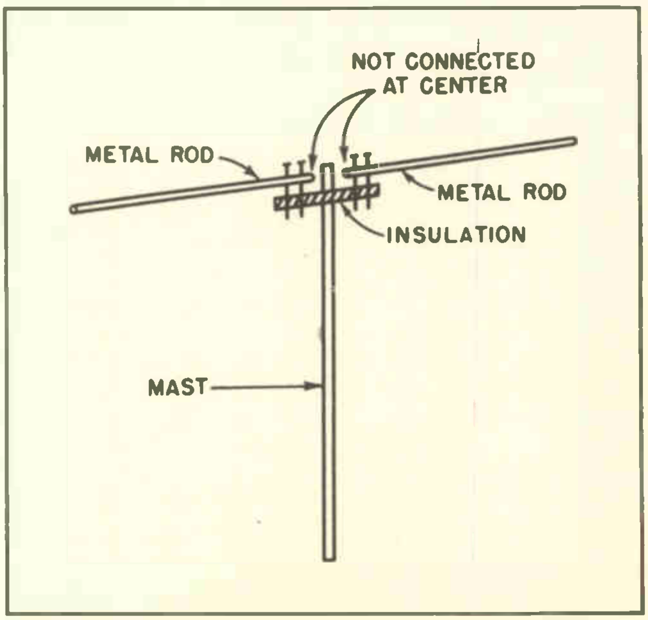

Fig. 12. Construction of a Dipole Antenna.

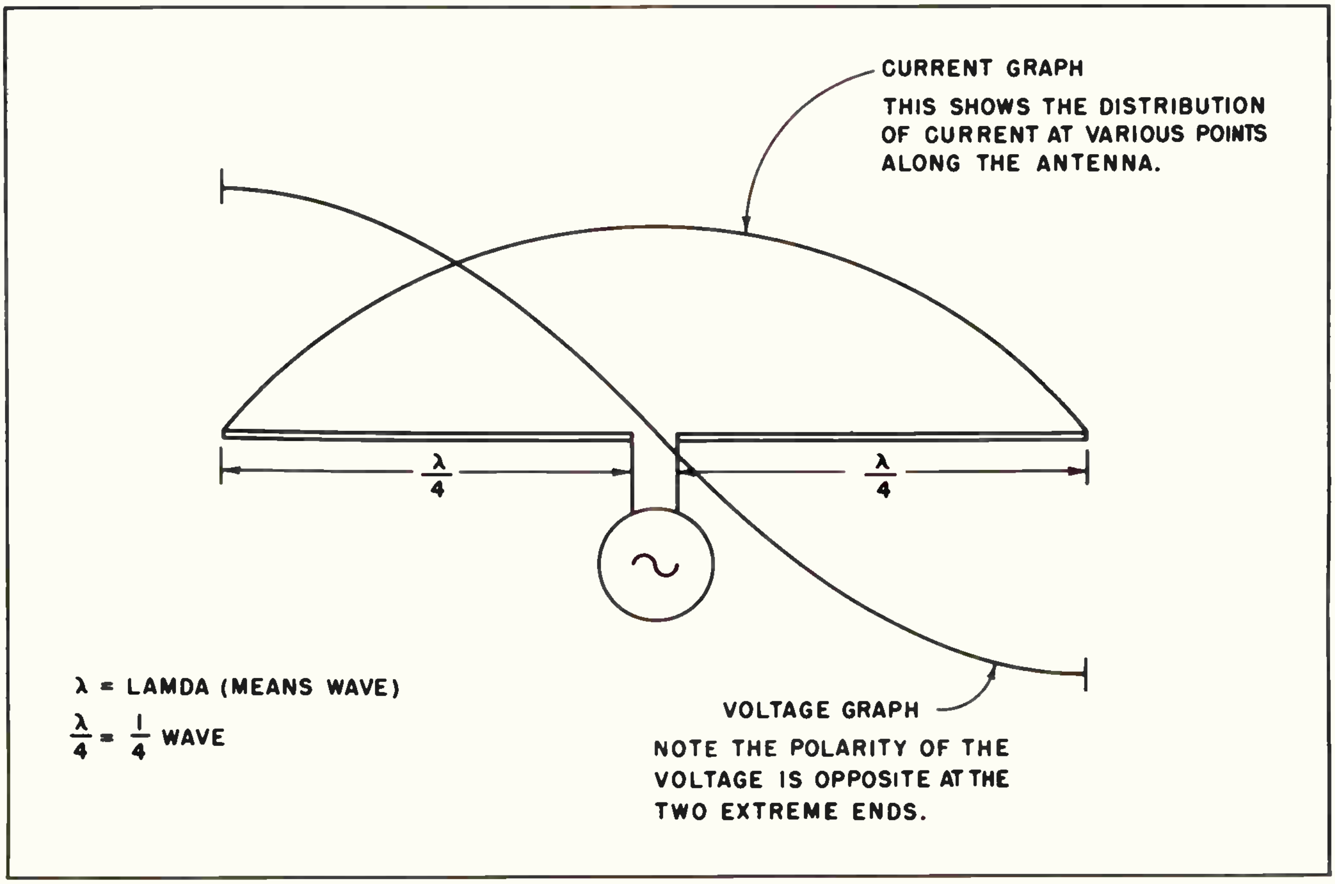

Fig. 13. Voltage and Current Distribution on a Dipole Antenna.

which means that *each* rod must be 1/4th wave-length long. A frequency of 50 megacycles has a wave-length of 6 meters. This means the total length of the antenna must be 3 meters, and the length of each rod, then, would be 1½ meters long. This means that each rod would have to be about 58½ inches long, making the total length of the antenna about 117 inches long. This would be almost 10 feet.

It is interesting to note the current and voltage distribution which is present in and around a simple dipole antenna when it is fed with a signal that will resonate with the antenna. A graph of the current and the voltage which is present is superimposed over an illustration of a dipole in Fig. 13.

When the A-C generator feeds a signal into the center of the antenna -- a signal which will resonate with the antenna -- current will be caused to flow in both quarter-wave sections of the antenna. The action in the antenna is similar to that we find near the end of an open-circuited transmission line. Just as we find the current at the end of an open-circuited transmission is at its minimum value, we also find the current at the extreme tips of the antenna to be minimum. And just as we find the current to be a maximum value -- a loop -- a quarter-wave length from the end of an open-circuited transmission line, so do we find the current to be maximum a quarter-wave length from the end of the antenna.

In the case of the antenna we find the location of a quarter-wave distance from each end to be the center of the antenna. This means the current distribution in a dipole antenna is at its maximum value at the center of the antenna, at the point where the two rods are separated, which is also the point where the line from the A-C generator is connected.

Just as we learned that the voltage in a transmission line is maximum at those points where the current is minimum, so do we also find that in an antenna we find the voltage to be greatest at each end where the current is at its smallest value. Furthermore, at the center of the antenna, where the current is maximum, we find the voltage to be minimum. You will also note that while the

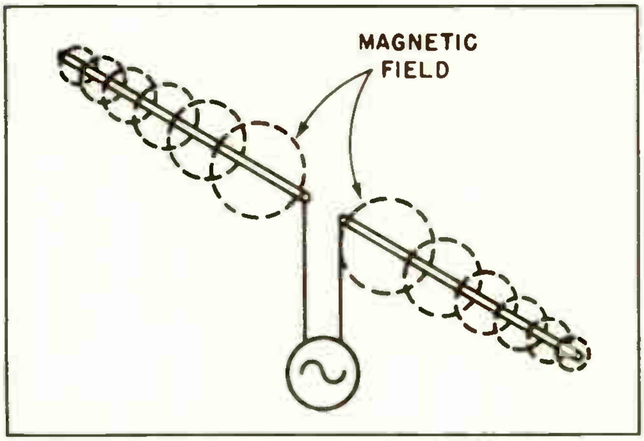

Fig.14. Magnetic Field being Built Up Around a Dipole.

voltage is maximum in one direction at one end, it is maximum in the other direction at the opposite end.

It stands to reason that any dipole antenna which has a reasonable length must resonate at a high frequency. This follows from the fact that the wave-length of a relatively low frequency would be so long it would not be practical to build a dipole sufficiently large to resonate with the low frequency. This means, of course, that it is only at the high frequencies that the use of a dipole antenna becomes practical.

Section 5. THE ACTION IN AN ANTENNA

Now let's see what happens when we feed a signal into a dipole which has a frequency of the right value to resonate with the antenna. The current flowing into the antenna is going to cause a magnetic field to expand in space around the antenna. (See Fig. 14.) Remember that the current in the antenna is *very high frequency* current, current that is constantly reversing itself very rapidly. This means that the magnetic field will scarcely build up to its maximum value before the current will reverse itself and start flowing in the opposite direction. In fact it will reverse so fast the magnetic field will not even have time to collapse. And while the magnetic field is still hanging out there in space wondering what to do, the current reverses again and builds up another magnetic field just like the first one.

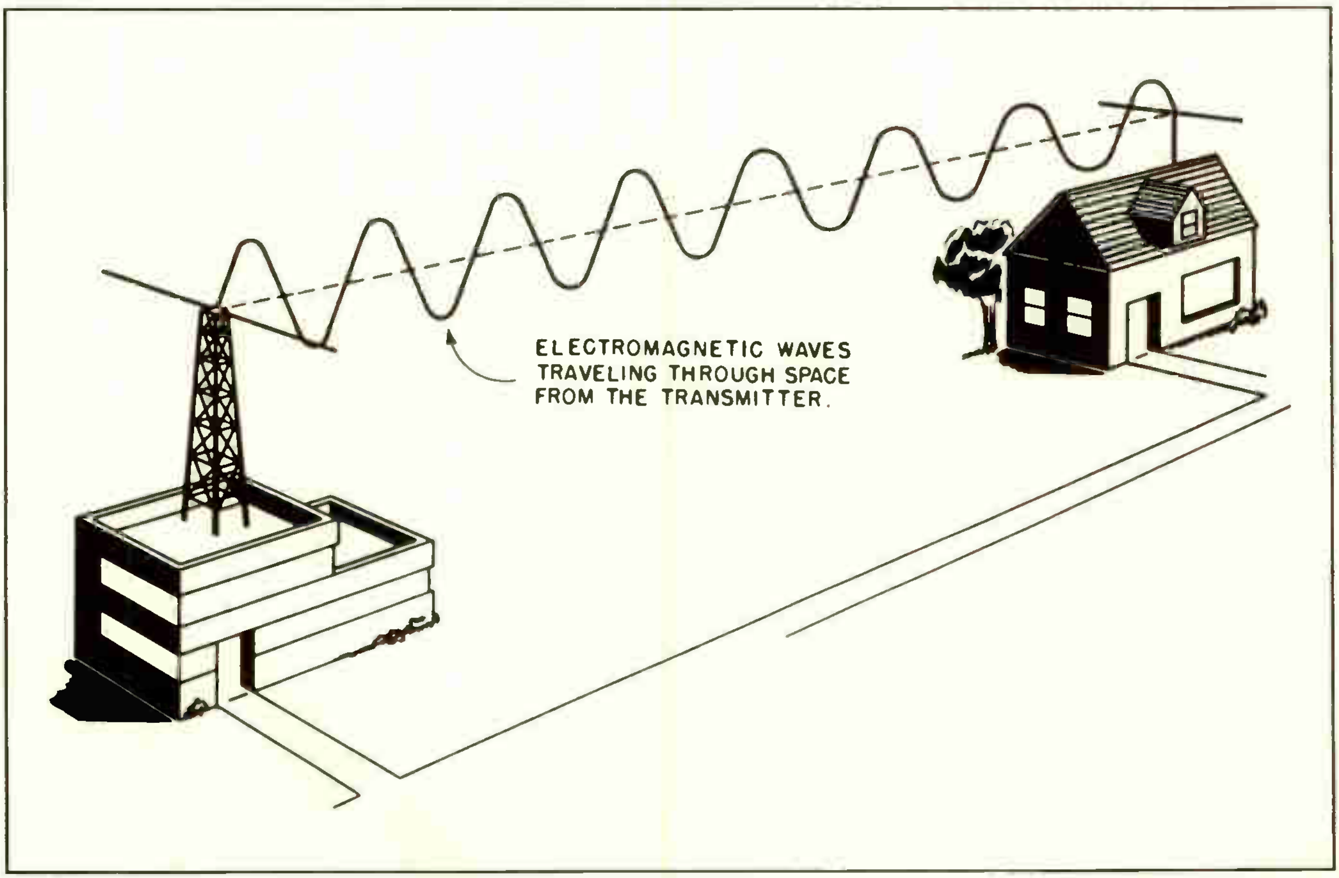

Fig.15. Polarization of Magnetic Waves Traveling from Transmitter to Receiver.

Now the first magnetic field *can't* collapse back into the antenna. It finds another magnetic field building up between it and the antenna which has a polarity the same as itself. Since two magnetic fields which have the same polarity tend to repel each other, there is nothing for the first magnetic field to do except move a little farther out into space.

An instant later, before either of these magnetic fields have been able to do anything except move a short distance away, the current in the antenna goes through another cycle, and starts building up a third magnetic field. This third field, having the same polarity as the first two fields, forces the first two fields out still a little farther into space.

And so it goes. The current in the antenna is constantly reversing itself, and each time it starts building up in the original direction it creates another magnetic field which tends to push the previous fields farther and farther out into space. The rising and the falling of the magnetic waves as they are pushed out into space is shown in Fig. 15 where we show how the waves leave the transmitter and move toward a distant receiving antenna. The form of the waves are not exactly as shown in that illustration. Actually, it would be more proper to regard the sine wave shown there as being a cross-section of a series of huge waves moving in every direction from the transmitter. But the graph shown in Fig. 15 is about the best way we can represent an invisible manifestation so that it will present a picture to your eyes and to your mind.

Now we have said that the current flowing in the antenna will create a series of magnetic waves as has been illustrated in Figs. 14 and 15. But there is another action taking place in and around the antenna, an action which also affects everything near it in space.

Fig. 13 illustrates the presence of an electric charge which exists between the two parts of the antenna. This is the electrostatic field which always exists between two conductors which carry opposite charges. It is worthy of note that the voltage becomes

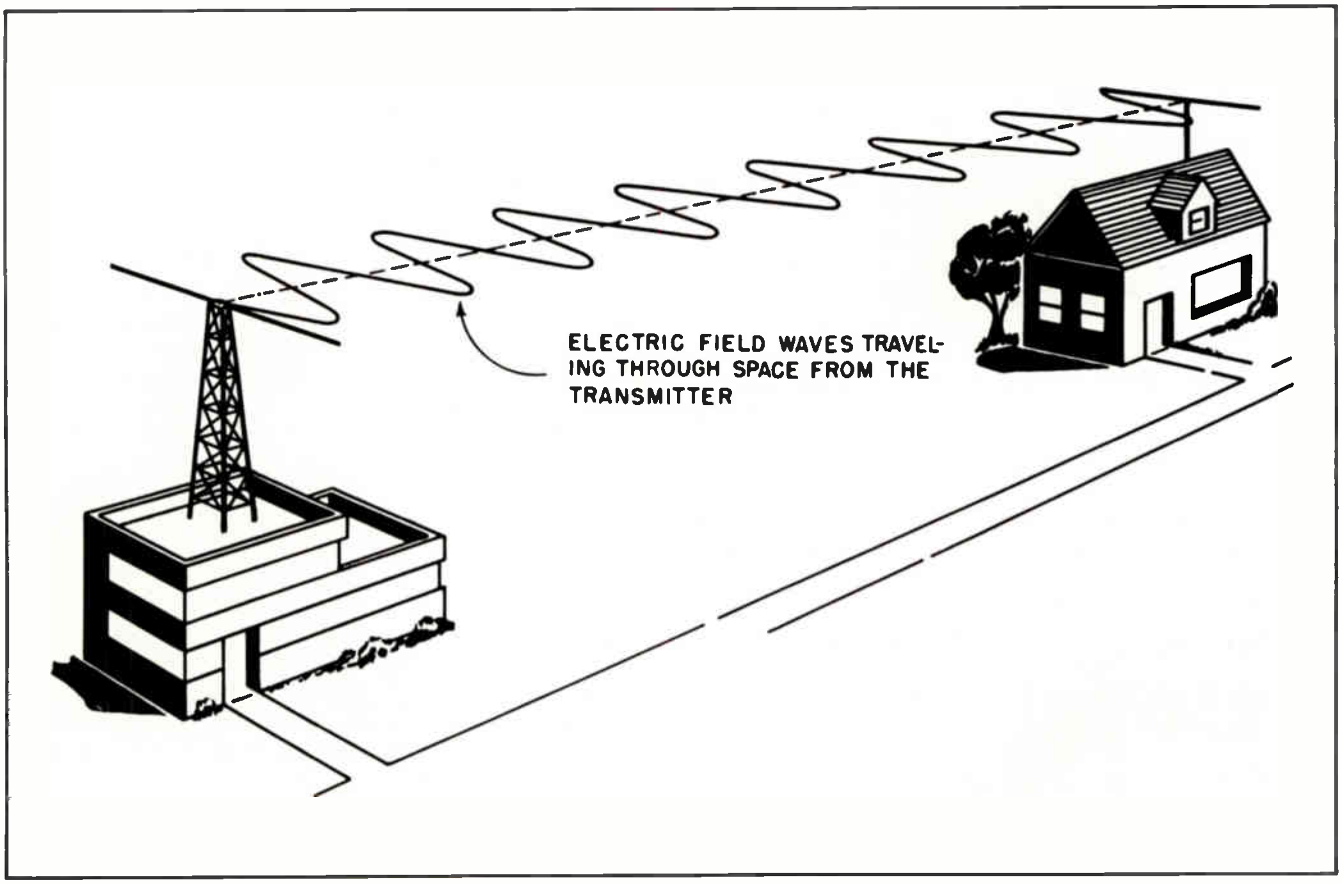

Fig. 16. Polarization of Electric Waves between Transmitter and Receiver.

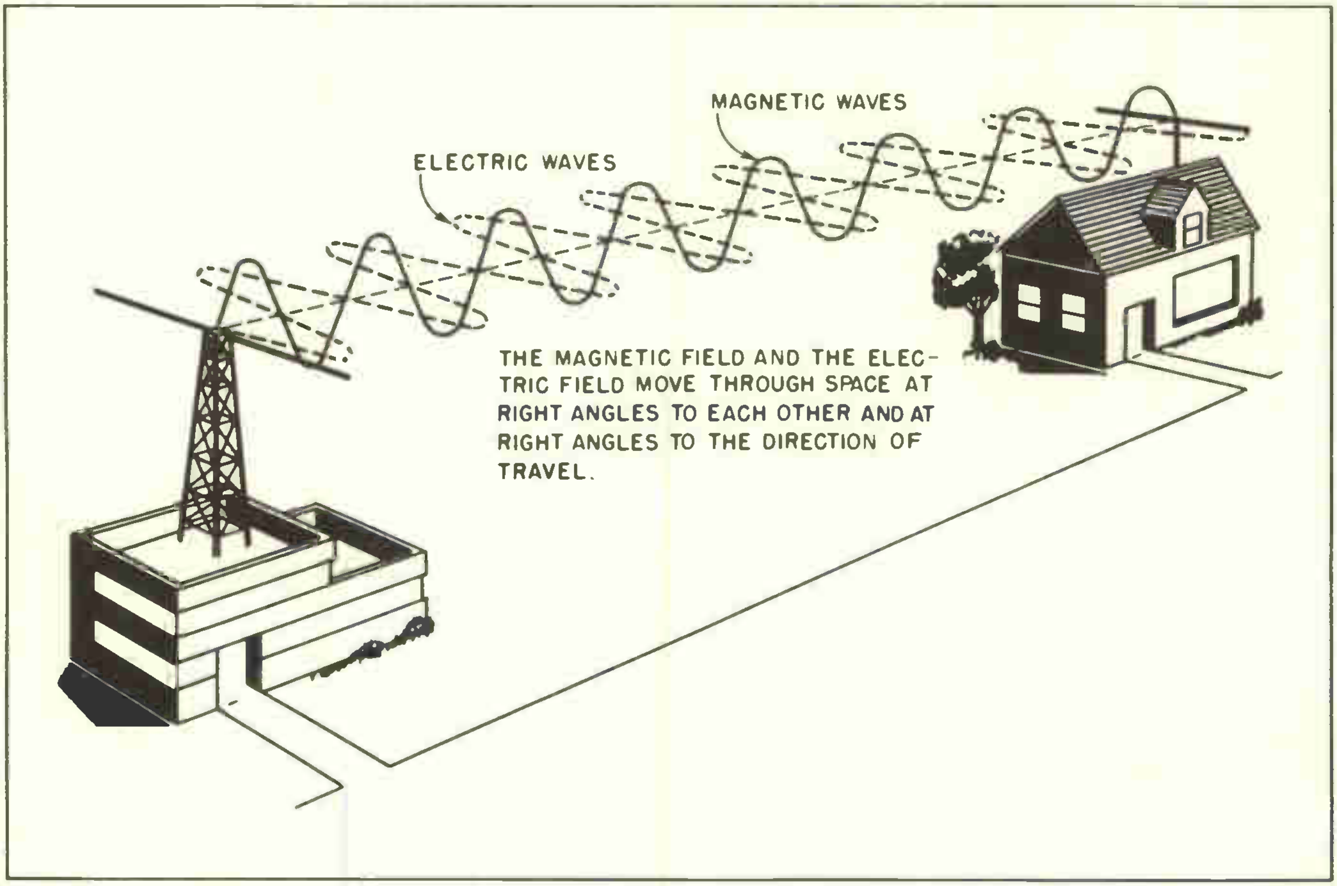

Fig.17. The Magnetic Waves and Electric Waves are at Right Angles to Each Other and at Right Angles to the Direction of Travel.

higher and higher toward the two ends of the antenna. And since the voltage at the two ends has different polarities, this all tends to create a strong electric field between the two ends of the antenna.

During the instant when the electric field will be built up to maximum value we will find that field to be a real, actual physical existence. During a short instant of time the space around the antenna will become charged as a result of the strong difference of potential which exists for that instant between the two parts of the antenna.

Then, as the signal from the generator reverses itself and goes into the opposite half-cycle, the electrostatic field will also reverse itself. And again, an instant later, it will be reversed again; then again, and again.

Just as the magnetic field created by the current flowing in the antenna found itself being pushed farther and farther out into space by new fields being built up around the antenna, so does the electric field created by the voltage between the two parts of the antenna also find itself forced out into space.

But there is a difference between the two waves. Whereas the *magnetic* waves move in a *vertical* plane away from the antenna, the *electric* field moves in a *horizontal* plane away from the antenna.

Section 6. POLARIZATION OF THE RADIATED WAVES

It is worth noting at this time that the transmitting antenna itself is shown in a horizontal plane. Whenever the antenna is physically located in a horizontal plane as shown in Figs. 15, 16 and 17, the electric field will be in a horizontal plane. It is customary to speak of such a radiated wave as being *horizontally polarized.* It is customary to use the *plane of the electric wave* to designate the polarization of the radiated wave. This is the reason that the radiated signal from a horizontal antenna is spoken of as being horizontally polarized and a signal from a vertical antenna as being vertically polarized.

The magnetic field which is radiated by an antenna is often referred to as a "Ground wave". At the higher frequencies the magnetic field, or "Ground wave" is rapidly attenuated. It does not travel very far from the antenna.

But the electric field continues to move farther and farther away.

Now we come to what may seem a peculiar situation, yet you may find it perfectly natural. As the magnetic waves move away from the antenna, *they are moving*. And, as you already know, a *moving* magnetic field tends to create an electric field.

Furthermore, we have a *moving* electric field. And a *moving* electric field tends to create a magnetic field. So we now have two fields moving together -- in phase -- away from the antenna. One is a moving magnetic field and the other is a moving electric field. As the two move through space the electric field acts continually to reinforce the magnetic field, and the magnetic field acts continually to strengthen or reinforce the electric field. The two acting together are capable of traveling great distances.

Section 7. DISTANCE OF TRAVEL

In previous lessons we explained how wave motion energy moving through a medium of travel would cause some of the energy to be reflected when the waves move from one medium to another, or from one concentration of a medium into a different concentration of the medium. It is well that we consider that situation here again and see just how it applies to the transmission of radiated energy from radio transmitters.

It should be clearly understood that there is a definite relationship between the length of a wave and the amount of energy which will be reflected by a change in the medium of travel. Further than this there is also a definite relationship between the *sharpness of the demarcation in the change* in the medium of travel and its ability to reflect wave-form energy.

As an example of this, suppose we have a wave traveling through a medium of some kind. If the wave-length is long and the change in the medium of travel is reasonably sharp, we can expect to find a considerable quantity of the energy is reflected. If the wave-length is perhaps six or seven hundred feet long and the change in the medium of travel occurs within a space of a few yards we are likely to find a considerable amount of the wave-form energy reflected.

On the other hand, if the wave-length is short, or if the change in the medium of travel is fairly gradual -- that is, extends over considerable distance -- the wave may be unable to detect any change, and will thus keep on going without reflecting any appreciable amount of energy.

This situation accounts for the peculiar conditions which surround the transmission of radiated radio energy. High above the Earth, at a distance of many miles, is a layer of ionized particles. These particles become ionized as a result of bombardment from the sun. This layer of the Earth's atmosphere is sometimes referred to as the *ionosphere,* and sometimes as the Kennelley-Heaviside layer. It was first discovered and recognized by two scientists working independently of each other, and the names of the two men are quite commonly used to identify the layer.

This layer in the atmosphere represents a definite difference from that portion of the atmosphere which lies closer to the Earth. In other words, a wave of energy moving outward from the Earth would pass from one kind of travel medium to another when it enters the *Ionosphere*. The height of the ionosphere varies from day to day, and from hour to hour. It also varies with the seasons, and is affected by sunspots. Sometimes the line of demarcation between the ionosphere and the layer beneath it is quite sharp, at other times the separation is much more gradual.

When radio waves at the lower frequencies, such as the broadcast band frequencies, are radiated from a transmitter and move outward in great circles, some of the waves move along the ground away from the transmitter while others move toward outer space. Since these frequencies are relatively low, it means the wave-length will be quite long. The length of these waves are usually much longer than the thickness of the line of demarcation between the ionosphere and the layer which lies immediately beneath it. This means that those waves which leave the transmitter and move toward outer space will soon strike the ionosphere. To the

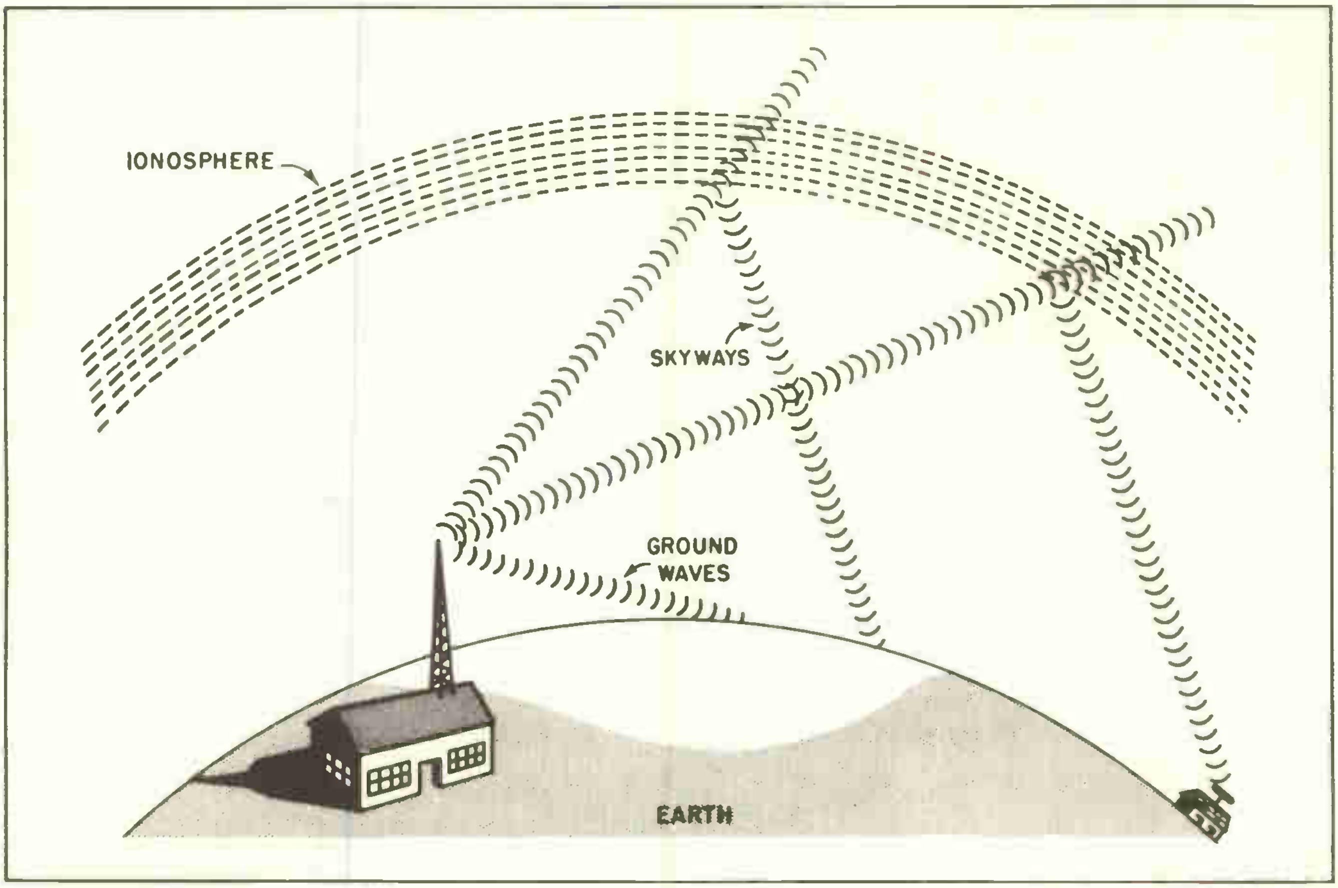

Fig.18. How the Ionosphere Produces "Sky Waves".

long waves the ionosphere represents a definite change in its medium of travel. Some of the wave energy will continue on toward outer space but a very large portion of it will be reflected back toward the Earth. This is shown in Fig. 18.

As the frequency of the radiated signal becomes higher, and the wave-length becomes shorter, the change between the other atmosphere and the ionosphere is not sharp enough to present a major change in the medium of travel for the radiated wave. Since the short waves of the high frequency signal do not detect any change in their medium of travel, little or none of their energy is reflected. This has the practical effect of permitting such energy to be wasted in outer space with little or none being reflected back toward the Earth.

In the case of ordinary radio broadcast frequencies it is possible to pick up the program at great distances from the transmitter. The signal carrying the program actually travels out to the ionosphere and is then reflected back to Earth. Such reflected signals are called *sky-waves*. Most of the long distance radio transmission depends upon such reflected signals.

Since the higher frequencies are seldom reflected by the ionosphere we cannot depend upon such a method of transmission for use at the television frequencies. This has the practical effect of restricting the transmission of television programs to such distances where the transmitting antenna is within line-of-sight of the receiving antenna. This is the reason we commonly speak of television signals as traveling in a straight line.

Section 8. LOCATION OF ANTENNAS

It is because of the necessity for locating the receiving antenna within line-of-sight of the transmitting antenna that it is so necessary to raise receiving antennas to such great heights in those "fringe" areas which are so far from the transmitter.

Most transmitting antennas are raised as high as it is possible or practical to raise them. In metropolitan areas they will usually be found on top of the highest buildings. In some communities they are located on the highest mountain in the area. In this manner it is possible to extend the distance to which programs can be sent. The effective range of reception depends upon the height of the transmitting antenna and the height to which the receiving antenna can be raised.

The Westinghouse Corporation has come up with an idea of locating some 13 huge four-motored airplanes in strategic spots throughout the country. These planes would then be loaded with transmitting equipment. Television programs would be sent from the ground studios by short wave and picked up by receivers on the plane. The signals picked up by short wave would then be used to modulate the high power transmitters on the plane. The great height of the plane would permit such programs to be picked up many miles away. Although Westinghouse claims they have perfected their system of transmission, that method has not yet been put into regular commercial operation.

Section 9. REFLECTED SIGNALS

While the television carrier signals are not generally reflected from the ionosphere in any great strength, one should not jump to the conclusion that none of the high frequency energy is so reflected.

At the time the FCC was allocating channels for television work shortly after the second World War, theymade their allocations on the basis of known experience at that time. Experience during the war years, and the experiences of amateurs and others indicated that none of the signals broadcast at the frequencies used for television work would be receivable in perceptible strength at distances much greater than which could be seen from the top of the transmitting antenna. Translated into practical language this meant that most television signals would not be receivable at distances much greater than 75 to 100 miles.

With these experiences in mind, the FCC prepared their allocation charts and proceeded to allocate frequencies to transmitting stations. The location of the stations, and the frequencies allocated to them, were such that there should have been little or no interference between two or more stations. No two stations within a 75 mile radius of each other were granted frequencies on *adjacent* channels. Since there are only 12 television channels now available, this meant that the greatest number of stations which could be located in one vicinity would be seven. As of now, only the New York and Los Angeles areas have the limit of seven stations.

Further than this, two stations operating on the *same* channel frequency could not be located closer than 150 miles of each other. Since experience had shown there was little likelihood of television signals being receivable at distances greater than 75 to 100 miles, this method of allocating the frequency channels seemed reasonably realistic.

Despite everything that was known about the action of high frequency signals at the time, it was soon learned that television signals did not always conform to their theoretical actions. In many parts of the country it soon became evident that television programs could be regularly and consistently picked up at distances much greater than 75 to 100 miles from the transmitter. In fact, reports soon began coming in from all parts of the country that signals were being picked up at what were seemingly fantastic distances.

Experienced engineers and amateurs began experimenting, and some of them soon found they could pick up distant programs almost as consistently as they could pick up local programs. There are now records of programs being picked up at distances as great as from 1000 miles to 1850 miles. One experienced radio engineer in Quebec, Canada has rigged up an elaborate booster for his television receiver. Despite the fact he is several hundred miles from the nearest television transmitter he is able, nevertheless, to pick up programs regularly from points as far distant as Texas, Florida, Louisiana and the midwest.

It should be kept in mind that most of this long distance (DX reception, in the jargon of the amateur) reception has been accomplished by experienced radio men using elaborate boosting circuits to strengthen the signals they were able to pick up with exceedingly elaborate and sensitive antennas. What they are doing, of course, is picking up the very weak signal which is reflected by the ionosphere, then boosting that weak signal to usuable values. While it is true, of course, that most transmitted television signals are not readily received by most commercial television receivers at distances greater than about 100 miles, the fact remains that traces of the transmitted

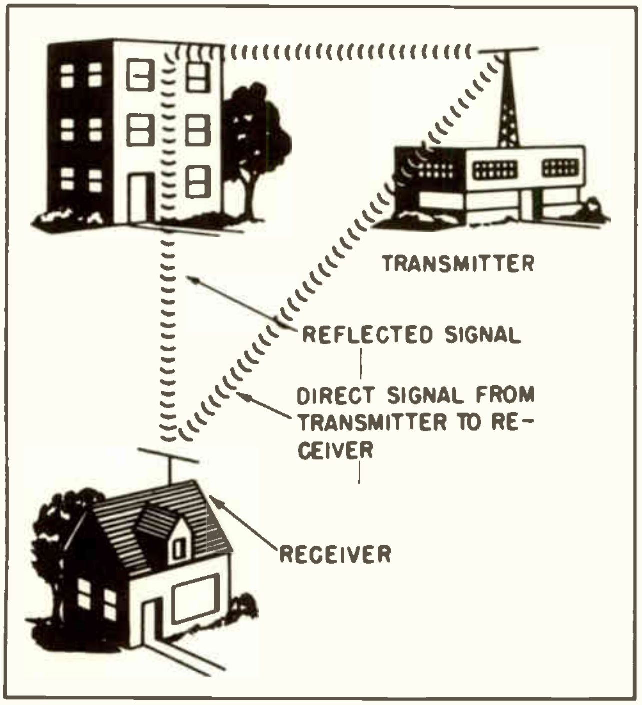

Fig. 19. Paths of Direct and Reflected Signals.

signal can be picked up at much greater distances by specially constructed, and extra sensitive, antennas and boosters.

It is also true that preamplifying boosters are being frequently attached to receivers by the purchasers or their service men, and the distance at which programs are being picked up regularly is gradually extending far beyond the 100 mile limit. This action has caused considerable concern to the FCC and the broadcasters. The result has been that the FCC has "frozen" construction permits, refusing to grant any additional transmitter permits until they are able to revise their experience tables in the light of the newer information which has been made available.

But there is another kind of reflected signal which is of far more concern to the practicing television service man. This is the signal which is reflected from buildings, watertanks, hillsides, signboards and other things.

While the high frequency television signal may not be readily reflected by the gradual change in the medium of travel represented by the change from the lower atmosphere to the ionosphere, there is no disputing the fact they are readily reflected by buildings and other solid objects. Signals bounce off such objects and are reflected almost as though they were mirrors. (See Fig. 19.) Radio signals also are reflected in a similar manner.

If you study Fig. 19 carefully you will probably be struck by the fact that the reflected signal travels a greater distance than does the signal which travels directly from the transmitter to the receiver. Since both signals travel at the same speed it means that it takes the reflected signal a little longer to travel from the transmitter to the reflecting object and then to the receiver than it does for the signal which travels directly from the transmitter to the receiver.

In the case of radios this problem of the reflected signals is not particularly serious. Even though the reflected signal does travel a little farther as shown in Fig. 19, it nevertheless reaches the receiver so closely behind the direct signal that it is still able to reinforce the direct signal. Two things help in making this true. The frequency of the broadcast signals is low enough that a signal would have to travel a very long roundabout path in order for it to arrive so late as to be unable to reinforce the direct signal. If the reflected path was so long as to cause the reflected signal to arrive so late that the phase of the reflected signal tends to cancel the direct signal, it will be found that the reflected signal would be so much weaker than the direct signal that it would not greatly affect the direct signal. Such action might cause what is known as "fading", but the AVC action of the receiver steps in and corrects the signal strength and the listener never knows anything has happened to affect the signal.

The other thing that tends to keep the reflected signal from seriously affecting a radio receiver is that the frequency of the audio signal is so very low compared to the speed of the waves through space that it makes little difference how far the reflected signal travels in its roundabout path, it still arrives in time to help reinforce the individual cycle of the audio signal. All this means that reflected signals scarcely affect radio reception.

But in television we have an entirely different situation. The direct signal from the transmitter to the receiver brings with it a modulating voltage which controls the electrons permitted to pass from the cathode of the picture tube to the screen of the tube. This means that the signal from the transmitter is constantly changing from instant to instant.

More than this, the beam of electrons is also moving swiftly *across* the face of the picture tube. It moves all the way from the left side to the right side in less than 55 microseconds.

Now suppose we have a signal traveling in a direct line from the transmitter to the receiver. It brings with it modulating voltages which draw a picture on the screen of the picture tube. If there is a vertical object or stripe in the picture, the signal will bring the necessary impulses to reproduce that object or stripe. And as each horizontal movement of the electron beam does its part to recreate the object it does so, then passes on to reproduce some other part of the picture.

But now suppose there is a part of the signal from the transmitter that strikes a distant building and is reflected toward the receiving antenna. This reflected signal is also going to affect the action of the receiver. The modulation that reproduced the original stripe on the picture tube is also going to be present in the reflected signal. But since the reflected signal travels a greater distance through space than does the direct signal, it will reach the receiver a little later than does the direct signal. The modulation in the reflected signal is also going to reproduce the stripe just as did the direct signal. But the stripe reproduced by the reflected signal is going to be a little to the right of the original picture because the electron beam has moved a little farther toward the right before the reflected signal affects it.

This action has the effect of reproducing double images on the screen of the picture tube. The second signal's picture is usually a little weaker than the original, or direct, signal's picture. It is usually referred to as a "ghost". The appearance of a ghost image is shown in Fig. 20.

There are many things which will cause "ghosts". Tall buildings, water tanks, billboards, passing airplanes, mountains, power lines, and many others. One important cause of ghosts which is often overlooked by service men is the possibility of creating the ghosts right in the lead-in system. If there is an impedance mismatch between the antenna and the transmission line, or between the transmission line and the receiver, there is a definite possibility of creating ghosts. This will be brought about by the fact that the mismatch will set up reflections right in the lead-in system itself, and these reflections will create ghosts.

The normal cure for ghosts which are caused by external reflections is to relocate the antenna to a position where the ghost disappears. By trying a number of positions it is usually possible to find a location where the reflected signal is weak. At this point it will disappear.

But if the ghosts are caused by reflections within the lead-in system it will not be possible to get rid of the ghosts by relocating the antenna.

Section 10. RECEIVING RADIATED ENERGY

Most of our discussion so far in this lesson has pertained to the action within an antenna when it was fed an A-C voltage directly from a generator of some kind. Now let us think of an antenna as being a resonant circuit which is *directly coupled* to the transmitting antenna by the magnetic and electric fields. When the magnetic and electric fields from the transmitting antenna strike the receiving antenna the two antennas will be coupled together very much as we would couple together the coils of two transformers.

The effect of the magnetic and electric waves striking the receiving antenna is to set up within the antenna a movement of the electrons in the metal of the antenna. The movement of the electrons in the antenna will depend upon the strength of the fields which strike the antenna, and will also depend upon how closely the antenna is resonant to the frequency which strikes it.

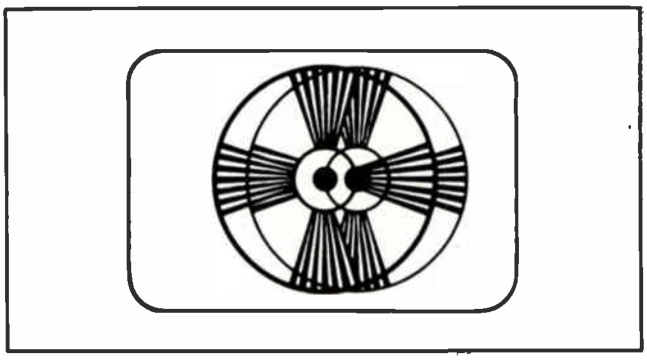

Fig. 20. "Ghost" Images.

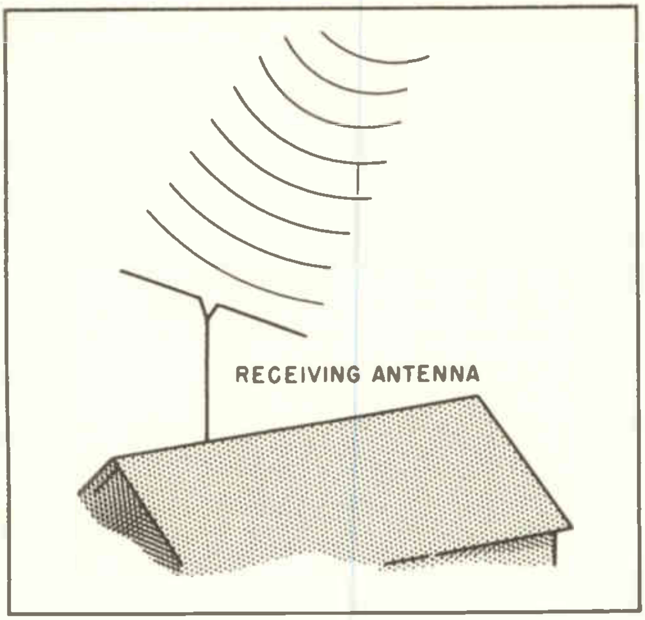

Fig. 21. Antenna Receiving a Broadside Signal.

If the antenna is cut to such a length that it is exactly resonant to the frequency of the radiating field we will find a very strong movement of the electrons in the antenna, and thus a very strong signal will be present there. On the other hand, if the antenna is of some other length which is not exactly resonant there will still be some movement of the electrons, but not so great a degree of movement.

There is still a third factor, and this is a very important factor. The angle at which the radiating waves strike the antenna will have a very large effect on the strength of the signal induced within it. If the radiating waves strike the antenna at right angles, as shown in Fig. 21, the signal induced within the antenna will be much greater than if the radiating waves strike from off the end of the antenna as shown in Fig. 22.

If the waves strike directly toward the end of the antenna there will be virtually no signal induced in the antenna at all. The nearer the waves strike at right angles, the greater will be the induced signal.

This factor of the angle at which the radiated waves strike the antenna is of great practical importance to the practicing service man. The best constructed antenna in the world will not pick up a signal unless the signal strikes it at an angle which will cause the antenna to resonate.

Experimenters and researchers have spent much time experimenting with antennas to determine the signal strength necessary to affect the antenna from the various angles or directions. In most cases they would set up an antenna, then retreat a little way from the antenna and generate a signal of a known strength. The strength of the received signal would then be measured at the antenna. The distance in various directions which would give the same signal at the antenna was then measured and noted on a chart. Such a chart is shown in Fig. 23.

It was found that when a stronger signal was generated by experimental device, the distance at which the signal would be picked up at the receiving antenna would form a similar pattern. From this it became possible to create what are called *field patterns*, or response patterns. These field patterns show how the strength of the received signal varies in the various directions. Such a field pattern chart is shown in Fig. 24. Note how the chart is marked off in degrees.

It will be seen that the same strength signal can be picked up from much greater distances at zero degrees and at 180° than at any other point. No signal at all will be picked up at any distance at 90° and 270°. One thing that will probably attract your attention is the fact that the signal is picked up equally well from either of two directions, that is, from direction

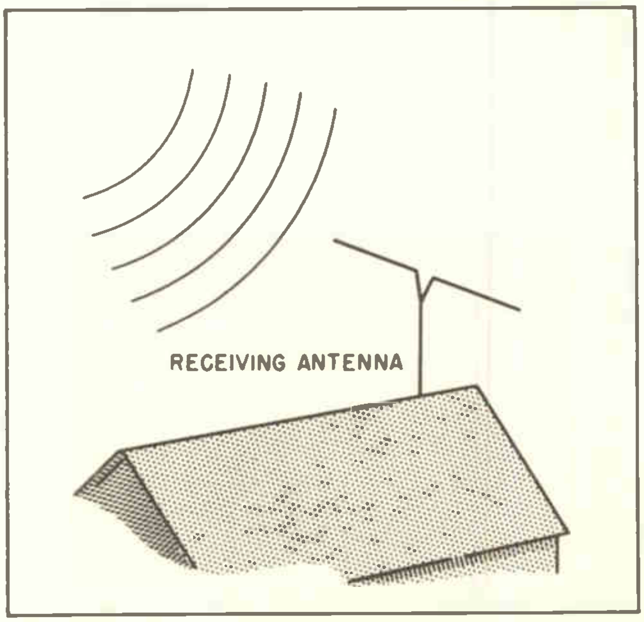

Fig. 22. Antenna Receiving a Signal from "Off-the-End".

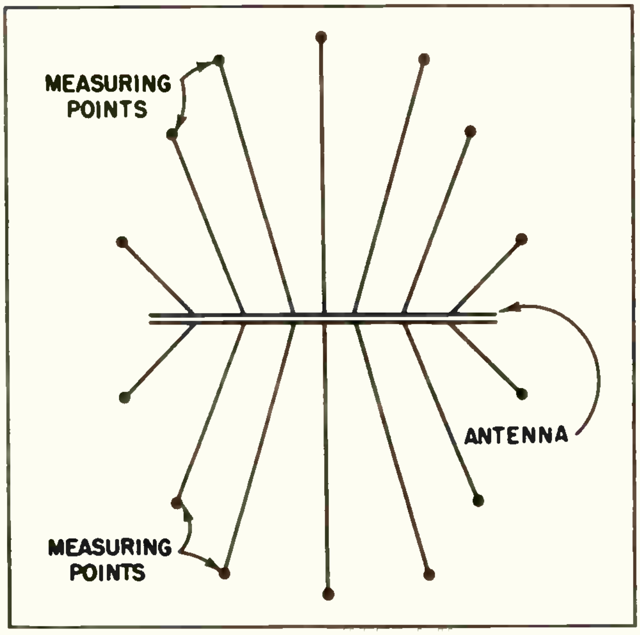

Fig. 23. How a Field Pattern, or "Response Pattern", is Plotted.

zero degrees, or from direction 180°. This condition is typical of all dipole antennas.

Section 11. DIPOLE ANTENNAS

The dipole antenna is the basis from which more than 90° of all television antennas are constructed. It would be well for us to pause for a few moments and consider a few more of the pertinent facts concerning the dipole antenna which it is desirable for us to know.

The dipole antenna is also commonly known as a Hertz antenna. It was by this latter name that it was most widely known before it became so popular in television work. It has also been commonly known as the doublet antenna, or the half-wave doublet. The dipole antenna is ungrounded. Thus it can be used in the air or anywhere else it is desirable to place it. It can be easily installed above the earth where it is away from other interfering objects.

The signal is taken from the dipole antenna at its center. It is important to note that the characteristic impedance of a dipole antenna is 72 ohms at the center where it is connected to the transmission line.

Although the dipole antenna is the basis around which nearly all television antennas are built, when used in unmodified form the dipole has some very definite limitations. One of the drawbacks is that the dipole is rather sharply resonant. This is all right where there is only one station to be received, but where there are several rather widely separated transmitting stations on the air it will be found that the dipole alone will not bring in a strong enough signal to provide the proper picture contrast. Usually there will be a considerable quantity of "snow" present when receiving some stations. "Snow" is the name given to the peculiar appearance of a screen when there is insufficient signal. Actually "Snow" is a form of noise picked up by the receiver. It may be present even when a strong signal is being received. But the strong signal will be able to override the "Snow" and make it unnoticeable.

Most present day receivers require approximately 200 to 300 or 350 microvolts of signal to work properly. This is considerably higher than is needed by most radio receivers. A weaker signal than these values will allow some "Snow" to appear on the screen.

Another drawback of the simple dipole is the ability to pick up signals from either of two directions with equal ease. This factor can be either an asset or a drawback, but it is usually a drawback. If there are stations in each direction from the antenna, both of which it is desirable to receive, the dipole might be desirable

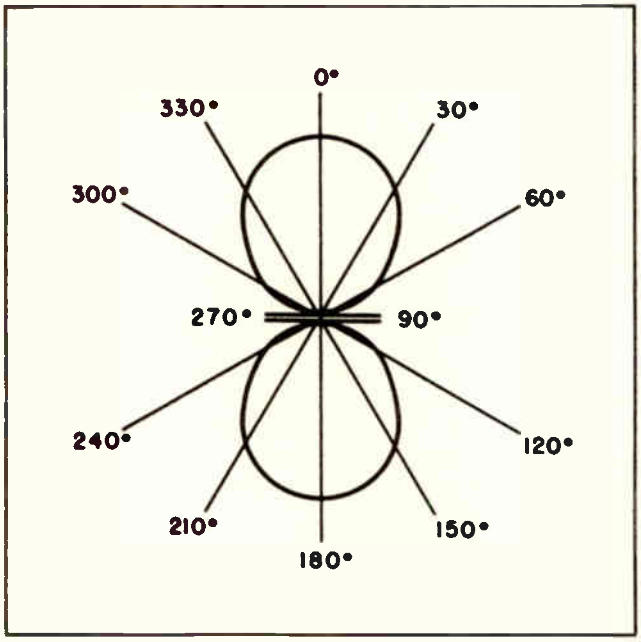

Fig. 24. Field Response Pattern of a Simple Dipole.

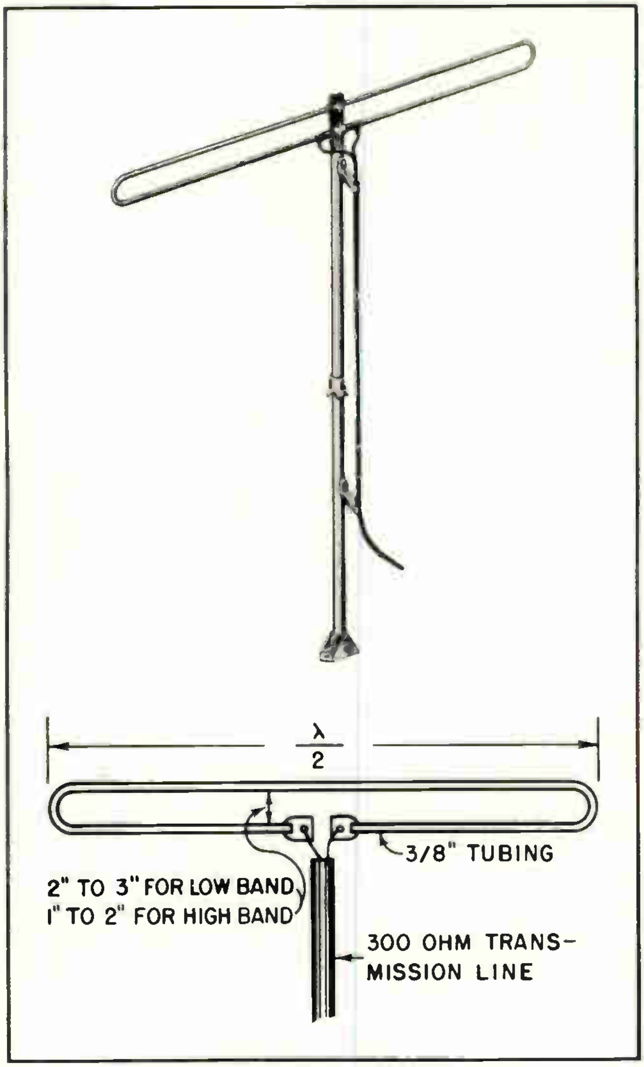

Fig. 25. A Folded Dipole Antenna.

on this account. On the other hand, there are often strong reflections from the rear. It is highly desirable to reject these reflections. The dipole will not reject them, instead it will readily accept them. The reception of these reflections can cause numerous "ghosts" on the screen of the picture tube.

Section 12. THE FOLDED DIPOLE

The folded dipole has come into widespread use with television receivers. It has several distinct advantages over the simple dipole.

The folded dipole consists of an ordinary center-fed dipole to which is connected an identical half-wave element. The second half-wave element is connected to the ends of the ordinary dipole as shown in Fig. 25. The material from which the two parts of the dipole are made should be the same or similar material. The separation between the two parts should be about as shown in Fig. 25.

The addition of the extra element to the simple dipole to form the folded dipole creates an antenna which has a much greater cross-section. This greater cross-section changes both the inductance and the capacity of the antenna. Changing these two electrical properties makes a radical change in the characteristic impedance of the antenna. Instead of being 72 ohms, as in the case of the simple dipole, we now have an antenna which has a characteristic impedance of 300 ohms. This change in the characteristic impedance can also be accounted for by the fact that the current at the center of the antenna is divided between the two parts of the antenna.

The folded dipole has a much lower "Q" than does the simple dipole. This means that it will resonate to a wider band of frequencies than will the simple dipole.

Section 13. DIRECTIONAL ARRAYS

To a greater or a lesser degree all television antennas can be thought of as having certain directional characteristics. Even the simple dipole will receive signals from certain directions better than it will receive signals from other directions. This was indicated in Figs. 23 and 24. Such an antenna will receive signals which are approaching from broadside much better than it will receive signals which approach from in the direction of the ends of the antenna.

But it is often desirable to have an antenna which has even greater directional characteristics than does the dipole. Instead of being able to receive signals from either of two directions it is very frequently desirable to have an antenna which will receive signals from only one direction. To achieve these particular aims it is necessary to modify the dipole some more.

In addition to the dipole antenna and its modifications there are a number of other types of antennas which possess well-defined directional characteristics. Some of these are the reasonably well-known Rhombic antennas, the Broadside arrays which are often used in radar work and in aircraft landing systems, colinear arrays and the corner reflectors. It is scarcely necessary to take up a discussion of these various types

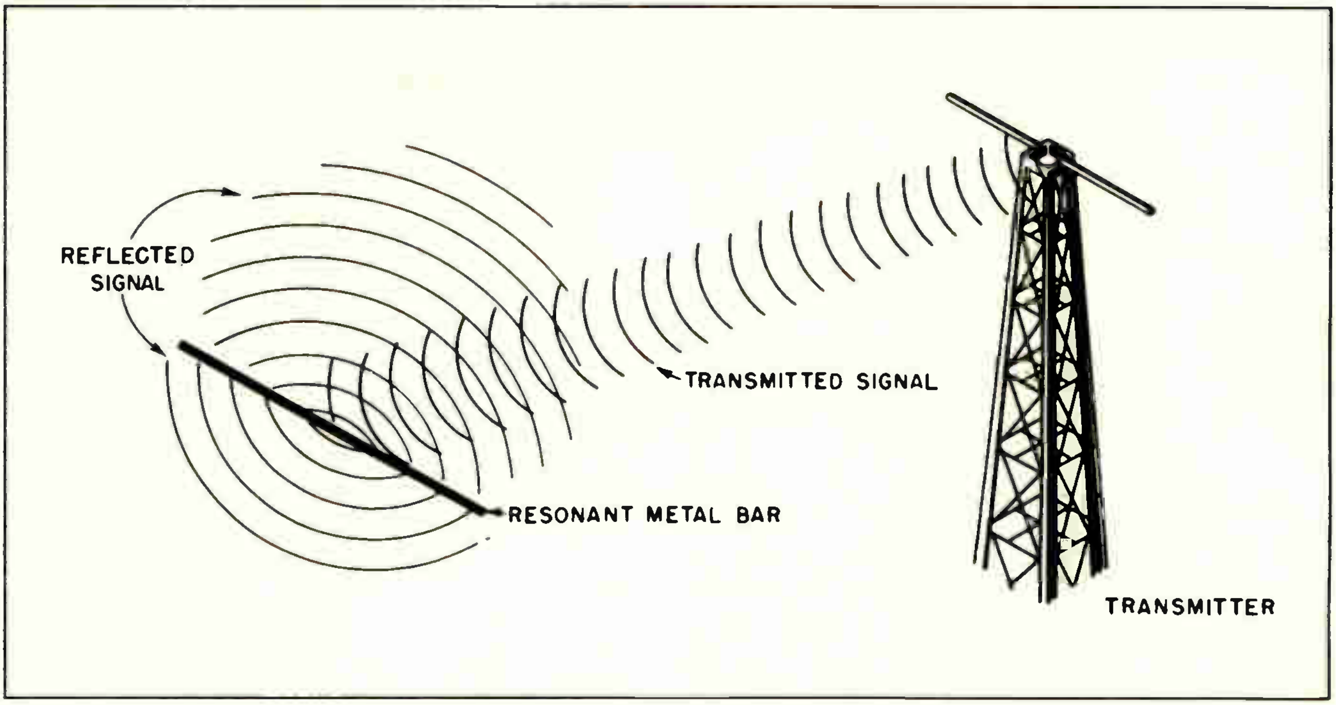

Fig.26. How a Conductor Cut to a Half-Wave Length will Resonate with a Transmitted Signal and will Set Up Reflected Waves of its Own.

of antennas since for several reasons they are not generally adaptable for most television installations. For the most part they take up far more space than is available to the users of most television receiver owners. Furthermore, they are usually more costly, and require considerable time for construction and erection. On top of all this, none of these types of antennas are commercially available; even where it is desirable to use one of these types, it would be necessary for the installer to construct his own antenna.

Before passing from our very brief mention of these other types of antennas it would be well for you to know that some of these types are sometimes used by experienced engineers and amateurs for long distance (DX) reception of television programs. A discussion of these various types, and their modifications, would fill a good sized book. They are far outside the scope of this course.

To get back to our discussion of the methods used to modify the simple dipole in order to give it more definite directional characteristics one of the first steps is to add an element to the dipole so that it will be sensitive to signals from one direction only. To accomplish this purpose it is the general practice to add one or more additional elements to the dipole. Such additional elements can take the form of either a *reflector* or a *director*, or a combination of them both. In some cases, particularly that of the *Yagi* antenna, there are often more than two additional elements.

Section 14. REFLECTOR ELEMENTS

In previous sections of this lesson we have explained in considerable detail how a piece of metal can be cut to a certain length, and then placed in such a position that it will be cut by the moving electric and magnetic fields from a high frequency transmitter. We have also explained how that piece of metal, when cut to a certain specified length, will resonate with the broadcast signal. Further than this, when the piece of metal resonates to a certain frequency a relatively strong current will be caused to flow within the metal.

So far so good. All this merely repeats what we have been studying so far in this lesson.

But note this: When the induced current starts flowing in the metal of the exposed length of rod, such currents will set up new electric and magnetic fields of their own. This situation is illustrated in Fig. 26.

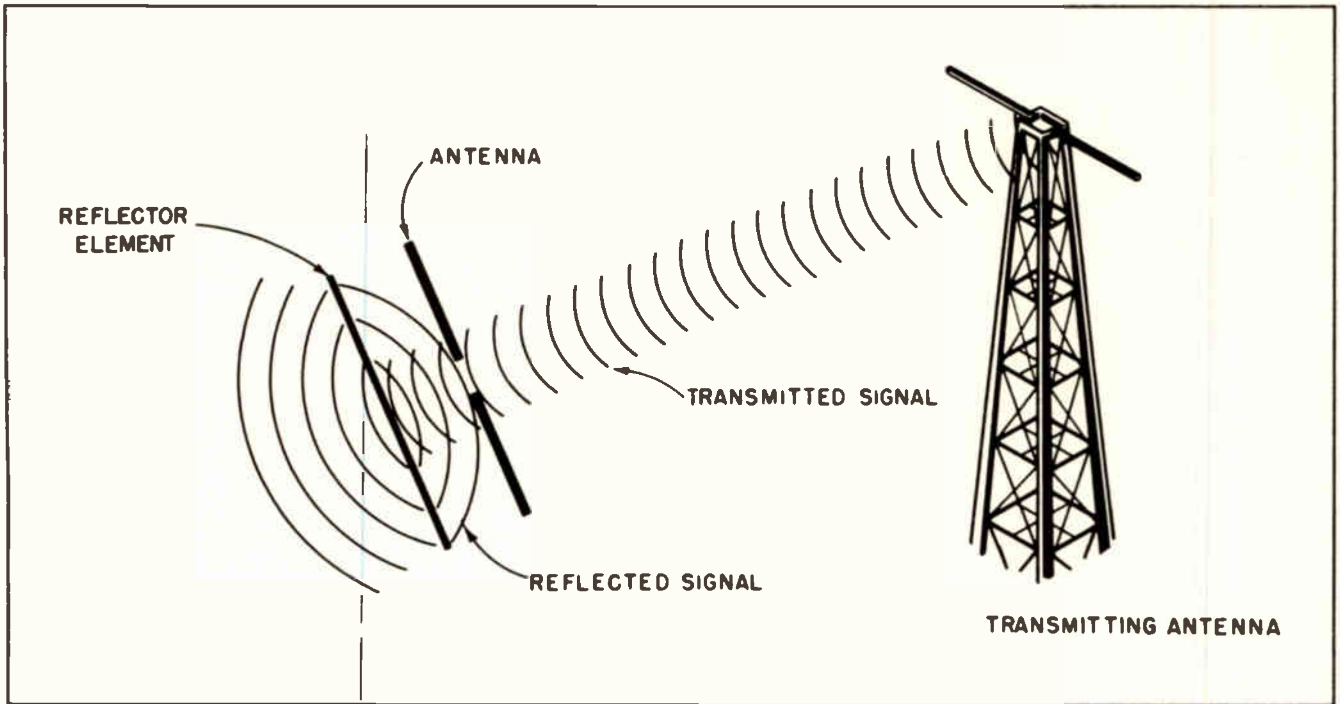

Fig. 27.

If such a metal rod of the proper length is placed in a certain position with respect to the receiving antenna, the reflections from the metal rod can be used to reinforce the signal originally picked up by the antenna proper. The distance between the antenna and the additional metal rod must be correctly spaced, the exact distance between them being determined by the wave-length of the signal that is to be received. The general location of the extra metal rod with respect to the antenna is shown in Fig. 27.

The extra metal rod is called a *parasitic element*. It does not radiate any of its own signals, it merely re-radiates signals it picks up from some distant transmitter.

When the parasitic element is placed behind the antenna as in Fig. 27, that is, on the opposite side of the antenna from the transmitter, it is called a *reflector*. The reflector serves two functions. It tends to reinforce, or strengthen, the signal in the antenna; and it tends to cancel out all signals which approach the antenna from the rear. The addition of the reflector element to an antenna, therefore, changes a simple dipole antenna from one that has bi-directional characteristics to one that has uni-directional characteristics. To put this in other words, it means that it changes the antenna from one that will receive signals from either of two directions to one that receives signals from only one direction.

It can be seen that the simple act of adding the parasitic reflector element to the simple dipole has changed the operating characteristics of the antenna considerably. Such an antenna will deliver a much stronger signal to the receiver, and will not be so greatly affected by "ghost" signals or other signals which approach from the rear.

The physical dimensions of the reflector element and its distance from the antenna proper are very important factors in the operation of a two-element antenna system. The reflector element should be slightly longer than one-half wave-length of the frequency to which the antenna itself is cut. Since the total length of the antenna is exactly one-half wave-length of the frequency to which it will resonate, this means the reflector should be slightly longer than one-half wave-length.

The reflector should be placed one-quarter wave-length, or slightly less, behind the antenna.

The action of the antenna and its reflector can be explained in general terms substantially in this manner: Both the antenna and the reflector will resonate to the same transmitted signal. But due to the slightly

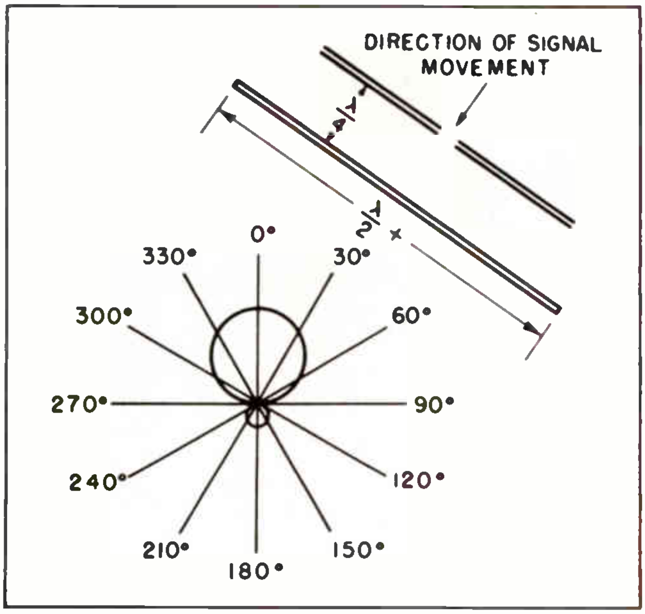

Fig.28. Field Response Pattern of Dipole with Reflector.

greater distance of the reflector from the transmitter the currents and voltages in the two elements will not be in phase. The voltages and current in the reflector will always be 90° degrees behind those in the antenna. This is due to the quarter-wave spacing between the two elements.

To explain this phase displacement a little more clearly we can understand it somewhat better by noting the action in each element as the result of a single passing wave. The wave strikes the antenna first. This will set up a voltage and current in the antenna. The passing wave will strike the reflector a little later. It will also set up a voltage and current in the reflector. But since the passing wave sets up the voltage and current in the reflector a little later than it did in the antenna, the movement of the current and the voltage in the reflector will always lag slightly behind those in the antenna proper.

So much for the phase displacement.

It should be understood that there will always be a phase displacement between the two elements. The exact amount of displacement will be controlled by the distance between the two elements and the length of the reflector.

The electric and magnetic field that is then re-radiated from the reflector moves out in all directions. Part of it moves toward the antenna element. The result is that the fields of the two elements add in one direction but cancel in the other direction. The entire action results from the phase displacement between the currents and voltages in the two elements, and varying results can be obtained by very slight changes in the dimensions or spacing of the two elements.

The arrangement of the elements, and the field pattern that will result from such spacing, is shown in Fig. 28. Note that the main lobe of the field pattern is directly toward the *zero degrees* direction, which is the direction from which such an antenna array will receive the strongest signal. If that side of the antenna array is then pointed toward the transmitter it is desired to receive the signal from that transmitter will then come in clear and strong.

Such an antenna is said to have a good "front-to-back" ratio. This means the ratio of the signal strength at the front is very good with respect to the signal strength which is received from the rear. When properly constructed such an antenna will receive very little signal from the rear,

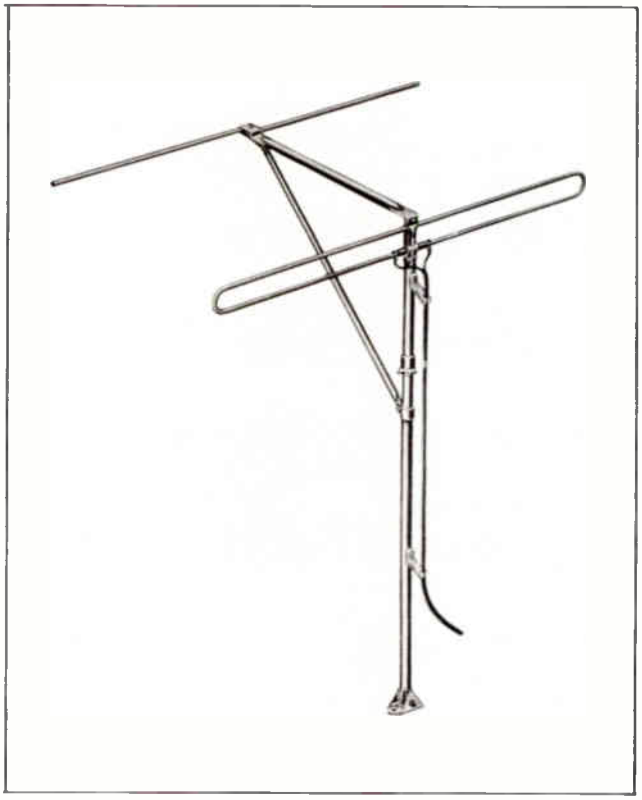

Fig.29. Folded Dipole with Reflector. (Courtesy American Phenolic Co.)

thus will tend to cancel out the reception of "ghost" signals from the rear.

Instead of using a simple dipole as the main driven element — the antenna proper -- a folded dipole can be substituted instead. The use of the reflector will be just as effective with the folded dipole as with the simple dipole, but there will be the added advantage of using an antenna which has a much higher characteristic impedance. Such a folded dipole with a reflector is shown in Fig. 29. The one illustrated is built by the American Phenolic Company, Cicero, Illinois.

Section 15. DIRECTOR ELEMENTS

In the preceding section we discussed the condition which is created by placing an additional element behind the antenna,

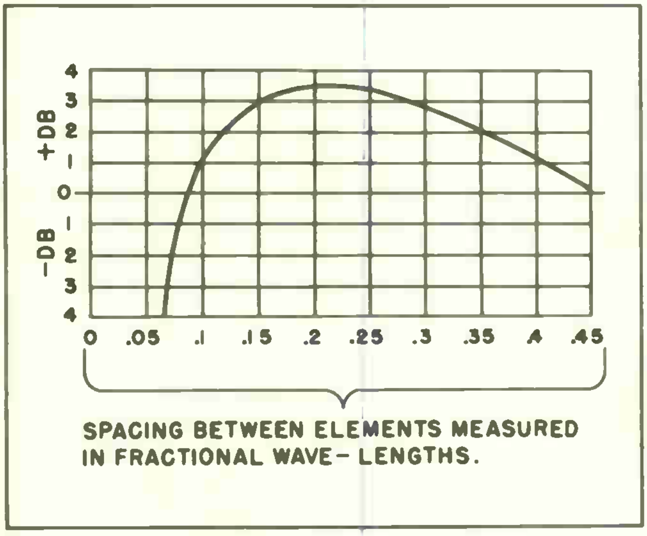

Fig. 30.

an element that is slightly longer than one-half wave-length.

Now we will take up the discussion of the condition which results when a parasitic element slightly *shorter* than one-half wave-length is placed near the driven element (the antenna proper), and in front. Such a parasitic element is called a *director.*

The action of the director is quite similar to that of the reflector. One difference is that the electrical phase difference between the currents and voltages in the director element are such that they tend to aid these in the driven element when the signal comes from the direction of the director, instead of tending to cancel such signals as in the case of the reflector.

The length of the parasitic elements must be properly proportioned. Otherwise their effect may turn out to be opposite that which it should be. For example, if the director element is too long, or is not properly spaced with respect to the driven element, it will act like a reflector rather than as a director.

Of equal, or even greater, importance is the spacing between the various elements. Perhaps this can be made somewhat more clear by means of a graph than by words alone.

Fig. 30 shows just how the spacing between a reflector and the driven element will affect the gain of the antenna. The graph is marked to show the effect when measured with various spacings. The distances are marked in decimal fractions of a wave-length.

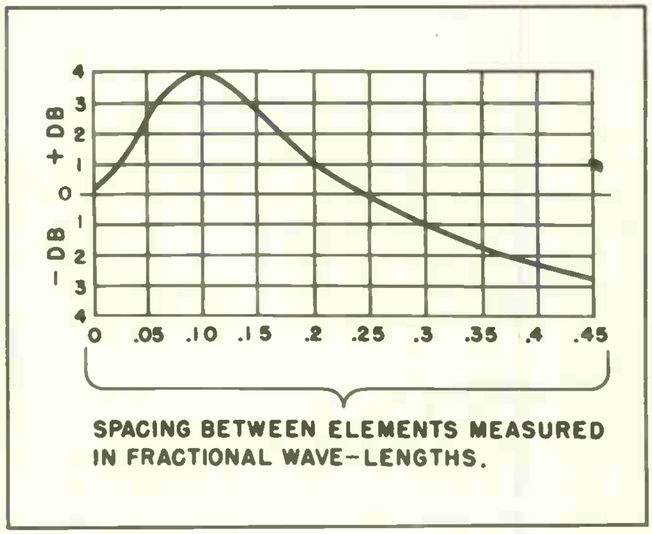

Fig. 31.

You will understand that .05 wave-length is the same as one-twentieth wave-length, .1 wave-length is one-tenth wave-length and .25 wave-length is the same as one-quarter wave-length. With this in mind you will note that when the spacing between the reflector and the driven element is somewhat less than one-tenth wave-length there is not any gain at all -- instead there is actually a loss of signal strength. This situation could also be looked upon as changing the parasitic element from a reflector in one direction to a director in the opposite direction.

But note that as the distance between the elements is increased to more than one-tenth wave-length there is a definite gain in the signal strength in the antenna. The maximum

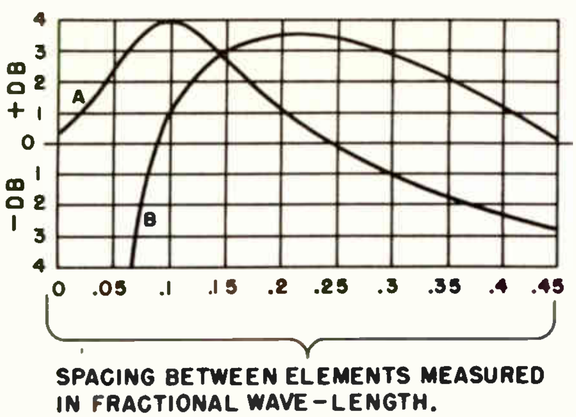

Fig.32.

gain is when the two elements are spaced just slightly less than one-quarter wave-length apart.

When studying the graph, always keep in mind that the reflector is usually cut slightly longer than one-half wave-length long.

Now let's study the situation with respect to the director. The director is slightly shorter than one-half wave-length. Being slightly shorter than one-half wave-length changes its electrical characteristics so that the current phases within it are somewhat different from that in an element which is slightly longer than one-half wave-length.

Fig. 31 shows the effect of the *director* upon signal strength within the driven element. For any distance less than one-quarter wave-length apart, the director adds gain to the driven element. The greatest gain is obtained when the two elements are approximately one-tenth wave-length apart. But when they are spaced a distance *greater than one-quarter wave-length* apart, the director actually causes a *loss* in the driven element rather than a gain. In this respect it can be thought of as acting as a reflector rather than as a director.

These two graphs point out the importance of the spacing of the elements from each other, and the effect of the length of each. A parasitic element which acts as a reflector when spaced at one distance from the driven element will actually act as a director if there is any great change in the spacing between the elements. And the converse is also true; an element which acts as a director when the spacing is of a certain distance will actually act as a reflector when there is a change in the spacing. Tables are included in the back of this lesson which show the actual dimensions to be used for each frequency channel.

Fig. 32 shows the two graphs superimposed upon each other. Thus they can be studied together. Fig. 32 is especially helpful in trying to understand the effects of length upon the action of the elements. *A* shows the action of the shorter director while *B* shows the action of the longer reflector.

The principal action of adding both a reflector and a director to a dipole antenna is to sharpen the gain in one direction and virtually eliminate any sensitivity in any other direction. Further than this, the antenna will become much more sharply resonant at its resonant frequency. The response of a three-element antenna is shown in Fig. 33.

Due to the sharp resonance of the three element antenna, consisting of the reflector plus the director in addition to the driven element itself, it has not come into general use for television reception. It tunes so sharply to one frequency that it tends to discriminate against some of the frequencies in a 6-megacycle band that must be passed for good reception even on one channel.

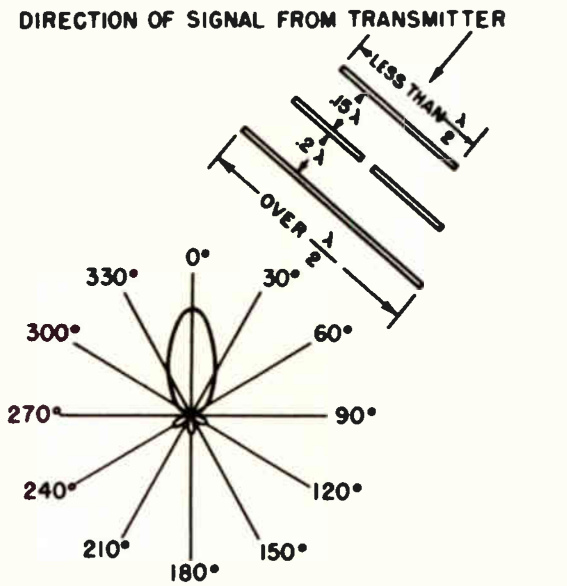

Fig.33. Field Response Pattern of Dipole with Reflector and Director.

Further than this, it is almost useless as a means of receiving two or more channels.

It does have the advantage that it is sensitive to weak signals which could not be picked up by the more broadly resonant antenna. For this reason it is often used in the extreme fringe areas where an effort is being made to pick up a single station. It is useful there where the reception of a single station is more important than an ability to pick up several stations on the same antenna. As a matter of fact, the addition of still more parasitic elements is sometimes resorted to in an effort to pick up a very weak signal. Such multi-element arrays are called *Yagi* antennas.

Radio amateurs commonly use four- and five-element beams to create extremely sensitive antennas. Such antennas are highly resonant at a single frequency and are capable of almost unbelievable action on that single frequency. But such arrays seldom fit the needs of the normal television service man.

Section 16. STACKED ARRAYS

One method of obtaining added gain from an antenna without restricting its use to a single frequency is to use what are called "Stacked Arrays". A stacked array merely consists of adding one or more similar antenna arrays to the original array. This is usually done by piling, or "stacking", one array on top of another.

It is necessary to connect the two arrays together so their phase relationship will add together. If this relationship is not observed there is a strong possibility of one array subtracting from the signal strength of the other rather than adding to it. This matter of phase relationship must never be lost sight of when working with stacked arrays.

One rather widely used type of stacked array antennas is called the "Lazy H". A diagram of a "Lazy H" array is shown in Fig. 34. The response pattern of such an array is also shown. One advantage of the "Lazy H" is that it can be used where the transmitters are widely separated, thus requiring an antenna with a fairly wide response pattern. Another advantage of the "Lazy H" is its ability to reject signals which come from beneath it. Thus it tends to reject much noise that originates at street level, such as automobile ignition and other types of man-made static.

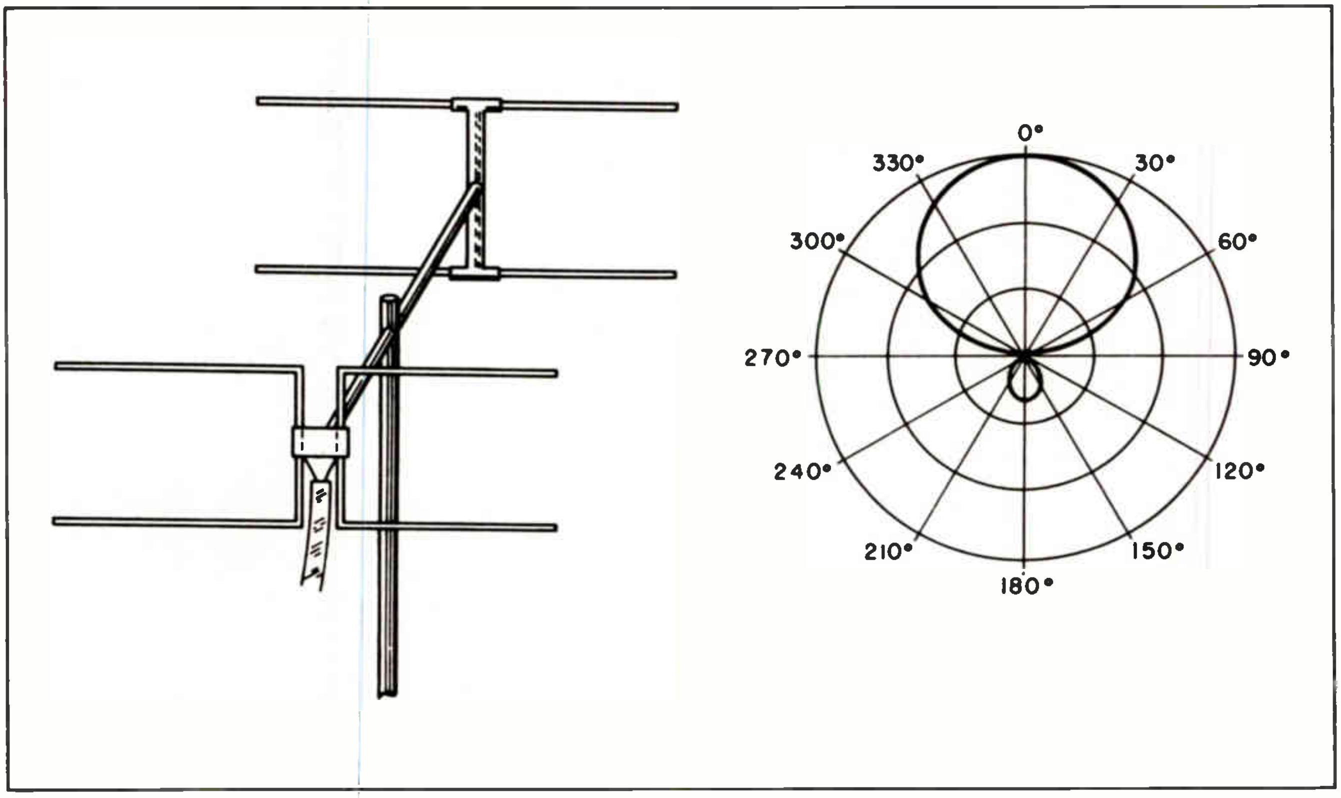

Fig. 34. "Lazy H" Antenna with its Response Pattern.

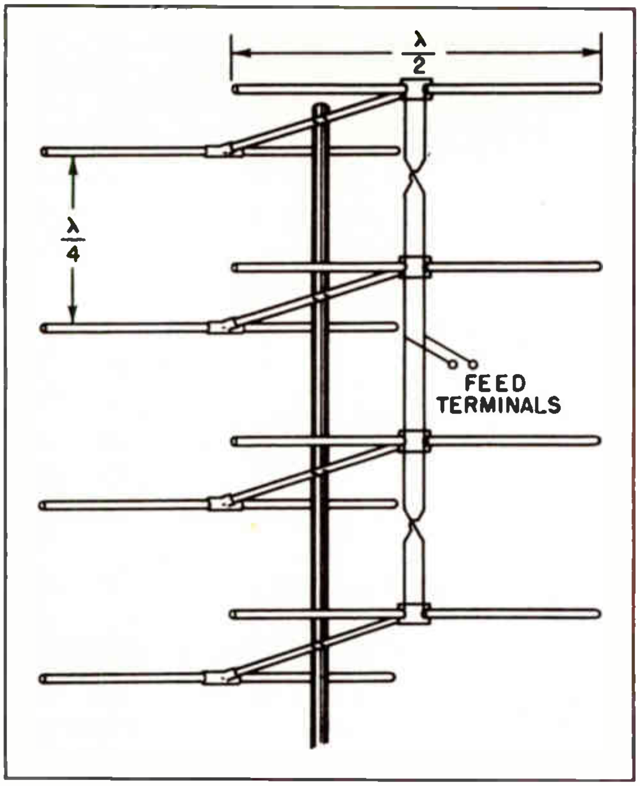

Fig. 35. A Four-Element Broadside Array of Dipoles with Reflectors.

The gain of a "Lazy-H" antenna when reflectors are employed with it amounts to about 4 or 5 DB. The frequency response is about average. It is possible to use a "Lazy H" antenna to receive both the high television band and the low band. While this ability is advantageous in some places such a use is not generally recommended as being good practice.

"Lazy H" antennas can be readily stacked to form multi-element broadside arrays. An example of such an array is shown in Fig. 35. Another type of stacked array using folded dipoles with reflectors is shown in Fig. 36.

Section 17. CONICAL ANTENNAS

It can be demonstrated mathematically, and by experiment, that a large crosswise dimension in an antenna with respect to its length is a desirable requirement if the antenna is to be used to receive signals at various frequencies. Such dimensions tend to reduce the inductance of the antenna and to raise the capacitance. This double action tends to lower the "Q" of the antenna. The reduction of the "Q" gives the antenna a much wider frequency response.

From the viewpoint of wide-band frequency response, a pair of metallic cones located as shown in Fig. 37 would be the ideal type of antenna.

But there are practical reasons against using such an antenna. In the first place it would be unduly heavy, and would use an unnecessarily large amount of metal. More than this, there would always be a great danger that the large broadside presented to the wind would make such an antenna vulnerable to destruction by the first heavy windstorm that would come along. Another hazard that would have to be taken into practical consideration is that of ice formation. Due to the massive physical size of such an antenna it could collect a heavy weight of ice, and thus become a source of real danger to anybody or anything that happened to be below it.

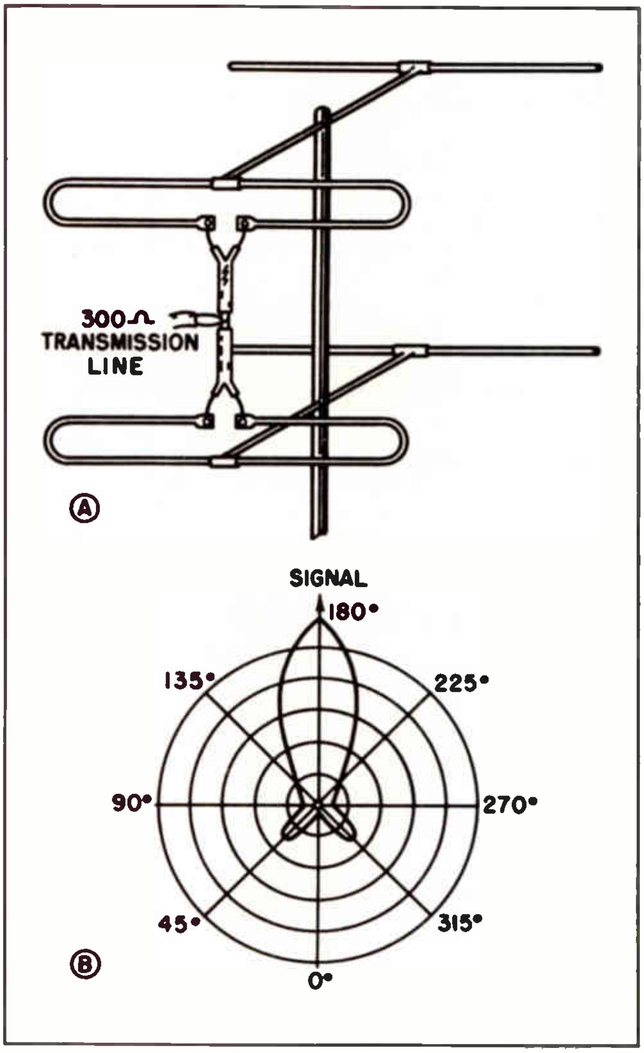

Fig. 36. Stacked Folded Dipoles with Reflectors.

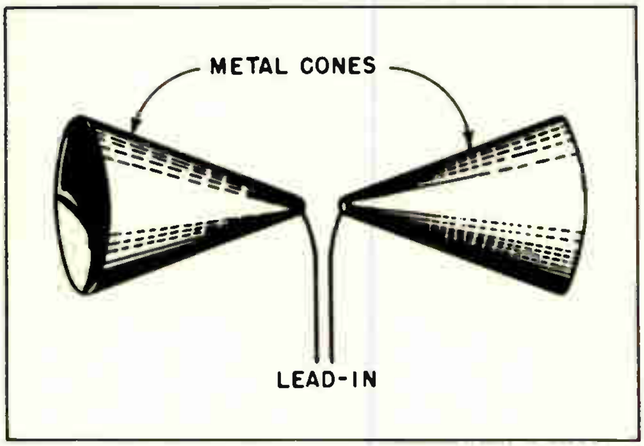

Fig.37. An Antenna Constructed of Two Solid Metal Cones.

Due to these drawbacks, the genuine conical antenna has never come into use on any appreciable scale. With UHF a modified conical called the "bow-tie" is coming into use. But other modifications of the conical antenna are in widespread use. Experimenters and amateurs frequently use a modification of the conical antenna which is constructed somewhat like that shown in Fig. 38. For all practical purposes such an antenna serves almost as well as one constructed of solid metal. The broadside presented to a signal is much the same as for one of solid metal, the difference being so slight as to be scarcely noticeable. Even so, such an antenna as that shown in Fig. 38 is generally restricted to home-made affairs. It is still too bulky for commercial manufacture, and its advantage over other modifications is not enough to warrant it being produced in commercial quantities.

A still further modification of the conical antenna has been made by antenna manufacturers. The Tel-Rex Company, of Asbury Park, N. J., manufactures several modifications of the conical antenna. It is widely used, especially where the stations to be received are widely separated in the frequency spectrum.

Section 18. COMMERCIAL ANTENNAS

Virtually every type of antenna imaginable is being manufactured by one or more of the many companies now operating in that field. A list of some of the more prominent manufacturers are listed at the end of this lesson, together with a summary of the types of antennas they build. Many things should be considered when selecting an antenna, either for yourself or for your customer.

The distance from the transmitter should always be kept in mind. An antenna which may be able to pick up the signal near the transmitter in sufficient strength may not have enough sensitivity or gain in the fringe area. On the other hand an antenna which is sharply resonant to a single frequency and can receive a signal at a great distance may not have a sufficiently wide frequency response to receive all the stations widely scattered throughout the frequency spectrum.

In some localities there are only one or possibly two stations operating. It is often possible to use an antenna there that could not be used where several stations are on the air. But in this connection one should be careful not to be led astray by false considerations. Even in those areas where there are only one or two stations you may find several other stations coming on the air some time in the future. Try to find out what the prospects happen to be in your locality in this respect. If there is any likelihood of additional stations coming on the air some time in the near future you should bring the importance of this to the attention of your customers.

It is often possible to install an antenna to receive only one or two stations but which will not cover the entire frequency spectrum. The difference between the cost of the two types of antennas is not usually very great. Certainly it is not very great compared with the total cost of the installation. Unless you warn a customer that his

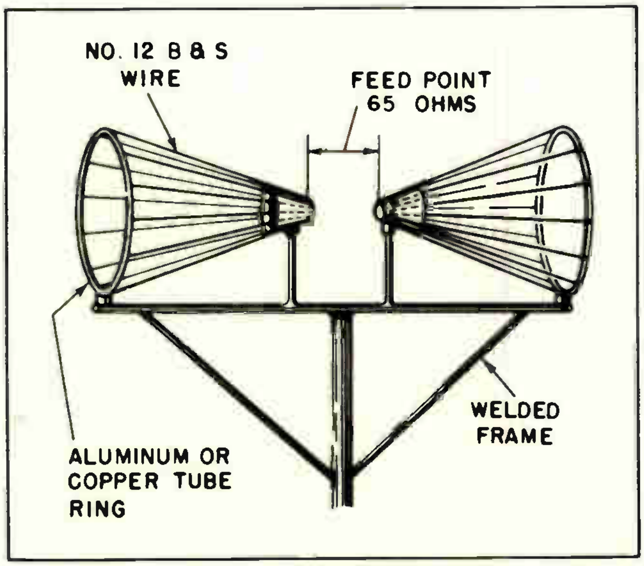

Fig.38. Conical Antenna Constructed of Wires, and Rings.

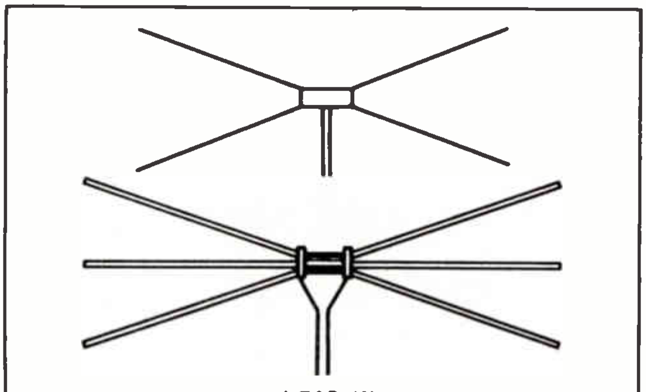

Fig. 39. Commercial Type of Conical Antenna.

installation is not capable of receiving future stations you may earn that customer's ill-will should additional stations soon come on the air in your locality.

In selecting an antenna for an installation, some of the things which must be kept in mind are the cost of the antenna, the total cost of the installation, the climatic conditions which prevail in the area, wind conditions, icing conditions, direction of the transmitting stations, neighboring installations, neighboring obstructions, and such like. Always remember the antenna is outside in all kinds of weather. It should be rugged enough to withstand heavy winds and bad icing conditions. The falling of an antenna can cause serious damage to a customer's roof, and possibly serious injury to some person. All these things will be gone into much more lengthily in a succeeding lesson on the installation of antennas.

Section 19. MULTI-CHANNEL RECEPTION

The frequencies now assigned to the television service is generally divided into two bands. One band contains those channels which use the frequencies between 54 megacycles and 88 megacycles. This includes channels 2, 3, 4, 5 and 6. This band of frequency channels is generally referred to as the low-frequency band of television channels.

The other band of frequencies contain channels 7, 8, 9, 10, 11, 12 and 13. This band includes the frequencies from 174 megacycles to 216 megacycles. A table of the television channels with their frequencies will be found in the back of this lesson.

It will be noticed when the frequencies are examined that the lowest frequency on the high band is more than twice as high as the highest frequency on the low band. This arrangement of the frequencies assigned to television work brings with it certain complications. Generally speaking, an antenna that will receive the stations in the low frequency band will not satisfactorily bring in the stations in the high frequency band.

To solve this problem it has become the general practice of television antenna manufacturers to build two antennas in one. They build one antenna designed to resonate at the low-band frequencies and another antenna to resonate at the high-band frequencies. Then they stack one antenna on top of the other.

The high-band antenna, being smaller, is usually placed on top of the low-band antenna. Such an arrangement is shown in Fig. 40. Such an antenna is not a stacked array. It is more generally referred to as a "piggy back" antenna, the name coming from the fact that the high-frequency antenna seems to ride "piggy-back" fashion on the low frequency antenna. There are many manufacturers who build such antennas.

The American Phenolic Company has designed a different type of antenna which attains the same objective in a somewhat different

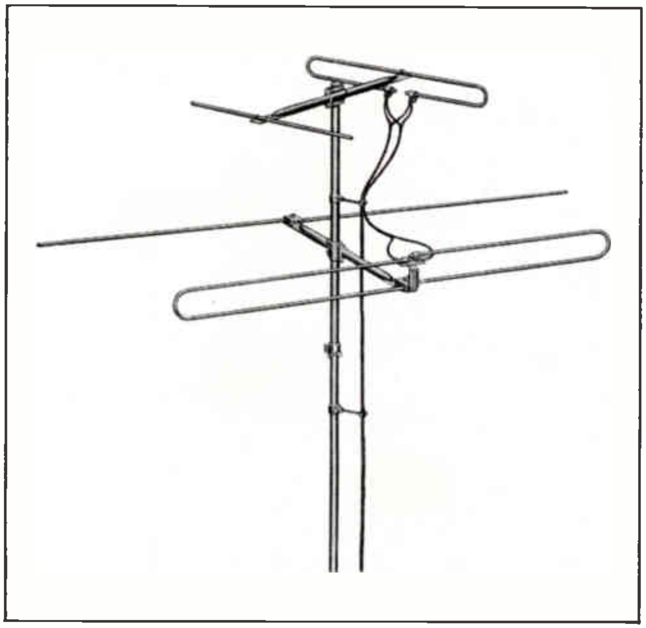

Fig. 40. A "Piggy Back" Folded Dipole Antenna with Reflectors. (Courtesy of American Phenolic Company.)

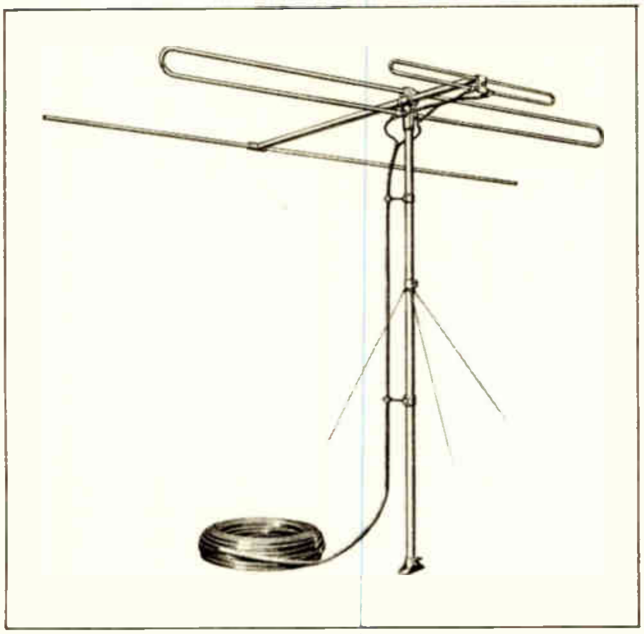

Fig.41. An "In-Line" Antenna. (Courtesy of American Phenolic Company.)

manner. They take advantage of the fact that the low-frequency antenna is longer than the high-frequency antenna. They place the low-frequency antenna behind the high-frequency antenna. The low-frequency antenna acts as a reflector for the high-frequency antenna. They place a normal reflector, slightly longer than the low-frequency antenna, behind the low-frequency antenna. This reflector acts as the reflector for the frequencies on the low band. A picture of such an antenna is shown in Fig. 41. Amphenol calls this antenna a "single bay" antenna, and advertises it under the name, IN-LINE Single-Bay Antenna.

Section 20. COMPARISON OF VARIOUS TYPES OF ANTENNAS

The simple dipole antenna is the simplest antenna of all. It has the advantage of simplicity but the disadvantage of low characteristic impedance, (72 ohms), bi-directional sensitivity, and little gain. If used with a 300-ohm line, or fed into a 300-ohm input receiver some method of matching the impedances must be resorted to. Otherwise there will be mismatching and ghost images.

Fig. 42 is a picture of a simple V-type dipole antenna for use indoors where it can be moved around or located to give the best reception. It has arms for picking up both the low-frequency band and the high-frequency band of the television channels. It is useful in apartment buildings and other places where it is impossible to install an outdoor antenna.

The dipole with a reflector is an advance over the simple dipole in some respects. In other ways its advantages are more apparent than real. The dipole with reflector has the advantage of being uni-directional, but it is larger than a dipole, thus takes up more space and its use indoors is seriously open to question. It is more useful outside than a simple dipole, but it has none of the advantages of other types of antennas. Few simple dipoles with reflectors are in general use.

A folded dipole with reflector has certain advantages over the simple dipole. It is uni-directional, it has a higher impedance to match the higher impedance lines and the higher imputs of receivers. But a single folded dipole should not be used where there are stations on both frequency bands, although it can be used to good advantage where there is only one or two stations on the same band and little likelihood of additional stations being erected in the area.

The conical antennas have certain advantages, but they have other disadvantages which must sometimes be considered. They are widely used in fringe areas where the antenna must be raised to great heights, and where the piggy-back type of antenna

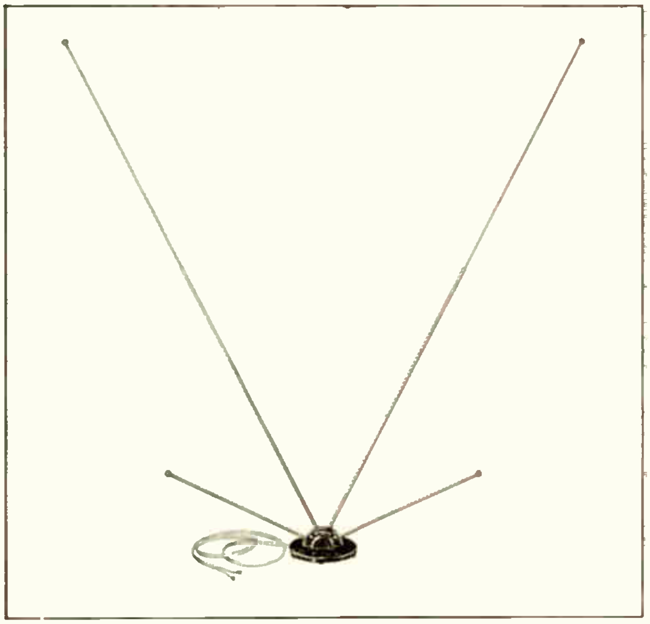

Fig.42. A Simple "V-Type" Dipole Antenna for Indoor Use. (Courtesy of American Phenolic Company.)

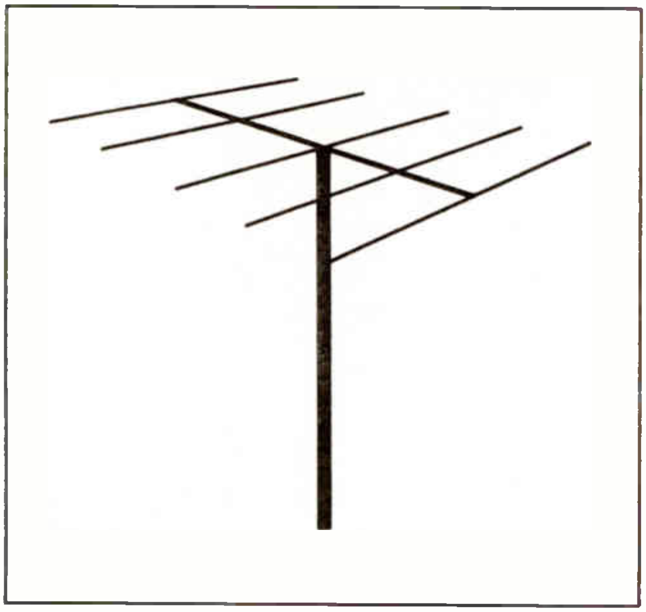

Fig. 43. A Yagi Antenna.

seems unnecessarily bulky. The lobe of the response pattern for a conical antenna is quite broad at the low frequencies but has a tendency to narrow down and become quite sharp at the higher frequencies. In some areas this may be a disadvantage, but in other cases it may be of little concern. Usually in the fringe areas all the stations in a given area will appear to be grouped geographically relatively close together. By this we mean that they will be in much the same general direction from the receiver. The narrowing of the response lobe is then of little importance.

The conical antennas can be stacked as can other types of antennas, and frequently they are so stacked. They also make use of reflectors to make them uni-directional and to add to their gain.

The narrowing of the response lobe of conical antennas may sometimes prove to be a problem in areas which are close to several transmitters. It may be difficult to orient the antenna so all stations will be brought in with equal strength. The best proof that most conical antennas are reasonably satisfactory is the fact that so many of them are used.

The Yagi antenna shown in Fig. 43 has the advantage of tremendous gain in signal strength. It can be used at extreme distances from the transmitter. It is sensitive to, and will pick up, signals at distances far greater than can be picked up by most any other type of antenna. But it has the rather serious disadvantage that it can be used to pick up only one channel. Even with only the one channel there is some danger of discriminating against some of the frequencies within the 6-megacycle width of the normal television channel.

Another type of antenna system that is rather widely used in extreme fringe areas consists of an array of stacked dipoles with reflectors. Such a system is shown in Fig. 44. Such a stacked array has great signal gain and is a very sensitive type of antenna. But it has the disadvantage of being able to receive only one, or possibly two, television channels. Further than this it is somewhat cumbersome and must be strongly braced and guyed to prevent damage from the wind.

An antenna which is called the double-dipole has found rather wide acceptance in many localities. It is pictured in Fig. 45. An antenna of this type is manufactured by the Tricraft Products Corporation, 1535 North Ashland Avenue, Chicago. This antenna has the advantage of low cost and all-band reception. But it is useful only in those areas which are reasonably close to the transmitting stations.

The In-Line Single-Bay antenna built by Amphenol has many advantages over other types of antennas, but like all other types it also has certain disadvantages. It has

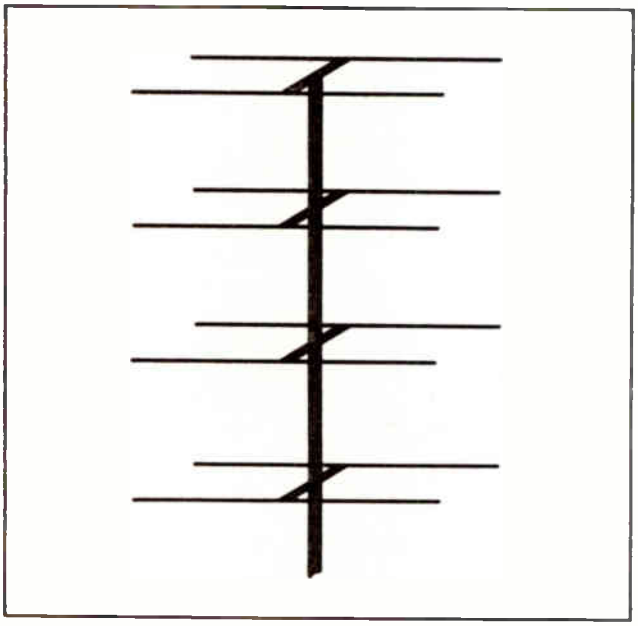

Fig. 44. A Stacked Array of Four Dipoles with Reflectors.

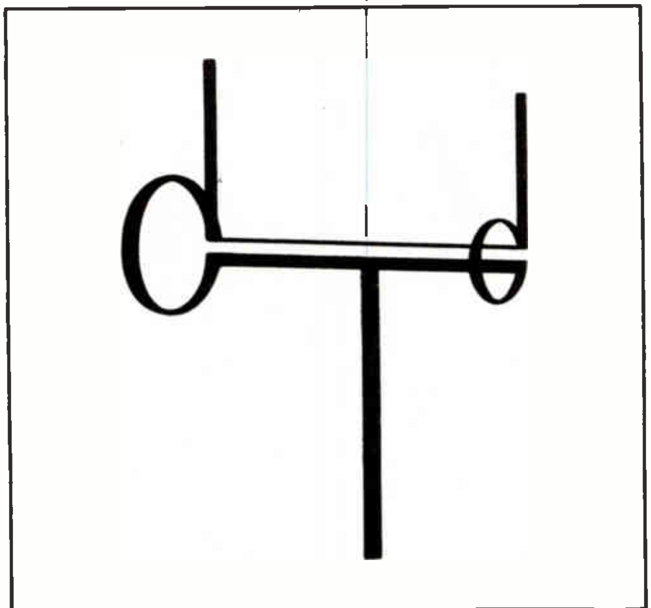

Fig. 45. A Double-Dipole Antenna.

wide frequency response, is sturdily constructed, matches the impedance of a 300-ohm line and all points are at D-C ground potential. It does not have the high gain in the extreme fringe area of the Yagi or the stacked array of dipoles.

The Amphenol In-Line Single-Bay antenna can be obtained in stacked arrays. Such a stacked array is pictured in Fig. 46. Such a stacked array compares very favorably with a Yagi or the stacked dipole array insofar as sensitivity is concerned.

Section 21. IMPEDANCE TRANSFORMERS

It is sometimes necessary to connect an antenna which has one impedance to a transmission line which has another impedance. Further than this it is also necessary at times to match a transmission line which has one impedance to a television receiver which has a different impedance.

If an antenna which has a characteristic impedance of 72 ohms is connected directly to a transmission line which has a characteristic impedance of 300 ohms there will be reflections in the line and the appearance of ghosts will be almost inevitable.

To overcome such problems it is the general practice to use *impedance transformers* to effect a proper match between the two differing impedances. Suppose, for example, that we find it necessary to couple an antenna which has a characteristic impedance of 72 ohms to a line which has a characteristic impedance of 300 ohms. Such a coupling can be effected if we can couple the two impedances together by a short quarter-wave transmission line which has an entirely different impedance from either of the other two impedances.

But it should not be thought that we can use just any impedance in the quarter-wave length of line. Far from it. The characteristic impedance of the short piece of line must be carefully arrived at.

It can be demonstrated mathematically, and can be proven by experiment, that whenever two differing impedances are coupled together by a third impedance which is equal to the square root of the product of the first two impedances, a proper impedance match will be effected.

In the above example of coupling a 72-ohm antenna to a 300-ohm line we first multiply the two impedances together to obtain their product:

$$75 \times 300 = 22{,}500$$

(We use 75 for ease in figuring)

We can use any of several methods to find the square root of 22,500. Whatever method we use we will find the square root to be 150.

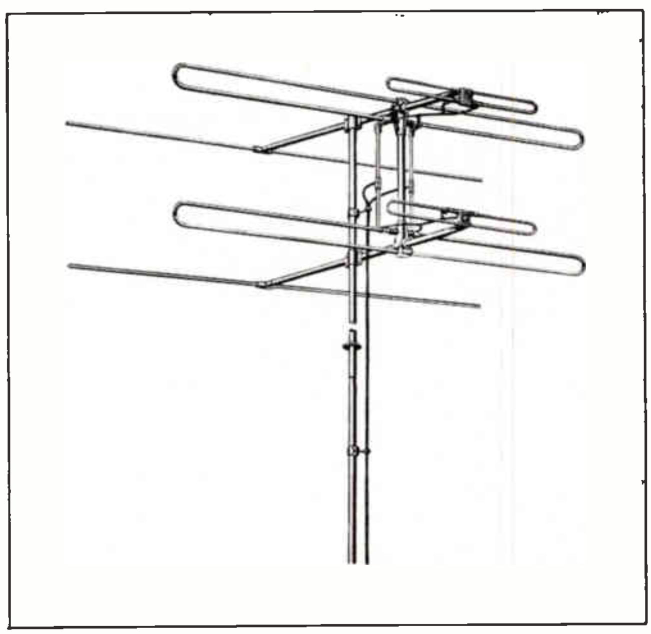

Fig. 46. A Stacked Array of "In-Line" Antennas. (Courtesy American Phenolic Co.)

What this all adds up to is this: If we want to couple a 75-ohm antenna to a 300-ohm line we can effect a perfect impedance match by coupling them with a quarter-wave length of 150-ohm line.

This can be set up in a formula in this manner:

Such a line has the impedances matched all along the line, and at all coupling points. There are no restrictions on the length of the line except that of the resistance. The line can be even wave-lengths long, odd wave-lengths long, or any fractional wave-length long. It makes no difference. The proper energy will be transferred without regard to length of the line or the wave-length of the signal.

$$Z_o = \sqrt{Z_1 Z_2}$$

where Z_o = the characteristic impedance of the short matching stub

Z_1 = the characteristic impedance of the first impedance

Z_2 = the characteristic impedance of the second impedance.

Section 22. RESONANT AND NON-RESONANT LINES

You will come across the expression *resonant* lines and *non-resonant* lines many times in your work. Both are used quite extensively in radio and television work.

A line that is terminated in its characteristic impedance is said to be *flat*, or *non-resonant*. The line is called *flat* because the current and voltage is distributed evenly along the line -- there are no standing waves.

The *resonant* line or *tuned* line has standing waves on the line. The tuned or resonant line must be some even length with respect to the wave-length of the signal.

The length of the line has a very definite effect upon the impedance at the point where the coupling is made. Care must be taken to cut the line to a length that allows the impedance of the coupling to match the impedance of the line at that point.

NOTES FOR REFERENCE

An antenna which will satisfactorily pick up a signal from a point nearby to a transmitter will not necessarily be suitable in a fringe area.

An antenna may pick up a weak signal at a great distance yet be of little use in a local area where there are several stations on the air.

Signals which move outward from a transmitter are composed of two parts. One is an electric wave and the other is a magnetic wave.

The electric wave and the magnetic wave which moves out through space from a transmitter are always at right angles to each other, and both are at right angles to the direction of travel.

A moving electric field will generate a magnetic field.

A moving magnetic field will generate an electric field.

The inductance of an antenna is determined by the length of the conductor.

The capacitance in an antenna is composed of the actual capacity which exists between the various parts of the antenna.

A simple dipole antenna is composed of two lengths of conductor, the total length of the two being equal to one-half wave-length of the frequency to which it is resonant.

When a conductor which is cut slightly longer than one-half wave-length is placed a proper distance behind a dipole antenna it will act as a reflector.

If a conductor is cut slightly shorter than one-half wave-length and placed slightly less than one-quarter wave-length in front of the dipole, it will act as a director and will tend to boost the gain of the antenna.

A dipole antenna has a characteristic impedance of 72 ohms.

The characteristic impedance of a dipole can be increased by "folding" it over. This is accomplished by placing an additional element in parallel with the dipole and connecting the two ends together. The characteristic impedance of most commercially constructed folded antennas is 300 ohms.

The higher frequencies used for television transmission are not generally reflected by the ionosphere with sufficient strength to provide reception at any great distances without the use of extensive arrays of antennas.

Commercial television broadcasting is limited to line-of-sight distances. This means the reception is limited to distances only a little beyond the horizon.

The Yagi antenna is an elaborate directional array consisting of five elements. It is very sensitive at great distances but its use is restricted to the reception of one channel.

A high-frequency antenna which is positioned above a low-frequency antenna is generally referred to as a "piggy back" antenna.

TABLE I

DIPOLE ANTENNAS

Channel No.	Frequency (inc.)	Length (inches)
2	54-60	49-1/4
3	60-66	44-1/2
4	66-72	40
5	76-82	35-1/4
6	82-86	33
7	174-180	16
8	180-186	15-1/4
9	186-192	14-3/4
10	192-198	14-1/4
11	198-204	13-7/8
12	204-210	13-1/2
13	210-216	13-1/4

Characteristic Impedance - 72 Ohms

TABLE II

FOLDED DIPOLE ANTENNAS			
Channel No.	Wavelength (feet)	1/2 Wavelength (feet)	1/4 Wavelength (inches)
2	16 ft. 5 in.	8 ft. 2-1/2 in.	49-1/4 in.
3	14 ft. 10 in.	7 ft. 5 in.	44-1/2 in.
4	13 ft. 6 in.	6 ft. 8 in.	40 in.
5	11 ft. 9 in.	5 ft. 10-1/2 in.	35-1/4 in.
6	11 ft. 0 in.	5 ft. 6 in.	33 in.
7	5 ft. 4 in.	2 ft. 8 in.	16 in.
8	5 ft. 1 in.	2 ft. 6-1/2 in.	15-1/4 in.
9	4 ft. 11 in.	2 ft. 5-1/2 in.	14-3/4 in.
10	4 ft. 9 in.	2 ft. 4-1/2 in.	14-1/4 in.
11	4 ft. 7-1/2 in.	2 ft. 3-3/4 in.	13-7/8 in.
12	4 ft. 6 in.	2 ft. 3 in.	13-1/2 in.
13	4 ft. 5 in.	2 ft. 2-1/2 in.	13-1/4 in.
Characteristic Impedance - 300 Ohms			

TABLE III

DIPOLE AND REFLECTOR DESIGNED FOR MAXIMUM GAIN		
Channel No.	Spacing Between Elements	Reflector Length
2	40 in.	108 in.
3	36 in.	98 in.
4	33 in.	88 in.
5	29 in.	78 in.
6	26 in.	72 in.
7	13 in.	36 in.
8	12-1/4 in.	34 in.
9	11-3/4 in.	32-1/2 in.
10	11-1/2 in.	31 in.
11	11-1/4 in.	30-1/2 in.
12	11 in.	29-1/2 in.
13	10-3/4 in.	29 in.

TABLE IV

FOLDED DIPOLE-REFLECTOR ANTENNA Designed for 3 to 4 Channel Bandwidth		
Channel No.	Element Spacing	Reflector Length
2	52 in.	114 in.
3	48 in.	102 in.
4	44 in.	92 in.
5	38 in.	82 in.
6	35 in.	74 in.
7	17 in.	37 in.
8	16-1/4 in.	35 in.
9	15-3/4 in.	34 in.
10	15-1/2 in.	33 in.
11	15 in.	32 in.

TABLE V

THREE-ELEMENT SINGLE CHANNEL Parasitic Array Designed for Optimum Gain				
Channel No.	Reflector Spacing	Reflector Length	Director Spacing	Director Length
2	40 in.	104 in.	25 in.	88 in.
3	36 in.	94 in.	22 in.	80 in.
4	33 in.	84 in.	20 in.	72 in.
5	29 in.	74 in.	18 in.	64 in.
6	26 in.	70 in.	16-1/2 in.	60 in.
7	13 in.	34 in.	8 in.	29 in.
8	12-1/4 in.	32-1/2 in.	7-3/4 in.	27-1/2 in.
9	13-3/4 in.	31-1/2 in.	7-1/2 in.	25-1/2 in.
10	11-1/2 in.	30-1/2 in.	7-1/4 in.	25-1/2 in.
11	11-1/4 in.	29-1/2 in.	7 in.	25 in.
12	11 in.	28-1/2 in.	6-3/4 in.	24-1/2 in.
13	10-3/4 in.	28 in.	6-1/2 in.	24 in.

TABLE VI

"LAZY H" TYPE ANTENNA			
Channel No.	Reflector Length	Reflector Spacing	Stack Spacing and Quarter Wave Dipole Element Length
Mid-Point Low Band	75 in.	30 in.	36 in.
Mid-Point High Band	29 in.	11-1/2 in.	14-1/4 in.
2	98 in.	40 in.	49 in.
3	88 in.	36 in.	44 in.
4	80 in.	33 in.	40 in.
5	70 in.	29 in.	35 in.
6	66 in.	26 in.	33 in.
7	32 in.	13 in.	16 in.
8	30 in.	12-1/4 in.	15-1/4 in.
9	29 in.	11-3/4 in.	14-3/4 in.
10	28-1/2 in.	11-1/2 in.	14-1/4 in.
11	28 in.	11-1/4 in.	13-7/8 in.
12	27 in.	11 in.	13-1/2 in.
13	26-1/2 in.	10-3/4 in.	13-1/4 in.

Characteristic Impedance - 72 or 300 Ohms
Depending on Matching Transformer.

NOTE: The two quarter-wave dipole element lengths can be obtained from the Stack Spacing Column, as the elements are stacked exactly a quarter wavelength apart.

(over)

TV ANTENNA EQUIPMENT MANUFACTURERS

Directory of Antennas, Boosters, Towers, and Other Pre-Front-End Equipment

Airflyte Electronic Co.,
22 Evergreen St.,
Bayonne, N. J.

Complete line of TV Antennas,
Chinmey mounts and brackets.

All Channel Antenna Corp.,
70-07 Queens Blvd.,
Woodside, N. Y.

Wide and narrow band arrays,
Biconicals,
Super-directional fans,
Folded high
Straight low,
Folded low,
Yagis,
Window antennas,
Indoor antennas,
Folded In-Line,
Double-V antennas.

Alliance Mfg. Co.,
Lake Park Blvd.,
Alliance, Ohio.

Booster matched with antenna rotator.
Antenna rotating devices.

A'par Mfg. Co.,
406 St. Francis St.,
Redwood City, Calif.

Small aluminum TV tower.

Alprodco, Inc.,
Mineral Wells, Texas.
Kempton, Ind.

Aluminum towers for TV.

American Phenolic Corp.,*
1830 S. 54th Ave.,
Chicago, Ill.

Broadband In-Line and Piggy-back folded Dipoles.
Indoor fixed dipoles,
Extension masts,
Matching transformers,
Lightning arresters,
Standoff insulators,
Transmission lines,
Twin-lead connectors and an automatic antenna rotator.

* Now called Amphenol Electronics Corp.

Antenna Products,
1809 N. Ashland Ave.,
Chicago 22, Ill.

Biconical antenna,
Dual rotation and Uni-rotation arrays,

Antenna Products, (Cont'd.)

Yagi antennas,
Chimney and
Wall mounts.

Astatic Corp.,
Harbor and Jackson Sts.,
Conneaut, Ohio.

All-channel,
Two-stage TV boosters,
Single-stage TV and FM booster.

Baker Mfg. Co.,
Evansville, Wisc.

Antenna towers and masts.

Barb City Industries,
1150 S. 4th Ave.,
De Kalb, Ill.

Uni-directional and bi-directional arrays,
Indoor collapsible array,
Attic antennas,
Foot mounts (universal and conventional)
Foot mounts for conduit tubing.

Blonder-Tongue Labs.,
20 Gunther Ave.,
Yonkers, N.Y.

Wide-band,
All channel automatically tuned booster amplifying all 12 TV channels simultaneously.

David Bogen Co.,
663 Broadway,
New York, N. Y.

TV boosters.

Brach Mfg. Corp.,
200 Central Ave.,
Newark, N.J.

Broadband antennas,
Bow tie,
V-type,
Biconical super-directional fans,
T-bar In-Line,
Indoor antennas;
Twelve models.
Masts,
Brackets and installation accessories,
Non-amplified master antenna systems,
TVI matching transformers with high-pass filter.
Two-set couplers.

Bud Radio, Inc.,
2118 E. 55th St.,
Cleveland 3, Ohio.

TV tower in 8-foot sections.

Camburn, Inc.,
32-40 57th St.,
Woodside, N. Y.

Straight and folded dipoles with and without reflectors,
Stacked conicals,
4- and 5-element Yagis,
Straight line single and double stacked arrays,
Window and indoor antennas,
Mast mounting brackets,
Screw eyes,
Lead-in Clamps,
Guy wire,
Lightning arresters,
Standoffs,
Miscellaneous accessories.

Camburn Sales and Mfg. Corp.,
392 W. Michigan Ave.,
P.O. Box 408,
Battle Creek, Mich.

Telescoping 3 sectional 50-ft. tower,
Guy ring for rotating antenna,
Antenna mount for roof or wall,
Universal mount.

Channel Master Corp.,
Ellenville, N. Y.

Folded and straight dipole combinations,
Conventional conical combinations,
Broad-band fan combinations,
Yagis,
Hi-lo combinations,
V antennas,
Masting and accessories.

Circle-X Antenna Corp.,
500 Market St.,
Perth Amboy, N. J.

All-purpose circular antenna,
Masts,
Ground rods,
Guy wirrs,
Mast clamps,
Chimney mounts.

Clear Beam Television Antennas,
618 N. La Brea Ave.,
Los Angeles 36, Calif.

V-cones, arrows,
Hi-lo dipoles,
Yagis,

Clear Beam Television Antennas (Cont'd.)

Clover leafs,
Pre-assembled kits.

Cornell-Dubilier Electric Corp.,
South Plainfield, N.J.

Various types of antennas,
Rotators,
Mounting accessories.

Crown Controls Co.,
124 So. Washington St.,
New Bremen, Ohio.

Compass-Indicating rotator.

DeciMeter, Inc.,
1430 Market St.,
Denver 2, Colo.

Balanced circuit preamplifiers,
TVI wave traps for FM,
Diathermy,
10-meter amateur,
Spurious i.f. in three ranges.

Delson Mfg. Corp.,
126 11th Ave.,
New York 11, N.Y.

Window antennas
High and low band folded telescoping tunable dipoles,
Conical,
Open dipole,
Stacked arrays,
Chimney and
Wall mounts and
Masts.

R. L. Drake Co.,
11 Longworth St.,
Dayton, Ohio.

TVI filters.

East Coast Electronics,
40 St. Francis St.,
Newark 5, N. J.

Yagi beams,
Wide and narrow band arrays,
Biconical antennas and
Masts,
Transmission line,
Coaxial cable chimney counts,
Wall brackets,
Accessories.

Easy-up Tower Co.,
427 Romayne Ave.,
Racine, Wisc.

TV towers.

Easy-Up Tower Co., (Cont'd.)

Mast mountings,
Guy wire clamps,
Thimbles,
Pole rings.

Electro-Voice, Inc.,
Buchanan, Mich.

TV booster.

Ebergy Farm Equipment Co.,
Monticello, Iowa.

Hydraulic TV mast.

Gadgets, Inc.,
3629 N. Dixie Drive,
Dayton 4, Ohio.

Indoor circular dipole.

General Cement Mfd. Co.,
919 Taylor Ave.,
Rockford, Ill.

Telescoping indoor dipole,
Single, Double, and
4-stack conical.

Don Good, Inc.,
1014 Fair Oaks Ave.,
So. Pasadena, Calif.

Low-loss 300-ohm television lead-in wire line,
Television high-pass filters,
TVI traps.

Haugen Co.,
412 So. Front St.,
Mankato, Minn.

Antenna mast hoist and roof mount.

Hi-Lo TV Antenna Corp.,
3540 N. Ravenswood Ave.,
Chicago 13, Ill.

Spiral antenna for high and low bands.

Hy-Lite Antenna, Inc.,
242 E. 137th St.,
New York 51, N. Y.

Single and stacked folded Dipoles,
Yagis,
V antennas.

Industrial Television, Inc.,
359 Lexington Avenue,
Clifton, N. J.

Untuned booster.

Insuline Corp. of America.
36-03 35th Ave.,
Long Island City, N. Y.

Wide-band antenna systems, including double and quadruple arrays in standard and heavy duty models,
Folded dipole antennas and
Arrays,
Window antennas,
Indoor dipoles and
Indoor Outdoor folded dipoles.

Jerrold Electronics Corp.,
121 N. Broad St.,
Philadelphia 7, Penna.

Multiple TV systems with separate 4-element Yagi for each channel,
Master control unit,
Amplifier strips for each of 12 channels, and
Power supply,
Antenna distribution outlets,
Wall outlets,
FM filter traps,
Solderless coax fittings,
Terminating resistor unit.

JFD Mfg. Co.,
6101 Sixteenth Ave.,
Brooklyn, N. Y.

Multi-element and Multi-bay dipoles,
Folded dipoles,
conicals,
Yagi beams,
Window and Indoor antennas,
Masts,
Extensions,
Brackets,
Arresters.

Knepper Aircraft Service Co.,
Aero Tower Div.,
1016 Linden St.,
Allentown, Penna.

Welded tubular aluminum towers and
Tower sections to 120 feet.
Pole kits with hardware and
Mounting accessories.

H. G. Loenig Eng. Co.,
735 Southwest Blvd.,
Kansas City 3, Kans.

Antenna rotators.

La Pointe-Plascomold Corp.,
Windsor Locks, Conn.

Antennas,
Masts,
Towers,

La Pointe-Plascomold Corp. (Cont'd.)

Mounts,
Guy Cables,
Guy rings and
Collars,
Turnbuckles,
Cable clamps,
Lightning arresters,
Transmission line.

Louis Bros.,
3543 E. 16th St.,
Los Angeles 16, Calif.

High and low folded dipoles,
In-Line,
Conicals,
Yagis, and
V Antennas.

Lyman Electronic Corp.,
12 Cass St.,
Springfield, Mass.

Yagi,
Folded dipole,
Single and Double stacked.

Lyte Products, Inc.,
46 Lawrence St.,
Newark, N. J.

Antenna rotators,
Conicals,
Stacked phased h.f. antennas,
Folded high and low band dipoles,
Telescopic aluminum mast,
Folded dipole with triple reflector.

Metalace Corp.,
2101 Grand Concourse,
Bronx 53, N. Y.

Antenna mounting devices,
Chimney mounts,
Wall mounts,
Eave mounts,
Miscellaneous mounts, and
Accessories.

Miner Mfg. Co.,
Box 4465,
Fondren Station,
Jackson, Miss.

All aluminum mast for 30 to 100-ft. installations.

National Co.,
61 Sherman St.,
Malden, Mass.

TV boosters.

Network Mfg. Corp.,
213 W. 5th St.,
Bayonne 7, N. J.

Narrow beam and wide band antennas,
Yagi,
Conical,
Folded hi-low assemblies,
Parabolic dish and Wire Mesh 400 mc to 100 mc development service.

Oak Ridge Products,
Div. of Video Television, Inc.,
37-01 Vernon Blvd.,
Long Island City 1, N. Y.

High and low band antennas.
Biconicals,
Indoor dipoles and
Window antennas.

Ohio Aerial Co.,
4553 Lewis Ave.,
Toledo 12, Ohio.

All-wave conicals,
Basic suspension for 4 types of antenna.

Walter E. Peck, Inc.,
2842 W. 30th St.,
Indianapolis 22, Ind.

Six-element single-channel arrays,
12-element single band stacked arrays for low channel operation,
16-element high channel arrays,
Quadrature phase stacked broad band (channels 7 to 13) double stacked closed dipole conicals.

Peerless Products Industries,
812 N. Pulaski Road,
Chicago 51, Ill.

Indoor dipoles.

Penn Boiler and Burner Mfg. Co.,
Lancaster, Penna.

TV towers in 10-foot sections, tubular construction.
Roof mountings,
Guy rings and
Collars.

A. A. Peters,
231 N. Seventh St.,
Allentown, Penna.

Antenna towers,
Portable tower rigs.

Philco Corp.,
Philadelphia 34, Penna.

Fan and V antennas.

Philson Mfg. Co.,
60-66 Sackett St.,
Brooklyn 31, N. Y.

Narrow band (Yagi type),
Indoor dipoles,
Folded dipoles,
Single dipole,
Stacked arrays of all types,
Masts.

Phoenix Electronics, Inc.,
50 Island St.,
Lawrence, Mass.

Dipole,
In-Line,
Conical,
Yagi.

Plymouth Electronic Corp.,
68 High St.,
Worcester, Mass.

Three-channel transfer switches,
6-strand guy wire,
Chimney mounts,
Roof mounts,
Wall mounts.

Premux Products Div.,
Chisholm-Ryder Co.,
Highland and College Aves.,
Niagara Falls, N. Y.

Ground rods and fastenings,
Antenna mountings and Accessories.

Price Tenna-Trailer Co.,
660 E. Walnut St.,
Watseka, Ill.

Portable TV Demonstrating unit,
TV masts.

Radelco Mfg. Co.,
7580 Garfield Blvd.,
Cleveland 25, Ohio.

Wide and narrow-band arrays including
High-low,
In-Line,
High gain conical and Yagi dipoles,
Indoor dipoles.

Radiart Corp.,
3571 W. 62nd St.,
Cleveland 2, Ohio.

Folded dipoles and reflectors,
Turnstile folded dipole,
High-lo all-channel,
Straight line all-channel,
Single and double stacked,
Conical all-channel,
Single, double and 4-stack,

Radiart Corp. (Cont'd.)

Yagi cut to channel,
5-element,
Single and double stacked,
Super V end-fire,
Indoor 2 and 3-section telescoping masts.

Radio Corporation of America,
RCA Victor Div.,
Harrison, N. J.

Single lobe antenna,
reversible-beam array,
FM folded-dipole,
Antenna mast mounting brackets,
Transmission line,
Lightning arrester.

Radio Merchandise Sales, Inc.,
1165 Southern Blvd.,
New York 59, N. Y.

Conicals,
Yagis,
Folded dipoles,
Straight dipoles,
Window antennas,
Indoor antennas.

Radion Corp.,
1137 Milwaukee Ave.,
Chicago, Ill.

Indoor dipole,
Indoor antenna in shape of photo album,
Conical window antenna.

Ramsey Radio and Television Co.,
Box 297,
Ramsey, Ill.

Welded steel TV antenna towers in 10-foot sections, with built-in rotor mounts, hinged feet, and lead-in insulators.

Ray Mfg. Co.,
441 Summit,
Toledo, Ohio.

Conical arrays,
Folded dipoles,
Special single and double stacked Yagis cut to any channel.
Chimney mounts,
Roof saddles,
Mounting bases,
Mast connectors and guy rings.

Regency Div., I.D.E.A. Inc.,
55 North New Jersey St.,
Indianapolis, Ind.

Television and FM boosters.

Rostan Corp.,
202 E. 44th St.,
New York 17, N. Y.

Self-supporting and guyed aluminum towers.

Walter L. Schott Co.,
9306 Santa Monica Blvd.,
Beverly Hills, Calif.

Wideband conical arrays with and without masts,
Yagis.

Mark Simpson Co.,
32-28 Forty-ninth St.,
Long Island City, N. Y.

All-channel TV booster.

Snyder Mfg. Co.,
22nd and Ontario Sts.,
Philadelphia, Penna.

Conicals,
Folded and straight dipoles,
Hi-lo, portable indoor,
Double V type, straight bay,
Biconical,
Window antennas.

Square Root Mfg. Co.,
391 Saw Mill River Road,
Yonkers, N. Y.

Built-in quadrature phased antennas,
Rotating rooftop antenna,
Indoor and
Window antennas.

Standard Coil Products Co.,
2311-29 No. Pulaski Road,
Chicago 39, Ill.

TV booster,
Front ends.

Tabet Mfg. Co.,
254 W. Tazewell St.,
Norfolk 10, Va.

Wide-band conicals,
Single and stacked arrays,
Window antennas,
Aluminum towers.

Taylor Mfg. Co.,
Lima, Ohio.

Aluminum and steel chimney mounts, and antenna bases,
Aluminum wall mounts,
Steel saddle and
Roof mounts.

Tech-Master Products Co.,
443 Broadway,
New York, N. Y.

TV booster kit.

Technical Appliance Corp.,
Sherburne, N. Y.

Twin-driven Yagi arrays,
In-Line and Piggy-back antennas.
Conicals,
Antenna amplifier distribution systems,
Lightning arresters,
Mast bases.

Tel-A-Ray Enterprises, Inc.,
335 Clay St.,
Henderson, Ky.

Wide-spaced Yagi arrays,
broadband butterfly,
antenna-mounted preamplifier.

Telematic Industries, Inc.,
One Joralemon St.,
Brooklyn 2, N. Y.

Conicals,
Folded, and straight dipoles,
Masts,
Mast couplers,
Ribbon-line wire strippers,
Detent replacement,
Stacking bars,
Conical element stabilizers, and
High gain signal sprus.

Television Equipment Corp.,
238 William St.,
New York 7, New York.

Untuned booster, multiple dwelling coupler and booster networks,
Color adapters and converters.

Telrex, Inc.,
Ashbury Park, N. J.

Conical V beams,
All channel arrays,
Outdoor and indoor antennas,
Accessories.

TELvision Labs, Inc.,
5045 W. Lake St.,
Chicago 44, Ill.

Built-in and under-the-rug printed circuit antennas.

Towers Corp.,
3332 E. 55th St.,
Cleveland 4, Ohio.

Five-foot steel mast extensions

Tricraft Products Co.,
1535 N. Ashland Ave.,
Chicago 22, Ill.

Seven-element all-wave array,
Single, double or 4-stacked,
Loaded dipoles,
Loaded dipoles with triple reflector,
Hi-lo folded dipole with reflector,
Conical, single, double and 4-stacked,
Single and double stacked 3-element Yagi,
Loaded window and indoor dipoles,
Masts (kits and preassembled units).

Trio Mfg. Co.,
Griggsville, Ill.

Yagis,
Attic antennas,
Wide-band arrays,
Two-channel Yagis,
Phase control and masts.

The Turner Co.,
Cedar Rapids, Iowa.

TV booster.

Veri-Best Television Products,
233 Spring St.,
New York, N. Y.

All-band outdoor antennas,
Yagis,
Stacks of all kinds,
Conicals.

Victoria Sales Co.,
619 No. Michigan Ave.,
Chicago 11, Ill.

Telescoping indoor dipole,
Under-the-rug antenna.

Wabash Mfg. Co.,
2300-18 So. Western Ave.,
Chicago 8, Ill.

Under-the-rug antennas.

Walco Products, Inc.,
60 Franklin St.,
East Orange, N. J.

Two-speed, 370-degree antenna rotator, with or without indicator.

Ward Products Corp.,
1523 E. 45th St.,
Cleveland 8, Ohio.

Folded dipoles,
Yagis,
Stacked arrays.

Warren Mfg. Co.,
250 East St.,
New Haven, Conn.

Complete line of TV antennas,
Hardware and
Brackets.

Western Coil and Electrical Co.,
215 State St.,
Racine, Wisc.

Semi-telescoping steel masts, 10 to 46 feet,
Self-supporting aluminum towers, 33 to 55 feet,
Guyed aluminum towers,
Steel lattice type and
Triangular type towers and
Tower sections to 100 feet.

Wincharger Corp.,
East 7th at Division,
Sioux City 6, Iowa.

Guyed and self-supporting roof-mounted towers.

Wind Turbine Co.,
260 E. Market St.,
West Chester, Penna.

Towers and masts,
Tripods,
Antenna support brackets.

Workshop Associates,
135 Crescent Road,
Needham Heights 94, Mass.

Double V and cut-to-channel Yagis,
Matching transformers,
Coax switches,
Connectors, and other Accessories.

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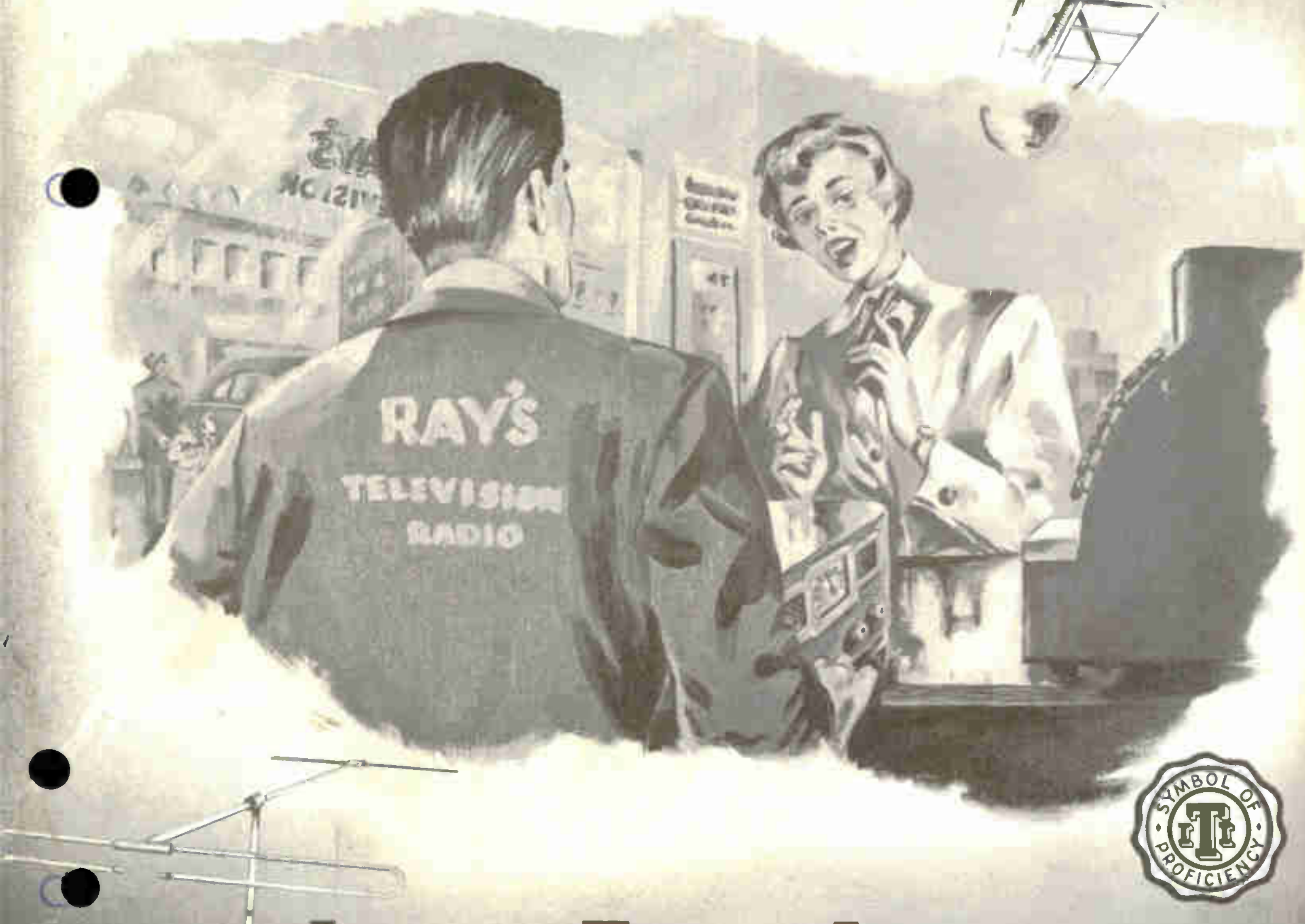

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INDUSTRIAL TRAINING INSTITUTE

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TECHNICAL TRAINING SERVICE

REVISED 1957

RADIO TELEVISION

INSTALLING ANTENNAS

Contents:

Section 1. INTRODUCTION

Perhaps this lesson would be more accurately entitled if it were called INSTALLING TELEVISION RECEIVERS. The truth is, however, that the biggest job in the installation of any television receiver is the proper selection and installation of the antenna on which the receiver depends for its interception of a broadcast signal. And since the major portion of our attention in this lesson will be directed toward the selection and installation of antennas, we have chosen to call the lesson by its present title.

Because there are so many kinds and types of television antennas on the market, and because most of them do a good, or an adequate job, in the field for which each is designed, one could easily get the idea that all a television installer need do would be select the handiest antenna and use it to make any installation. Unfortunately, the job is not quite that simple. The lesson on ANTENNAS has probably prepared you to understand the reason why that cannot usually be done.

One could almost say that the problems to be faced in the installation of a television receiver are seldom completely duplicated in any two jobs. Some are installed in private homes, others in apartment buildings; some in residential areas, others in factory areas; some in taverns, restaurants and other places where the public gather to eat or to drink or to otherwise make merry, others in the recreational rooms adjoining houses of worship; some are located near the transmitter, others in the "fringe" areas; some will receive signals from several stations which are all located in the same general direction; others will receive signals from two or more stations which are located in opposite directions from the receiver; some will be located in parts of the country where the land is level, others will be located in mountainous areas. In other words, television receivers will be located in as many, and as diverse, locations

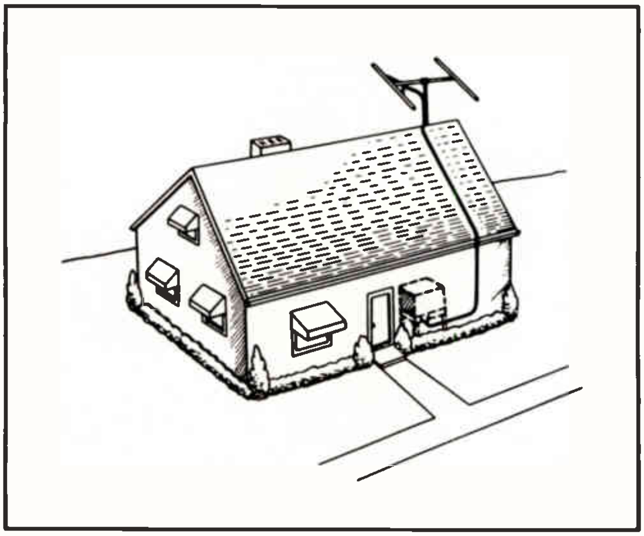

Fig.1. A Rooftop Antenna with the Transmission Line going to the Receiver.

as there are kinds and types of people and their individual habits of living.

The problems faced by a television installer are almost as diverse as the habits of the people he is called upon to serve. One of his principle jobs is to size up the needs for a particular installation, install the receiver, and then select and install an antenna which is suitable for that location. There are some locations which will tax the knowledge and the ingenuity of the most capable and experienced television expert.

In a lesson such as this we must try to anticipate and discuss the problems which all servicemen will encounter at some time. This means that we will discuss many problems which some servicemen can automatically eliminate as not applying to them since it is not likely they will encounter those particular problems. The installation of television receivers in mountain areas create certain special problems which servicemen working in those areas will encounter and which they must take into consideration and solve. These will be problems which servicemen living in the level country areas need not worry about.

Servicemen who install television receivers in locations like the Loop District of Chicago, or the Manhattan Island District of New York, must cope with the problem of picking up signals which come from many different directions, and with the "ghosts" which are caused by signals bouncing off the many tall buildings. Servicemen who operate only in the "Fringe" areas can often forget about most of those kinds of troubles. But they, in turn, have the problem of picking up weak signals and making them usable.

Many customers live in apartment houses where the landlord forbids the erection of television antennas on the roof. Here the television installer must attempt to provide some kind of indoor antenna that will prove to be reasonably satisfactory.

Climatic conditions must always be kept clearly in mind when installing an antenna. A television installer working in southern Florida would not normally have to give much consideration to the formation of heavy ice on the exposed antenna, but he should remember that strong winds might be just as dangerous, and present a different kind of hazard that must be considered. In the middle latitude belts of the United States freezing rains are a frequent occurence. Such rain freezing on the exposed antenna can quickly load it with such a weight of ice that the entire installation may come tumbling down unless it has been properly prepared to ward off just such danger.

Section 2. HOW TELEVISION RECEIVERS ARE SOLD

There are almost as many different ways of selling television receivers to the public as there are manufacturers of receivers; it might be said there are almost as many ways as there are dealers selling them. Despite all this, the methods of selling television receivers do fall into several fairly well defined patterns.

We might mention first the "bargain" or "cut-rate" dealer who sells any and all kinds of receivers. Usually he sells for cash, but sometimes on time payments. When he sells a receiver, he ordinarily sells it "as is", without installation and without warranty. After the customer buys the receiver it is still up to him to install it and make it work. The prices charged by such "cut-rate" dealers are usually much lower than those charged by other dealers, and for this reason many radio and television men who are not actually working in the service field often buy their own receivers from such "cut-rate" dealers and service the receivers themselves.

Another type of dealer will sell his receivers with the understanding that he will guarantee the receiver to work properly in the customer's home. Such a dealer will often handle his own installation jobs, but will not give a warranty with the receiver, nor provide any service after the receiver is once operating properly after the original installation.

Other dealers include the cost of installation in the selling price of the receiver, then warrant the operation of the receiver for some definite period for an additional fixed fee. Still others warrant the receiver itself, and provide whatever service is needed for some definite fixed fee for some definite period. Some dealers handle all their own service on the receivers they sell. Others "farm out" their service to service companies who specialize in the servicing of television receivers.

One might be tempted to think that such a diversity of methods of handling the selling and servicing of television receivers indicates a chaotic condition in the Industry. As a matter of fact, an honest observer is forced to admit that a certain amount of chaos does exist. An Industry that has grown so fast as has television will find such a condition almost inevitable until some degree of settling has taken place, and until some experience tables can be formulated on which to base a more permanent and consistent method of operation.

There has been considerable complaint from some customers concerning the kind of service they are getting under the "service policies" they bought at the time they bought their receivers. On the other hand, many of the service companies complain they are losing money on their "service policies" because far too many customers are extravagant in their use of the time of expensive service men, many of whom are called for the most trivial complaints -- or no real complaint at all. Modification of the terms of the so-called "service policies" are being made.

The "service policies" are written contracts which are often sold the customer by the dealer at the time the customer buys a television receiver. The terms of such policies differ widely, but in general they provide for the service and maintenance of a receiver for some stated period of time for a certain sum of money. The cost of such service policies range from the neighborhood of $25 a year to $100 a year, the amount depending upon the terms of the policy, and the length of its validity.

The preceding remarks scarcely fall within the realm of television operating techniques. Nevertheless, presumably you will soon be embarking upon a career in the television field. A short discussion of the general practices in the merchandising of television receivers is deemed to have considerable practical importance. This is particularly true when it is remembered that the exact type of antenna which is to be installed is often dictated by the policy of the selling organization, or the terms under which the customer has purchased the receiver.

While there can be no quarreling with the statement that the operation of a television receiver can be no better than the signal fed to it by the antenna, nevertheless the cost of a good antenna -- plus its installation -- constitutes a major item in the overall cost of the installed television receiver. Very often a choice must be made

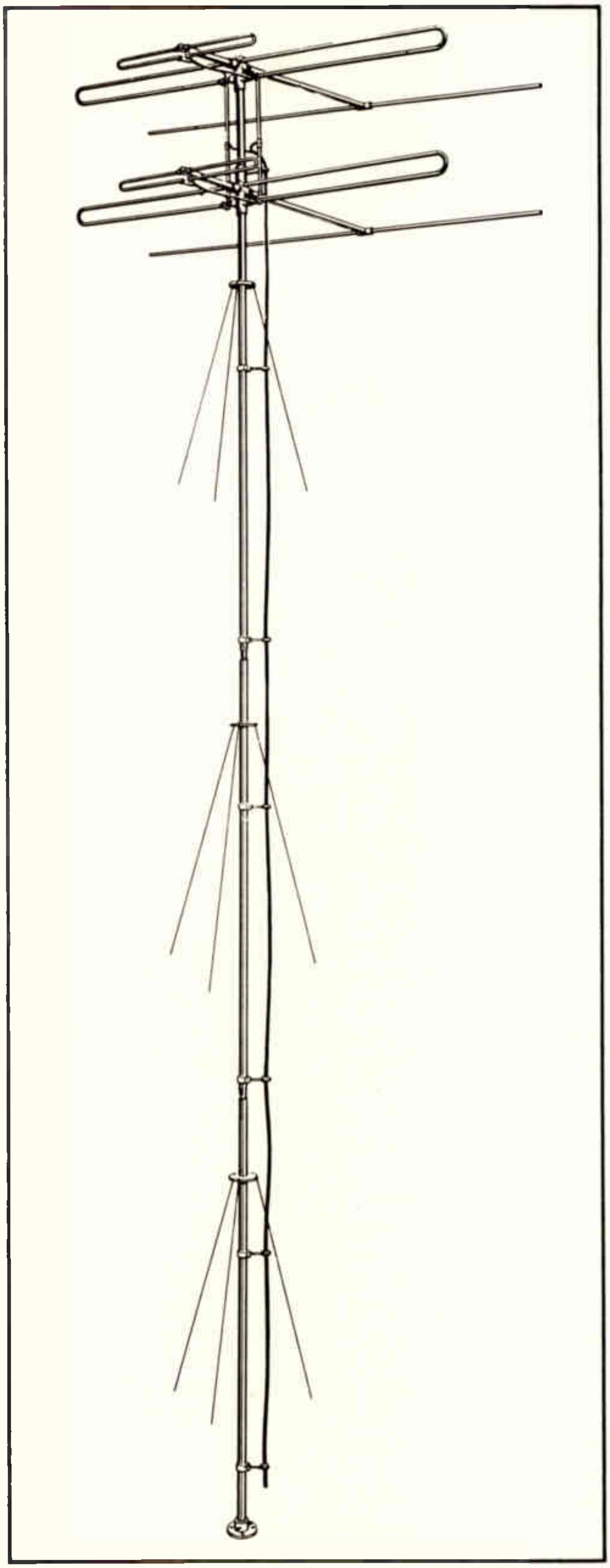

*Fig. 2. A Stacked Array of In-Line Antennas on Top an Antenna Mast. (Courtesy of American Phenolic Company.)**

* Now called Amphenol Electronics Corp.

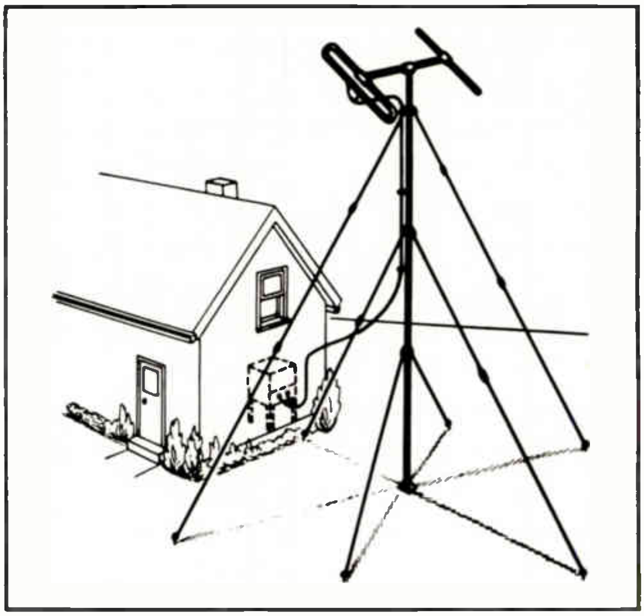

Fig.3. An Antenna Mast Anchored Directly to the Ground.

between the best type of antenna to use and the type which can be installed within the limitations of the cost allowed for it. It should be remembered that the final determination is frequently made, not by the technician, but by the customer or by one of the non-technical men within the selling organization.

Section 3. BASIC MATERIALS USED IN SUPPORTING THE ANTENNA

We will direct our efforts in this lesson toward the method of making the actual physical installation of the antenna, and how to connect the antenna to the receiver. In most cases the antenna will be on the roof of a building or on the top of a high tower. The receiver will usually be inside the home or other building. The two must be connected together by some kind of a "lead-in". These situations are indicated in Figs. 1 and 3. Fig. 2 shows a pair of "In-line" single-bay antennas stacked on the top of a high mast. The lead-in transmission line can be seen. It is held away from the metal mast by insulated screws.

A better view of the insulated screws is shown in Fig. 4. The end of the screw is formed into the shape of a loop. Within the loop is an insulated grommet. Sometimes the grommet is rubber, frequently it is some other type of dielectric insulating material.

The screw is often of a type that can be screwed directly into the wood on the side of a building or can be screwed into a hole in a piece of metal. The screw is often fastened to the supporting mast by specially prepared fittings such as those shown in Fig. 5. The metal band is slipped around the metal supporting post, then the screw is inserted in the threaded hole. Finally the screw is twisted, thus forcing itself into the holder. Often the metal band holder is so designed that screwing the long screw into the threaded hole operates much like the effect of a water hose clamp on an automobile. Tightening the screw tightens the band around the mast, and thus both are made rigid.

The masts themselves are manufactured in sections. The sections come in various lengths, but five feet is a very common length. The metal sections of the masts are made in many forms. Some are slightly tapered so the small end of one section will fit inside the larger end of another section. In this manner any number of sections can be connected, thus raising the antenna to whatever height is desired.

Sometimes the mast sections are made in the manner shown in Fig. 6. When so constructed it is possible to couple two sections of the mast together by fitting another section into the coupling fastened to the upper end of the mast section shown in Fig. 6. The two sections are then

Fig.4. Insulated Stand-Off Twin-Lead Line Supports. (Courtesy American Phenolic Co.)

Fig.5. Mast Clamps. (Courtesy American Phenolic Company.)

tightened together by means of screws that fit into the screw holes which are visible in Fig. 6, or by pins.

In making an actual installation it should be kept in mind that the antenna should be raised to whatever height is necessary in order to pick up a signal of sufficient strength to operate the receiver. If there are already a number of television receivers in the neighborhood where you plan to install a new receiver you can often determine the height to raise your antenna by observing the heights of the neighboring antennas. If there are a number of other antennas in the neighborhood and they are all raised to a fairly uniform height, you will be reasonably safe in assuming that is the proper height to which yours should be raised.

Of course, if your installation is for a customer who wants the ultimate in satisfactory performance and is willing to pay for it, you would be justified in making extensive field strength tests. You would also be justified in raising the new antenna to greater heights than those of the neighboring antennas. But you should always keep in mind the expense which is attached to increasing the height of an outdoor antenna. Unless it is carefully discussed beforehand, you will not usually be justified in running up extra expenses unless such extra tests are clearly requested by the customer who must pay the bill.

Sometimes the base of the antenna mast is fastened directly to the ground as shown in Fig. 3. In some respects such an installation has certain advantages, especially when raising an antenna to a great height. For one thing you will be working on the ground where you can obtain secure footing while you work; you will not be having to keep one eye open for the precarious positions where you must place your feet while working, such as is often the case when you are working on the rooftop. Furthermore, it is often easier to raise an antenna mast directly from the ground than it is to raise it to a vertical position when working on top of a roof. This is the reason many installation men who work in the fringe areas prefer to raise high masts directly from the ground than to place them on the rooftop. The weight of the very high mast can place a considerable strain on the roof. This must also be considered.

On the other hand, raising an antenna mast from the highest point on a rooftop makes it possible to use a much shorter length of mast than when the antenna is raised all the way from the ground. If the highest point on the roof is 25 to 30 feet from the ground, or even 35 to 40 feet as is true of some houses, it means that you will need from 25 to 40 feet less mast for your installation.

To take a practical example. Suppose you have determined that an antenna should be

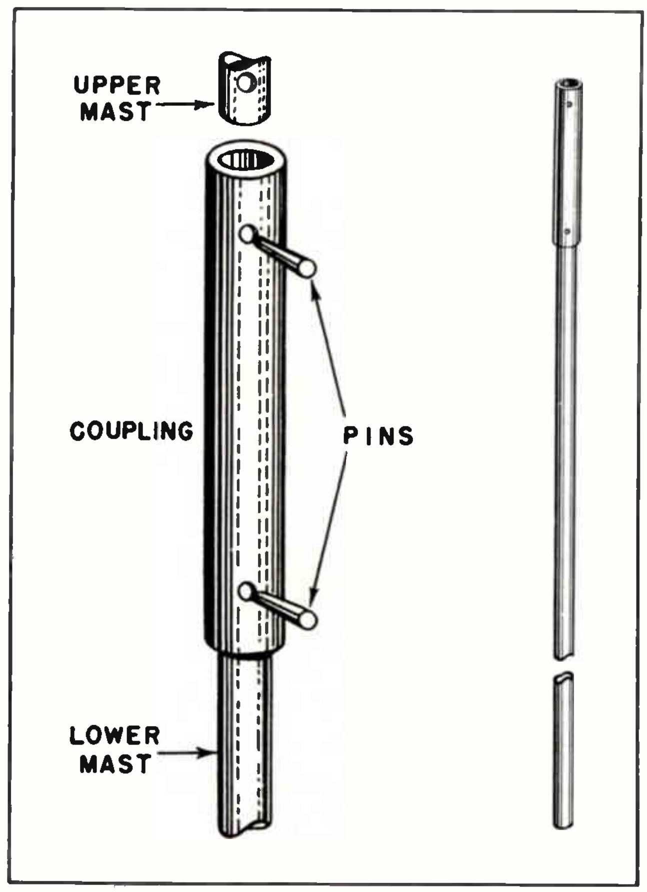

Fig.6. Section of Antenna Mast. (Courtesy American Phenolic Company.)

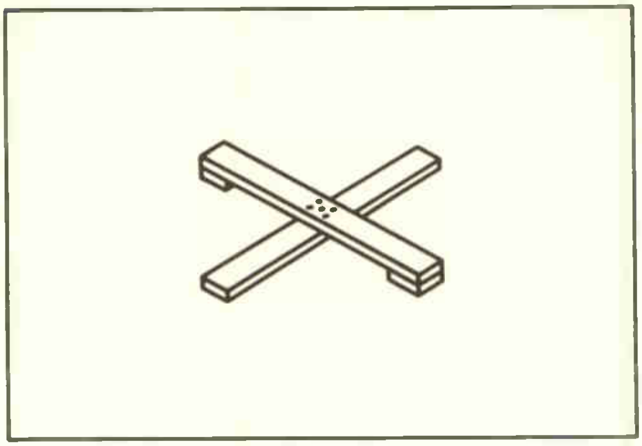

Fig. 7.

raised 70 feet above the ground. And suppose further that the house where you intend to install the receiver is 40 feet high at the highest point on its roof. You then have the choice of using a mast 70 feet high anchored on the ground or a mast 30 feet high anchored on the highest point on the roof. If the roof is one of the steep, peaked kind you might experience considerable difficulty in raising a 30-foot mast from the top of the roof. In that case it might be wiser to place a 70-foot mast directly on the ground. The cost of the 70-foot mast would be somewhat greater than the shorter one, but the longer one might be raised more quickly. The difference in the time needed for the installation might make the cost of the longer mast even less than the cost of the shorter one on the roof.

On the other hand, if the roof has a flat top it will usually be better to use the shorter mast and anchor it on the top of the roof.

Many things enter into the matter of determining just where the base of the antenna mast should be anchored. It is very difficult to give any general rule. The individual characteristics of each installation should govern.

Section 4. ANCHORING THE ANTENNA MAST TO THE ROOF

The method of anchoring the base of an antenna to the rooftop is a matter that should be given much consideration. The method of anchoring should insure that the mast is securely anchored. Care should be taken to avoid damage to the roof. Where the roof is flat, one good method is to construct a "cross" of two pieces of lumber. They should be crossed in much the same manner one would build a stand for a Xmas tree. The method of construction is suggested in Fig. 7. The length of each piece of lumber is determined by the height of the antenna, but they should never be less than six feet long in each direction. The wooden base can be constructed of ordinary 1 x 4 common lumber, but a more substantial foundation will result from the use of 2 x 4 lumber.

When such a base is used, guy wires should extend from the end of each piece of lumber to a location on the mast about twice as high as the end of the lumber is from the base of the mast. This means that if the end of the lumber extends three feet in each direction from the base of the mast, the guy wires from the ends of the lumber should be fastened to the steel mast six feet above the base.

If the wooden base is firmly anchored to the rooftop and the mast is not very high, it may be that the guy wires just mentioned will be sufficient to properly anchor the mast and the antenna. But it is a safer practice to use additional guy wires. The extra wires need not be more than three for any given height rather than four as mentioned in the previous paragraph. These extra guy wires should be anchored somewhat higher on the metal mast than the first mentioned ones. They should extend outward from the mast in directions 120° apart.

All three guy wires should be firmly anchored to the roof, the parapet surrounding the roof, or some other solid object. They

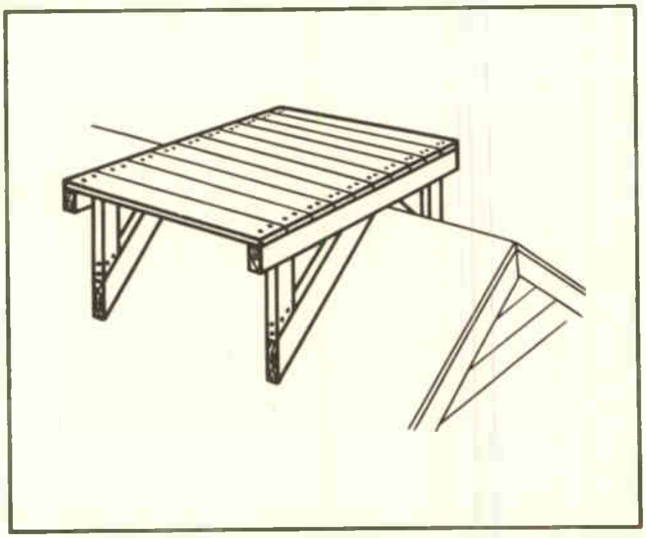

Fig. 8. A Rooftop Platform for Peaked Roofs.

should not be fastened to the wooden cross members which supports the mast.

If the mast extends to a great height, still more guy wires should be used. There should be a separate set of guy wires for each ten feet of height of the mast.

Where the building has a peaked roof a different method must be used to anchor the base of the mast. There are special metal anchors on the market which fit directly over the peak of the roof and provide a solid support for the mast. Care must be taken when using such anchors to make certain they are actually securely anchored to the roof. They should be so located that they can be fastened directly to one or more of the rafters, and not merely to the roof sheathing. Another type of anchor is shown in Fig. 16.

In some ways it is better to construct a wooden platform on which to place the base of the mast. If the mast is quite high it is somewhat easier to raise the mast if a platform sufficiently large is constructed for the base. Such a platform will also serve to distribute the weight of the mast and the stresses from the wind somewhat better than the smaller metal anchor. The general method of constructing such a platform is shown in Fig. 8.

The platform shown in Fig. 8 has the advantage of simplicity of construction and general sturdiness. It must be so located on the roof, however, that the bracing under the platform will rest directly on the rafters. Otherwise there is some danger of weakening the roof. A somewhat better method of constructing the supports under the platform is that shown in Fig. 9. The principal difference between the two is that in Fig. 9 there is a transverse support running crossways of the rafters. Such support will rest on three or more of the rafters, and this will tend to distribute the weight and the strain of the platform and the antenna mast.

Regardless of which method of constructing and supporting the platform is used, you should use great care to see that no leaks are made in the roof. Some good grade of roof patching compound such as the pitch-asbestos compounds now on the markets should be used all around the pieces of lumber that rest directly on the roof. Such compound will seal any leaks that might have been created in the roof.

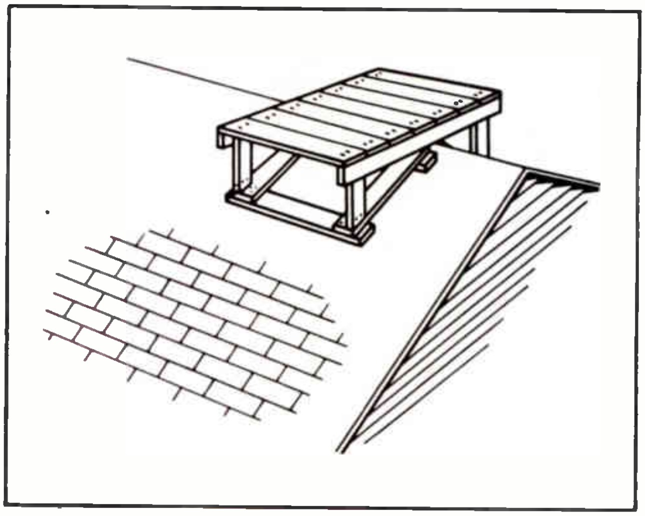

Fig. 9.

Section 5. PORTABLE INSTALLATION PLATFORMS

While the platforms which have just been described are favored by many television men and by many home owners, you find that some home owners and landlords will object to their erection on the roof of a house. Unless very carefully constructed they can present an unsightly appearance, and this appearance is very objectionable to some people. Before attempting to erect such a platform you should make very certain it is not objectionable to the owner of the property.

The use of the platform has the very definite advantage of providing a firm support for a very high mast. It also makes possible the erection of a high rooftop mast, something that is difficult without the use of a platform. Where the ground area around the building is somewhat restricted, it is sometimes better to use the platform than to place the base of the mast on the ground.

Some television installation men build themselves a portable platform for use on top of peaked roofs. The portable platform is constructed very much as the one shown in Fig. 9. One difference is that the platform is built of lighter materials and generally uses adjustable supports so it can be adjusted to fit the top of any roof. The use of such a portable platform provides the workman with a place on which to stand during the erection of high roof-mounted antenna masts.

By using the portable platforms it is possible to raise very high antenna masts

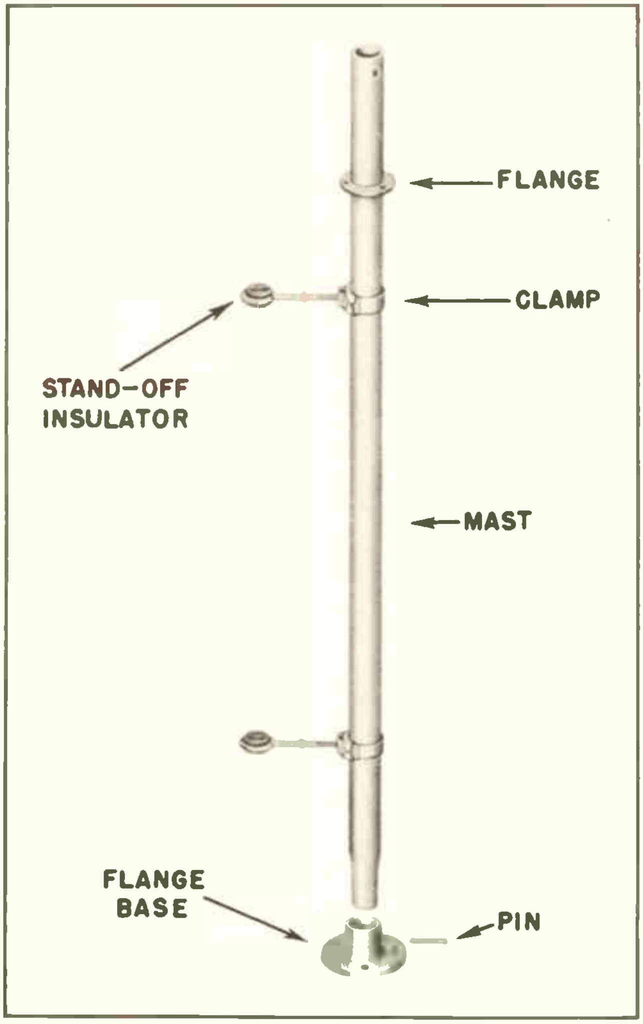

Fig.10. An Antenna Mast with Base and Stand-Off Line Holders. (Courtesy American Phenolic Company.)

on top of high roofs. Usually the base of the mast is then anchored to one of the metal anchors made by several manufacturers.

Section 6. ANTENNA MAST BASES

There are a number of types of mast bases manufactured by various companies. But the one shown in Fig. 10 is typical of the kind in general use. Such a base can be fastened directly on top of a wooden platform such as the one described in a previous section of this lesson. It can also be fastened to one of the commercially built anchors we have mentioned.

The base itself is fastened directly to the platform or the anchor. Then the mast is raised until the bottom end of the mast will fit into the recess on top of the base. The bottom of the base is then fastened to the base by means of a pin which is inserted into a hole through the base and through the end of the mast.

Fig. 10 also shows how the supports for the lead-in transmission line is held away from the metal of the mast by means of the insulated screws, and further shows how the screws are fastened into the clamps which fit around the mast. These screws and clamps were described in an earlier section in this lesson.

Section 7. SAFETY PRECAUTIONS AND INSURANCE

The installation of television antennas definitely falls into what is generally termed a hazardous occupation. If you intend to engage in the work of installing antennas, or if you open your own shop and hire someone else to install your antennas for you, you should understand some of the liabilities which can attach to such work.

Most states have what are called Workmen's Compensation Laws. If you hire others to erect your antennas for you it will be to your interest to see that you are protected against disastrous claims for liability resulting from accidents. Climbing around over roofs is quite dangerous, and if one of your employees falls and injures himself while working for you, you can be held liable for his injuries. Before hiring anybody to do that kind of work for you, make certain that you are properly protected by insurance.

There is another type of liability against which you should also protect yourself. That is the damage that might result from one of your antennas falling and injuring someone, or damaging property. Unless you do all your work yourself it is going to be difficult for you to be absolutely certain all the antennas and antenna masts you have erected are perfectly safe. Should one of them fall and cause damage or injury to anyone you may find yourself with a lawsuit on your hands, and possibly a judgment for heavy damages. You will be very wise to protect yourself against such claims by carrying adequate insurance.

Under the laws of most states the owner of a building on which an antenna is being erected will be held responsible if a workman falls and injures himself while working on it. To protect themselves many property owners will demand a signed release before permitting such work to be done. Whenever such demand is made on you it is to your interest to sign the release. You should then protect yourself by carrying proper insurance.

Should you fail to sign such release, you will soon find yourself without any work. After all, it is not properly the responsibility of the property owner to assume liability for your workmen. That is your responsibility. This is true even though the law may technically make such property owner liable unless he has been given a release. Many companies write insurance to cover just such contingencies, and such insurance is not very expensive. Furthermore, it is a part of the expense of doing business.

While it is true that the installation of television antennas can, and should, be classified under the general heading of hazardous occupations it is also true that reasonable precaution can reduce those hazards to a point where little or no danger is involved. The following rules should always be observed.

1. Always wear a safety rope when working on steep roofs.

2. Always keep one hand free when carrying an antenna up a ladder.

3. Keep one hand free when carrying tools up and down a ladder.

4. Firmly anchor your ladder before using it. Make certain it will not slip. If the bottom is resting on a concrete walk the bottom of the ladder should rest on non-slip rubber pads.

5. Be very careful when using magnesium ladders or other types of metal ladders. Such types of ladders are less heavy than wooden ones, and are often preferred by television men. But touching the end of one of those metal ladders to a high voltage power line can give you a shock sufficiently violent as to kill you, Many men have been killed by just such accidents.

6. You should always wear rubber-soled shoes when installing antennas. They will protect you against the hazards of accidental electric shock and will provide you with better footing when climbing around on steep roofs.

7. Do not stand on the edge of a roof when elevating the antenna. If it is absolutely necessary to work near the edge of the roof tie a safety rope around your waist and anchor the end to a secure fastening.

In all cases observe the rule of safety first. And do not allow familiarity with your work to breed within you a contempt for the danger. Your first accident may well be your last one.

Section 8. ANTENNA INSTALLATION EQUIPMENT

It is hard to suggest just what you should have in the way of supplies and equipment if you are to go definitely into the business of installing television antennas. If you intend to go into that business, however, we believe we are safe in saying that you should go into it whole-heartedly or not at all. We do not believe anyone should consider going into the business of erecting antenna masts on a part-time basis.

To go about the job of properly and safely installing and erecting television antennas and television masts one should have the proper kind of equipment. This is especially true if the antennas and their masts must be raised to considerable height. The antennas and their masts are fairly bulky and not easily carried in an automobile. A regular panel truck should be specially equipped and used for the job of installing antennas.

This being true, it follows that due to the nature of the equipment necessary to do the job properly one should go into that end of the business on a full-time basis or not go into it at all. A person can do a good job of servicing television receivers in one's own shop without going into the business of installing antennas. By this we mean that it is possible to operate a repair and service shop by one's self, but turn over the antenna business to some other firm. These kinds of arrangements are quite common in the television service business. You will find some firms who specialize in antenna installations while others specialize in servicing the receivers alone. Of course, there are other firms, lots of them, who handle both kinds of work.

But to get back to the equipment one should have to properly install antennas. A mobile vehicle is necessary to carry the antennas, masts, ladders and other equipment

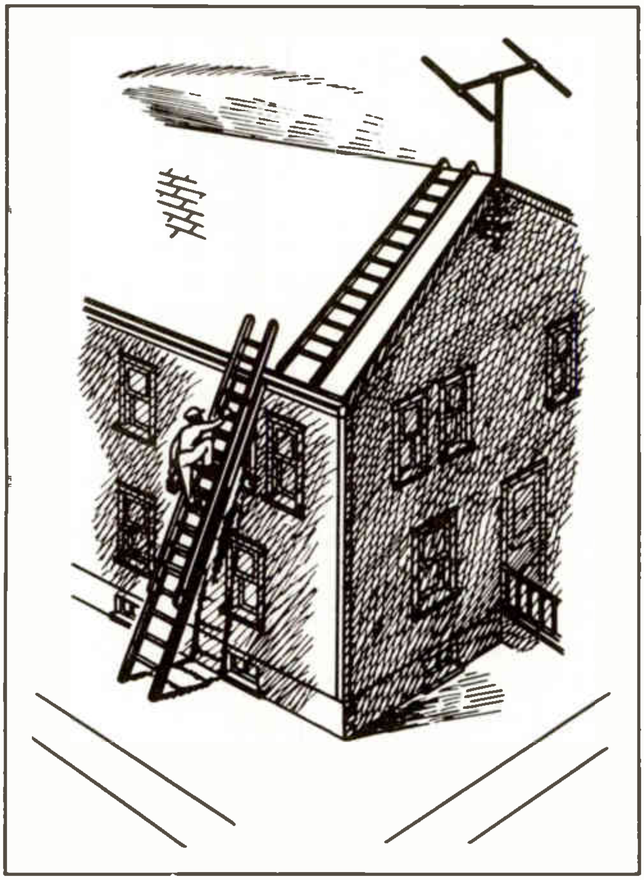

Fig.11. Types of Ladders Needed for Antenna Installation Work.

to the site of the job. While some servicemen solve this problem by equipping their private automobiles with carrying racks of various kinds, a panel truck is much better. We recommend a panel truck even though you must use a second-hand one.

Several kinds of ladders should be carried as a regular part of the installation equipment. Fig. 11 indicates that a minimum of a two-piece extension ladder and one "hook" ladder should be available for each job. The two-piece extension ladder should be long enough to reach to the eaves of a two-story house. Since the eaves of many two-story houses which have a high basement are 30 to 35 feet above the ground, the extension ladder should be able to reach at least that far. A 40-foot extension ladder will probably prove its worth before you have owned it very long, although it might be a little unwieldy when used on some of the single story homes.

The "hook" ladder can be one which you fit up for your own needs or have made-to-order, or it can be of a type which can be purchased on the open market. It should be so constructed that it will fasten over the peak of the roof, and thus provide a means of climbing from the top of your extension ladder to the peak of the roof. The hook ladder should be neither long nor heavy. If it is too long it will be awkward to handle when you are standing at the upper end of the extension ladder. The weight of the "hook" ladder is of great importance. It must be raised through the air and hooked over the peak of the roof at a time when your footing is none too secure. This is one place where the magnesium ladders are useful. The danger of touching a "hot" power line is not very great. Even though you did happen to accidentally touch a "hot" wire, the fact that you are standing on a wooden ladder will save you from injury. The magnesium ladders are strong, but very light.

In addition to the provisions for carrying the ladders on your truck you should also have racks on which to carry the sections of the mast. Some jobs require quite a few sections, and since it is conceivable that you may erect two or three antennas during the course of a single working day you should carry enough sections of mast to erect them all. This means that you should be able to carry thirty or more sections of mast at one time.

You must also have some provision for carrying the antennas themselves. It so happens that most antenna manufacturers pack their antennas "knocked down". They are packed in long cardboard boxes. Not all antennas are the same length, but on the whole the lower frequency antennas will range around eight feet long. This means that the boxes in which the antennas are packed will seldom be less than eight feet long, and some of them are even longer. This makes it a little difficult if one tries to carry two or more antennas in one's car. This is another argument in favor of using a panel truck.

The other tools needed for antenna installation work are somewhat less bulky, but it is wise to make provisions for carrying them. If you have a panel truck you can build compartments inside the truck for carrying them. We are listing, in a table at the end of this lesson, some of the more important tools which you should always carry with you on an installation job. At first glance some of them may not seem entirely necessary, but experience will soon show you that "it is better to have them and not need them than to need them and not have them".

It is seldom wise for one man to attempt to install an antenna by himself. Most television antenna installation crews consist of 2 or three men. A 2- or 3-man crew is more economical than one man working alone. Two men can do considerably more than twice as much work as one man alone, and three men can do considerably more than three times the work of a single man. There are some installations where it is almost impossible for one man working alone to properly install the job. There is the added factor of safety. In addition to all these things there is the matter of aligning up the receiver itself, and matching it to the antenna. Two men can do a job there that is almost impossible for one man alone.

Unfortunately, it is not always possible to pick out the most suitable spot on the roof of a building and then just arbitrarily locate the antenna on that spot. The antenna should be so located that it will pick up the desired signals at their greatest strengths, and to reject all unwanted "ghost" images. The signals which pass through the air do not have the same strength at all places. The radiated signals frequently act very much like standing waves on a transmission line. An antenna may be unable to pick up a signal at all at one location, yet will bring it in at maximum strength only a few feet, or even a few inches, away.

When an antenna is being installed this situation must be kept in mind. The antenna must be tried at several locations to see what location will bring in the strongest signal. The best way to do this is to use some mode of two-way communication between the man on the roof and the man adjusting the receiver. The two-way "sound-powered" telephones developed by the Army Signal Corps have become quite popular with television installation men. Such telephones do not require any batteries, thus they are relatively light. Furthermore, they are quite rugged and for that reason do not often get out of working order. The way these telephones are used is shown in Fig. 12.

The method of locating the proper place for the antenna follows a fairly general pattern. The television receiver is turned on. The various controls are adjusted for what appears to be the best operation. A length of transmission line is used to connect the receiver with a test antenna on the roof. The test antenna can be the actual antenna which is to be used or it can be some special type used only for the purpose of testing.

Once the receiver seems to be working properly the technician tunes in one of the broadcast stations. Then he tells the man on the roof to move the antenna around until the picture comes in with maximum strength. When that spot has been located the man at the receiver tells the man on the roof to mark that location.

The unitiated might easily jump to the conclusion that once the "hottest" spot has been located the problem of locating the antenna had been solved. But that is not necessarily true. Remember, in many parts of the country there is more than one station. The antenna should be so located that it will bring in all stations with acceptable signal strength.

After a "hot" spot has been located for one station the technician at the receiver next tunes in another station. The location of the original hot spot is tested for the second station. If that spot also brings

Fig.12. Two-Way Sound-Powered Telephones are useful in Antenna Installation Work.

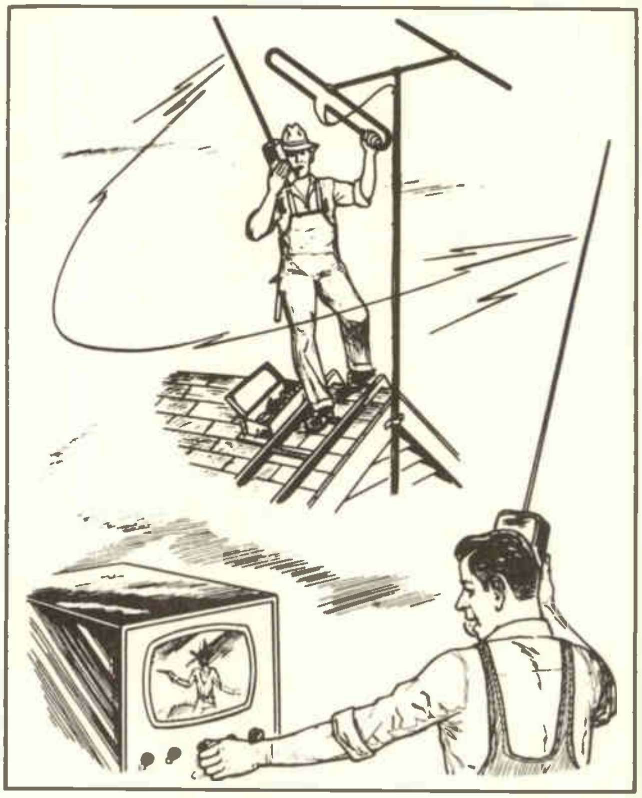

Fig.13. Handy-Talkies can Also be Used for Two-Way Communication between the Roof and the Receiver.

in the second broadcast everything is well and good, but if not, some other spot must be found which will bring in the second station with acceptable strength.

After a spot has been located which will bring in the first two stations the technician at the receiver will tune in a third station. Again the procedure of seeking a "hot" spot is gone through. And so it goes until a spot is located which will bring in all the stations with acceptable strength.

All this sounds rather complicated, and one might think that finding the right location for a television antenna is a tedious problem. Sometimes it is. But more often, fortunately, a spot can be found without much difficulty. The important thing, however, is that such a spot must be found. The locating of the antenna cannot be left to guesswork; the antenna must be located where it will pick up an acceptable signal from all the desired stations.

Usually it is necessary to make some compromises in finding the proper location. Frequently it is impossible to find a location where all signals will come in with maximum strength. But so long as the signal is acceptable it is not absolutely essential that it be maximum.

In finding the location that will receive an acceptable signal from all stations it is sometimes found that it is impossible to pick up an acceptable primary signal from one or more stations. In that case it is sometimes necessary to seek out a reflected signal and aim one of the parts of the antenna toward the reflection. This is one of the advantages of the "piggy back" type of antennas. The low-frequency portion of the antenna can be pointed in one direction and the high-frequency portion pointed in another direction.

We are often reminded of the experience of an antenna installation man who was called upon to install the antenna for a television receiver located in the basement of a 40-story skyscraper in the heart of the Chicago Loop. The receiver was turned on and placed in operating condition, a co-axial line was run down one of the elevator shafts and then the men went about the business of trying to find a good spot on the roof for the antenna.

At first glance one would think that their job was little more than a "snap". The transmitting antenna of station WBKB was so close they could almost hit it with a thrown stone. WGN-TV was only a little farther away, and the other stations were close. They soon found their job was by no means as simple as they had anticipated. If they placed their antenna where it would pick up one station they would be unable to pick up one of the others or they would pick up such a strong ghost it ruined the picture. After spending an entire day on that one job, and rigging up several special adjustments to eliminate one ghost or another, they finally found one spot which provided acceptable signals from all stations.

While these things can happen, we want to emphasize that they are uncommon rather than the general rule. We might mention that these men chose to use co-axial line to transmit the signal from the antenna to the receiver because of the high noise level in that vicinity. Where the noise level is high, especially in the vicinity of elevators, hair clippers, food mixers, electric razors, and certain other types of electrical equipment, it may be found that a co-axial line must be used in order to bring in an acceptable signal. An unshielded line will pick up so much "noise" that the picture may well be ruined.

Section 9. HANDY-TALKIES

While many installation men prefer to use the sound-powered telephones we mentioned earlier, some men prefer other methods of communication. In the summer time when the windows can be opened it is often convenient for the man inside the house to merely stick his head out the window and call instructions to the man on the roof. This dispenses entirely with all systems of electrical communications.

The "handy-talkie" radio transceivers developed by the Army Signal Corps during the second World War have also been put to use by antenna installers. The handy-talkie is somewhat more heavy than the sound-powered telephone but it has the advantage of having no dragging wires to become entangled. Often it is much more convenient for the man on the roof than the telephone set. The use of the handy-talkie is illustrated in Fig. 13.

The handy-talkie has another advantage over the telephone system. If the distance between the antenna and the receiver is greater than a couple of hundred feet the wire needed to connect the two sets becomes definitely unwieldy. The handy-talkie can cover considerably greater distances without difficulty.

Section 10. ANCHORING THE ANTENNA TO CHIMNEYS

In those areas where the receiving antenna is located not more than ten or fifteen miles from the transmitter many of the receiving antennas are being anchored to the chimney of the home. Despite the fact that many such installations are being made, its desirability is somewhat debatable. The strain on the chimney when heavy winds blow against the antenna has caused damage to many chimneys. It can be argued that if the chimney was properly constructed it should be strong enough to withstand the strain. And such is probably true. But the fact remains that many chimneys have been seriously damaged by the strain imposed upon them by the whipping of a television antenna in heavy winds.

However, if the owner of the property has no objection to the use of his chimney as a support for his television antenna it is doubtful if the installation man should worry too much about it.

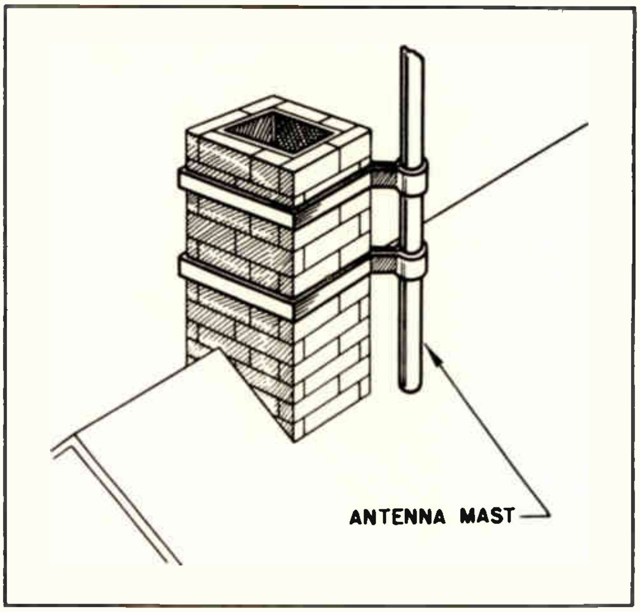

Fig. 14. One Method of Anchoring the Antenna Mast to the Chimney.

Usually the antenna mast is fastened to the chimney by means of two steep straps as shown in Fig. 14. The straps are fastened rigidly to the chimney and hold the mast rigidly in position.

When there is no "lip" or coping on the top of the chimney the installation shown in Fig. 14 is entirely satisfactory. If there is a overhanging lip on the top of the chimney a special type of strap must be used. The special type holds the mast a somewhat greater distance from the chimney than is shown in Fig. 14.

Some installations which are fastened to the chimney depend solely on the chimney for support. A much better practice is to guy the mast to the roof of the house so as to provide additional support. The use of guy wires takes a major portion of the strain off the chimney when high winds strike the antenna.

Section 11, GUY WIRES AND THEIR ACCESSORIES

Any antenna which is mounted on a mast which is over ten feet high should be guyed. It is good practice to guy those installations where the mast is less than ten feet high.

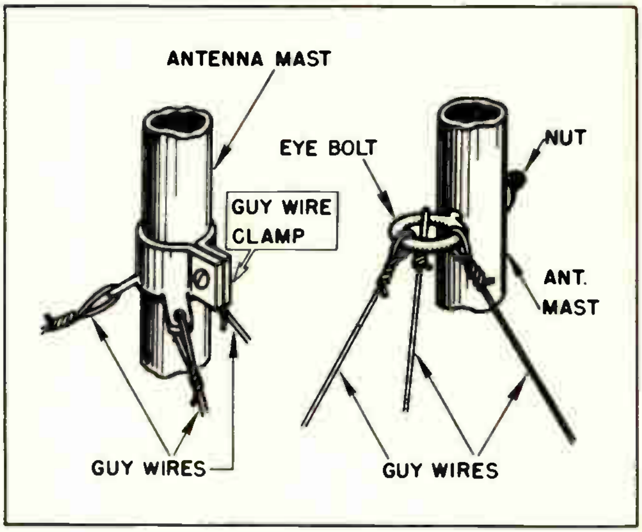

Fig.15. Methods of Anchoring the Guy Wires to the Mast.

The size of the wire used for guying a mast depends somewhat on the height of the mast and the type and weight of the antenna. The length of the guy wire itself should also be taken into consideration.

No. 10 aluminum wire is quite commonly used as guy wire. It can be purchased almost everywhere since it is commonly used for clothes-line. Nearly all hardware and notion stores carry it. The ability to bend aluminum wire easily and its lack of any tendency to kink readily contribute to its popularity as a guy wire. It does not corrode easily, and does not rust.

Stranded steel wire can be used, but it should be galvanized. Solid steel wire should not be used. Solid steel wire has a tendency to weaken and break if it is bent. Copper wire does not have sufficient strength for use as a guy wire; it is easily damaged, and when damaged has a tendency to break.

Care must be taken in connecting the guy wire to the mast, especially the ones which are connected near the antenna itself. Particular care must be taken to see that the guy wires do not act as reflectors of television signals. If the guy wire must be connected to the mast nearer than 7 or 8 feet to the antenna, the guy wire should be cut and an insulator inserted between the two sections of the guy. The guy should be broken about 3 or 4 feet from its connection to the mast. As a matter of fact, if the guy is connected closer than 9 feet to the antenna this precaution should be taken. The 9 foot limit is used because that is slightly longer than one half-wave length of the lowest television channel frequency. Those parts of the guy wires which are greater than one half-wave length from the antenna will have little effect on the antenna insofar as ghost signals are concerned.

There are a number of methods which can be used to fasten the guy wires to the antenna. Two methods are shown in Fig. 15.

The other end of the guy wire must be firmly anchored. The exact method to be used will depend upon the medium to which the guy is anchored. If it can be anchored to a wooden portion of a house, ordinary screw eyes can be used. Such a screw eye is shown in Fig. 16. If the guy must be fastened to brick or other masonry surface it will be necessary to drill a small hole and insert some kind of expansion bolt or expansion fastener. An expansion anchor similar to the kind made by Ackerman-Johnson is ideal for that purpose. A screw eye can be screwed directly into such expansion anchor.

An insulator which is used to divide the guy wire into sections is also shown in Fig. 16. The illustration also shows how the strain insulators are placed in the guy wire.

The guy wires must be tight. A loose or slack guy wire can be almost as bad as none at all. It will be found almost impossible to fasten the guy wires as tight as they should be. Therefore it is always advisable

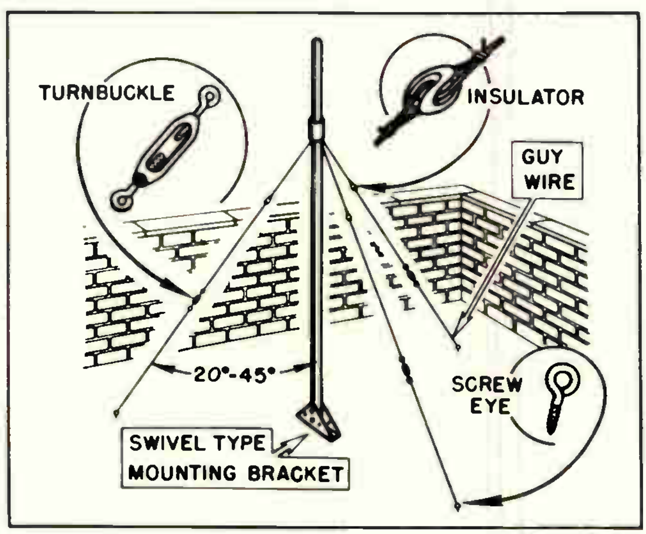

Fig.16. The Eye-Screws, Turn-Buckles and Guy Wires used to Anchor an Antenna Mast.

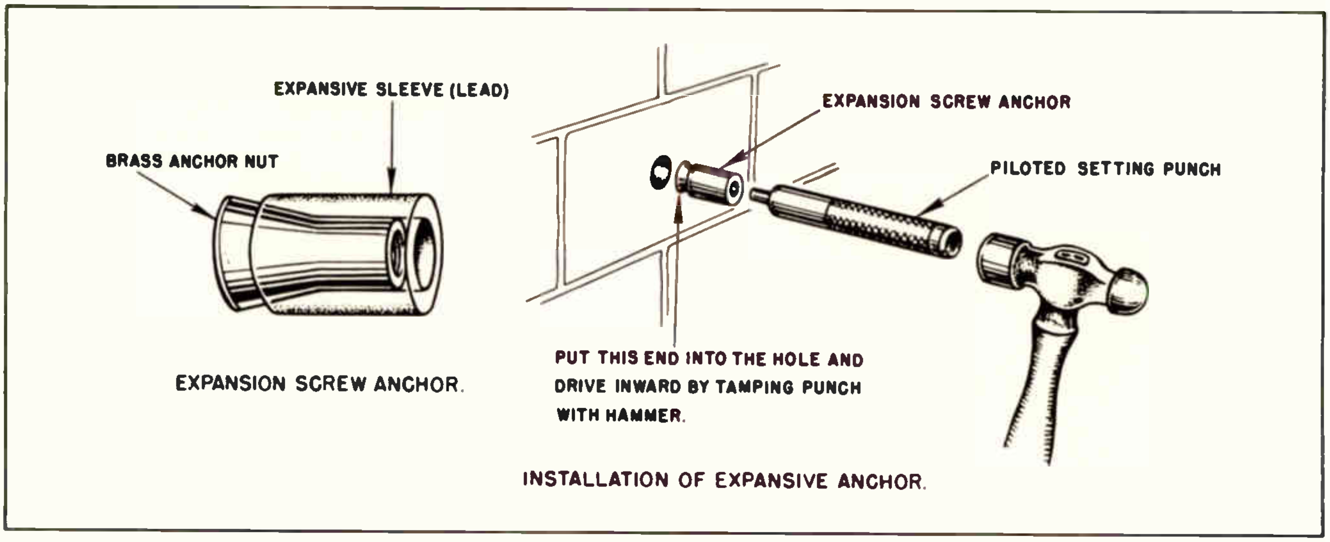

Fig. 17. An Ackerman-Johnson Expansion Anchor and its Installation.

to insert a turn-buckle into the guy wire during the installation. The turn-buckles are not expensive and are readily available. After the guys have all been anchored in their proper places the turn-buckles can be tightened and the installation made secure. If the mast is not standing exactly straight it can usually be straightened by adjusting the tension on the turn-buckles. The use of the turn-buckles is also shown in Fig. 16.

The method of using an Ackerman-Johnson expansion anchor is shown in Fig. 17. First a hole is drilled in the brick or other masonry. Then the anchor with its surrounding lead shield is inserted into the drill hole. Next the lead of the shield is tapped into place with a hammer and a special punch. This anchors it firmly in place. The final step is to screw the eye-screw or other type of screw into the leaded anchor. Such an installation will withstand extreme pulls without coming out.

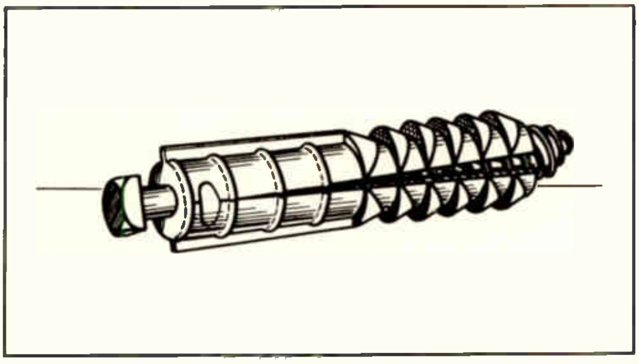

Fig. 18. An Expansion Shield often used with Wood Screws and Lag Screws.

A somewhat similar, yet slightly different type of lead anchor is shown in Fig. 18. The one shown there uses a lag bolt or screw. But the smaller anchors will accept eye-screws and ordinary wood screws.

The holes can be drilled with an ordinary star drill and hammer. But that is rather slow and is a lot of work. If you are going into this business of installing antennas as a regular part of your work, you will be well advised to buy a 1/4-inch electric drill and some small masonry drills. These masonry drills are specially constructed drills which are tipped with carborundum or with special tungsten steel. They bite through brick and other masonry almost as fast as other drills bore through steel. They can be bought at most hardware stores and other places which specialize in equipment for electricians and television men. They can also be purchased by mail order from Montgomery Ward and Sears, Roebuck & Company.

Section 12. LIGHTNING ARRESTERS

Before leaving the outdoors part of the antenna installation we must take a few moments to talk of lightning and the methods used to protect television installations from its effects. The danger from lightning must always be considered when installing a television antenna. You must remember that the antenna is the highest thing around a building, and frequently the highest thing in the neighborhood. Since it extends so far from the earth toward the sky it is especially susceptible to being struck by lightning.

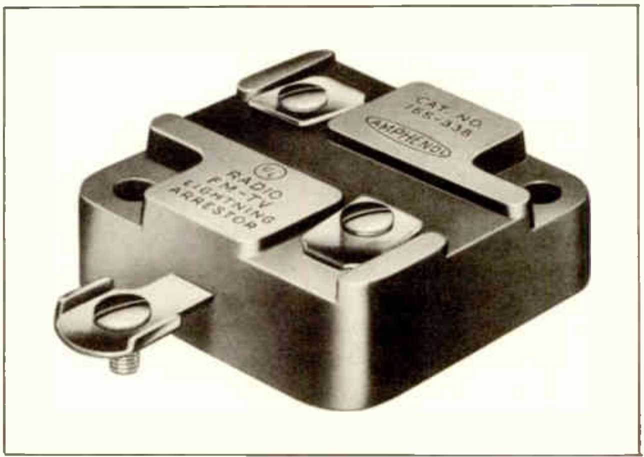

Fig. 19. A Lightning Arrester for Use with Twin-Lead Line. (Courtesy American Phenolic Company.)

As was mentioned in an earlier lesson, lightning represents a vast accumulation of electrons or a great deficiency of them. In either case there is a strong electrical field set up between the clouds and the Earth. When the strain becomes too great the terrific voltage which is built up will break down the dielectric of the air and a discharge will take place between the clouds and the Earth.

The Earth and the clouds can be regarded as the two plates of a huge capacitor. When the voltage between the two plates of any capacitor becomes too great for the dielectric to withstand, the dielectric will break down, the voltage will puncture the dielectric, and a discharge will take place between the two plates of the capacitor.

The same thing takes place in nature. When the discharge takes place between the clouds and the Earth, the discharge will take place at the point where the dielectric strength is the weakest. This point is usually something which extends from the earth toward the sky: A tall tree, the chimney of a house, a tall building, or something else of a similar nature.

Since the antenna installation for a television receiver is deliberately raised to a considerable height above the earth it is a natural target for lightning. For this reason, provisions must be made for protecting the receiver, and the house itself, from the effects of lightning.

Whenever a metal mast is used, and this is now the general practice, the mast should be connected directly to the earth by a grounding cable of some kind. The mast can be connected by means of a heavy grounding cable to a water pipe which leads directly into the ground. Or a metal pipe or rod can be driven into the ground and the cable connected to it.

When the television antenna mast is grounded in this manner the antenna installation actually acts as a protection against lightning rather than as a hazard. The high antenna will tend to "bleed" the electrons from that vicinity, and thus prevent the build-up of an electrical stress which would eventually erupt as a stroke of lightning.

If the antenna mast is not grounded, however, it can create a definite hazard for the home owner. Instead of bleeding off the accumulating electrons and thus lessening the chances of a stroke of lightning in that vicinity, the ungrounded antenna provides a path of somewhat lower resistance for a short distance. This is the metal part of the mast. But between the lower end of the mast and ground is the framework of the home. When the heavy electrical charge strikes the framework of the home it can cause great damage, and possibly injury or death to the occupants of the home.

Special bonding clamps can be obtained in any electrical supply house and in most television supply houses. These clamps can be used to bond the metal mast to the grounding rod.

It is unfortunate that many television installation men do not realize the importance of properly grounding their antenna masts. Their very ignorance has caused a number of cities to pass ordinances which require all television antennas to be grounded.

It is also wise to protect the lead-in wires against lightning. There are a number of lightning arresters on the market. One type made by Amphenol is typical of most. It is designed to fit over a 300-ohm lead-in wire and then clamp tight. A third connection for the grounding wire is provided on the side. An illustration of the arrester is shown in Fig. 19. The 300-ohm line fits into the top of the arrester. The ground wire connects to the side.

The grounding wire is not electrically connected to the lead-in wires in most such arresters. There is a very small gap between the conductors and the ground wire.

The voltage created by the television signal is not great enough to leap the gap. But the surge of voltage caused by lightning can easily bridge the narrow gap. The principle is the same as that used by the telephone companies to protect their customers against any lightning which might strike their lines.

It should be mentioned that a direct strike of lightning is not always necessary in order to cause damage. A heavy strike of lightning nearby may pass tens of thousands of amperes of current. The passage of such a terrific current is capable of inducing some relatively high voltages in the antenna installation. This voltage must be quickly dissipated to ground to prevent damage to the receiver or to the home.

Section 13. INSTALLING THE TRANSMISSION LINE

The physical acts needed to install a transmission line to bring in the signal from the antenna to the receiver should be studied carefully. Considerable thought should be given them so the line will be physically secure, electrically undisturbed, and esthetically unobtrusive.

The line should be kept clear of metal objects, particularly of iron or steel. When a line passes very close to a piece of iron the presence of the iron will change the inductance of the line. Changing the inductance results in a change in the characteristic impedance of the line at that point. Changing the characteristic impedance causes reflections in the line, and these reflections create standing waves.

If the standing waves have sufficient magnitude they can create troublesome ghosts on the screen of the picture tube.

Between the point where the transmission line is coupled to the antenna and the base of the mast the line normally follows along the mast. It should be held as far from the mast as possible. Stand-off insulators, such as those shown in Figs. 4 and 10, should be used to hold the line away from the metal of the mast. This is particularly true if the line is the common 300-ohm twin-lead transmission line.

More than this, the transmission line should be twisted so there is a turn to about every 12 to 15 inches of length. Twisting the line tends to reduce the pick up of noise. If the line were not twisted there would be the possibility of one of the wires picking up more induced "noise" voltage than the other. This unbalance of the noise voltage would affect the receiver, and would be carried clear through the receiver to affect either the picture or the synchronization. By twisting the transmission line the noise voltage is equally impressed on each wire, and thus tends to cancel each other out. In this way the actual noise voltage that is applied to the picture tube or to the synchronization circuits is radically reduced.

This matter of twisting the line and keeping it away from the metal of the mast is not so important when co-axial line is used. Since the outer conductor of the co-axial line shields the internal conductor there is little influence from the metal of the mast, and there is little pick-up of electrical "noise". As a matter of fact it is a common practice to bring the co-axial line from the top of the mast to the bottom by placing the line inside the hollow metal mast.

The use of the co-axial line, with the line brought down through the inside of the mast, has the advantage of providing maximum protection to the lead-in line. When the line is inside the mast it is protected from the wind, rain, snow and other elements of the weather. The use of a co-axial line, however, does present the problem of matching the line to the antenna and to the receiver. The characteristic impedance of a co-axial line varies from about 50 ohms to 100 ohms. That which is most commonly used in television work does not usually greatly exceed about 50 ohms.

If a simple dipole antenna is used it is not much of a problem to match the co-axial line to the antenna, since the characteristic impedance of a dipole is 72 ohms at the center. But there is a growing tendency to use antennas which have an impedance of around 300 ohms. When such an antenna is used, some method of matching the line to the antenna must be used. Impedance matching transformers have been discussed in another lesson.

Section 14. PASSING THE LINE THROUGH THE WALLS OF THE HOUSE

The simplest method of bringing a transmission line into the house is to merely bore a hole through the wall and push or

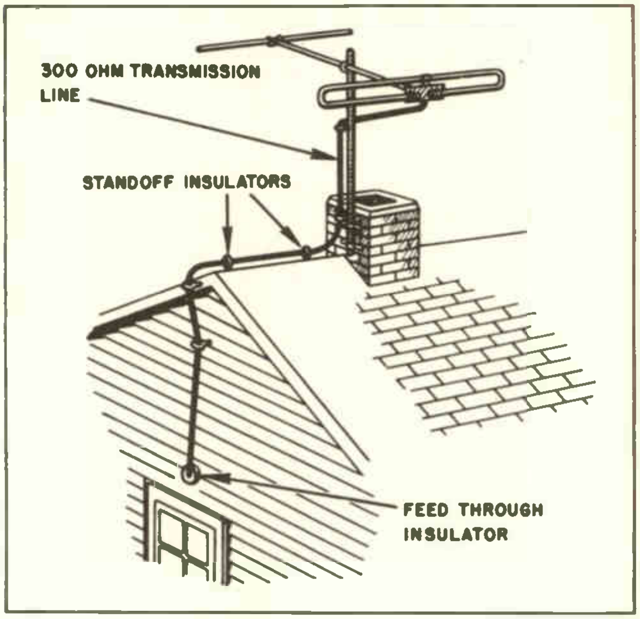

Fig.20. One Method of Bringing in the Transmission Line.

pull the line through the hole. But unless care is used in selecting the location for the hole, and care is taken not to bore it too large, the resultant installation will provide a very crude appearance.

A common method used to bring the transmission line into the house is to bore a reasonably large hole, then insert an insulator into the hole. The line is then passed through the insulator. Such an installation is shown in Fig. 20. The hole should be bored so there is a slight slant to the insulator. The insulator should slant toward the outside so there will be no possibility of rainwater entering the end of the insulator and following the inside of the insulator to the inside of the house. Fig. 21 shows how the insulator passes through the wall and how it is slanted.

A very common method of bringing the 300-ohm line into the house is to bring it down the side of the building to the top of a window. A very small groove is then cut in the top of the window, or in the frame that surrounds the window. Since the 300-ohm line is quite flat and rather thin, the groove need not be very wide nor very deep.

Once the line is in place, a little putty can be placed around the groove and the line to keep out the moisture in the atmosphere and the outside air. Care should be taken to make certain there is no metal around the window. If there is, this last method cannot be used.

Where the main walls of a building are brick but a gable is closed in with wood siding, it is often advisable to bore a hole through the siding close up under the eaves near the peak as shown in Fig. 22. Once inside the building the lead-in transmission line can be passed down through the studding of the wall, or brought out behind the molding and passed down on the inside of the wall. The exact construction of a building often determines the exact method of bringing in the line.

If the line is dropped down through the wall between the studding it is usually possible to then drill a hole in the wall just above the baseboard and bring the line into the room at that point. A spot should be chosen that will be hidden by the television receiver. There are newly designed plastic boxes now on the market which can be used to cover the hole made in the plaster and the wall. The use of such plastic boxes finishes off the job in a much more workmanlike manner. Metal boxes, such as those used by electricians, should not be used.

Before deciding to bring the line down the inside of the wall between the studding you should make very certain that metal lath is not used in the construction of the

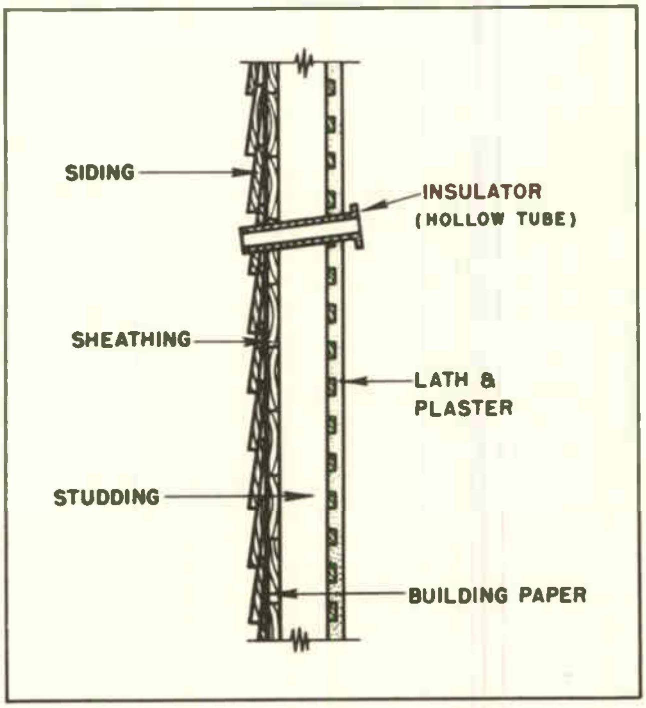

Fig.21. How a Tubular Insulator is Passed through a Wall as a Passage-Way For the Transmission Line.

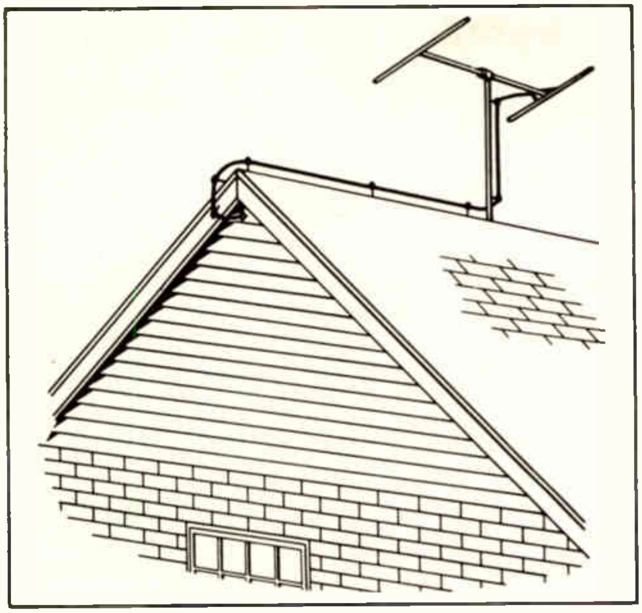

Fig. 22. Bringing the Transmission Line through a Wooden End Gable of a Brick House.

wall. Presence of the metal lath can play havoc with the characteristic impedance of your line, and may create a whole series of ghosts.

Section 15. MULTIPLE RECEIVERS FROM ONE ANTENNA

At the present time the transmitting stations for broadcasting television are restricted to areas having a high density of population. The very density of the population means that many owners of television receivers will live in apartment buildings and other multiple occupancy buildings. There is also a growing tendency toward installing television receivers in office buildings where there are many offices.

These things mean that in many cases there will be a large number of television receivers trying to operate in the same building.

There are several reasons why it is not desirable for a large number of receiving antennas to be placed on the same roof. Usually a variety of antennas on the same roof has a very unsightly appearance. The owner of the building often objects to the erection of an antenna for each occupant of the building.

A second reason why a large number of antennas on the same roof is objectionable is due to the interaction between the various antennas. Remember, each of the antennas is deliberately constructed so it will act as a resonant circuit. Since each is a resonant circuit, each will also re-radiate some spurious signals. The interaction of all the resultant spurious signals can ruin the pictures on all the television receivers.

Where there are only a couple of receivers to receive a signal from a single antenna it is possible to create a matching network so both receivers can be connected to the same antenna. But it should be kept in mind that merely coupling two receivers directly to the antenna lead-in line as in Fig. 23 would not be satisfactory.

Each of the receivers has an input of 300 ohms. When these two are in parallel as in Fig. 23, the impedance presented to the line from the antenna is 150 ohms instead of 300 ohms. The old rule of impedances in parallel holds true here.

If a resistance network specifically designed to match the line from the antenna to the lines leading to the receivers is used to couple the receivers to the antenna line, it becomes possible to effect a perfect impedance match. Such a matching network is shown in Fig. 24.

Such a network will bring about a good impedance match but there will be some attenuation of the signal strength. No attempt should be made to couple two receivers to the same antenna unless the signal strength is sufficiently great that

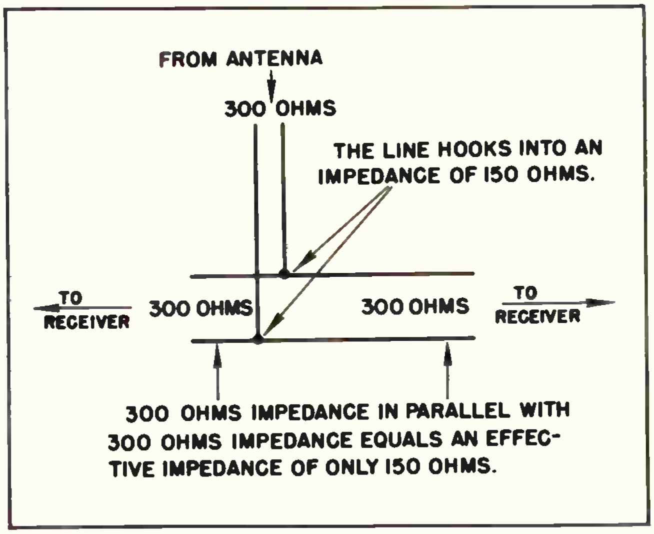

Fig. 23.

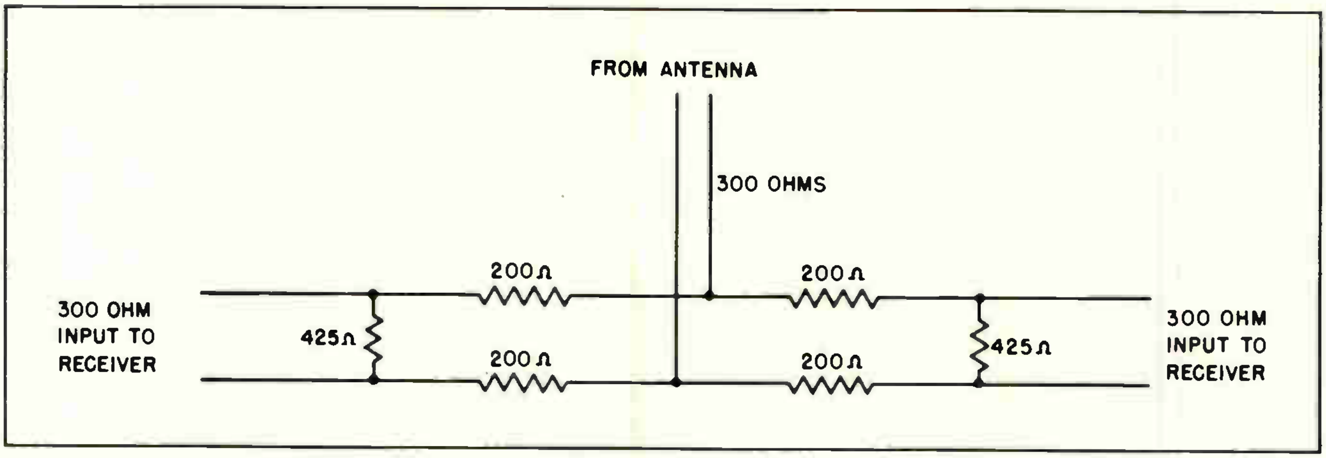

Fig. 24.

a signal strength loss of approximately 6 or 7 DB can be tolerated.

Several companies have designed equipment to be used in apartment houses, office buildings and other multiple-occupancy buildings where there are a number of television receivers. This equipment uses a single antenna which feeds into an electronic amplifier which can be generally described as a booster. Intricate matching networks are then so arranged that lines from the amplifier can be coupled into the input circuits of television receivers all over the building.

These multiple-unit antenna boosters cost from $200 to $300 up to amounts greater than one thousand dollars. The cost depends upon the size of the unit and the number of receivers to be served. There are some installation companies who specialize in the installation of such equipment.

A detailed description of those systems is entirely outside the scope of this lesson or of our course of training. In case you are interested you can obtain full information by writing to any of the manufacturers who build such systems.

There are several general methods followed by the manufacturers of such antenna equipment. Some use a separate antenna for each television channel. The signal from that antenna is then amplified and fed to those receivers desiring to tune into that channel.

Others use only one antenna for all stations, or a single antenna for the low band and another for the high band.

Section 16. INPUT CIRCUITS TO RECEIVERS

There are two general types of input circuits to television receivers. One is a resistive load and the other is an inductive load. The more common type is the inductive load, although the resistive load is receiving much attention of receiver designers.

When an inductive load is used the inductance is commonly divided by a center tap as shown in Fig. 25. The input circuit is so designed that a line connected to the

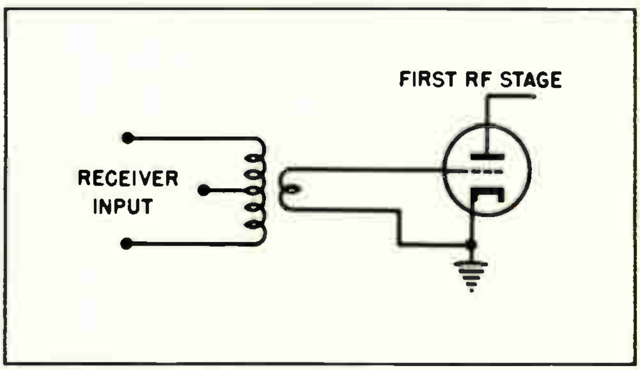

Fig. 25.

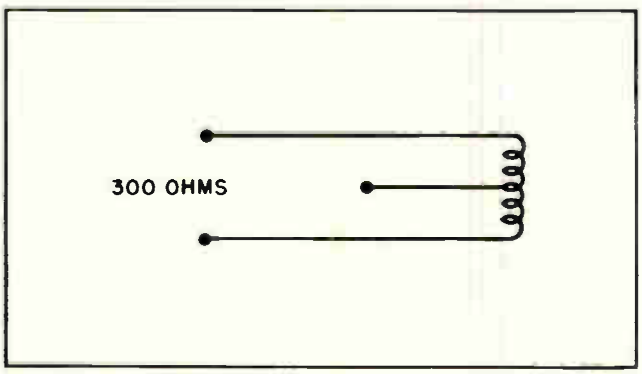

Fig. 26.

extreme ends of the input circuit will "see" an impedance of 300 ohms. This is indicated in Fig. 26.

You learned long ago that reducing the number of turns in a coil by one-half would reduce the inductive reactance to approximately one-fourth. This is a rule-of-thumb and is not mathematically accurate. But it is approximately accurate -- accurate enough for these purposes.

If, instead of connecting the transmission line to the two outside terminals, it is connected to one of the outside terminals and to the center-tap terminal, the transmission line will "see" an impedance of approximately 75 ohms instead of 300 ohms. Actually the impedance will be slightly less than 75 ohms, but that is a good estimate.

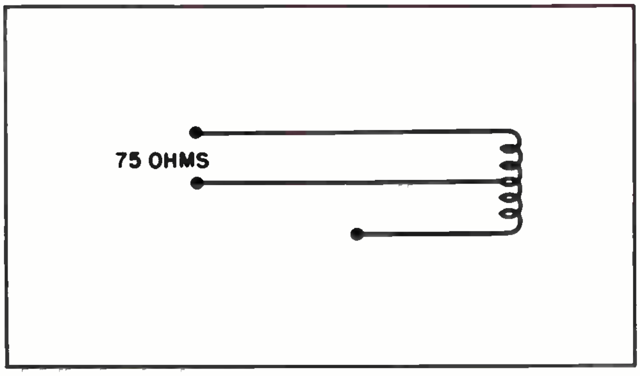

Fig. 27.

If all three of these leads are brought out to a terminal strip where the transmission line can be connected we have a choice of the amount of impedance we will use in the input circuit. If we are using the common 300-ohm transmission line we would connect that line to the outside terminals on the terminal strip, thus making use of the full input impedance of the receiver. On the other hand, if we are using a co-axial line, a twisted pair of some of the other low-impedance lines, we would make the connection to the terminal strip by connecting to one of the outside terminals and to the center-tap terminal.

In Fig. 28 we can see how a 300-ohm dipole antenna can be coupled to the 300-ohm input impedance of a television receiver by using a 300-ohm transmission line. Here we find all the impedances properly matched. So far as the line and receiver are concerned no ghost will be created within the input circuit from the antenna to the receiver.

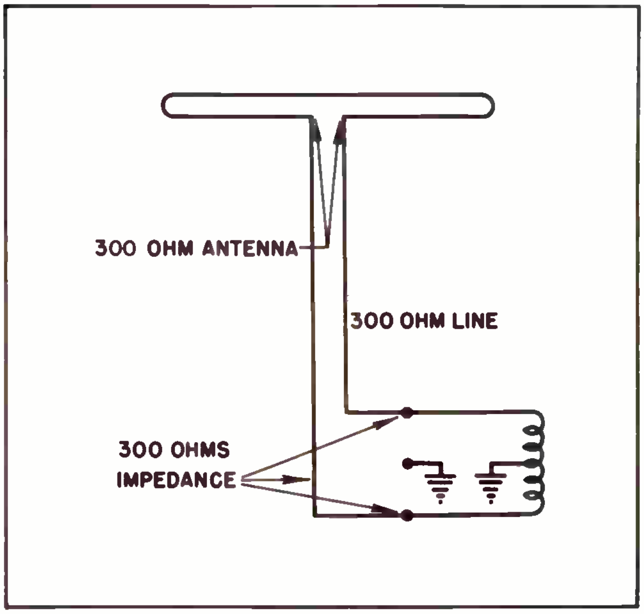

Fig. 28. How a 300-Ohm Antenna is Matched to a 300-Ohm Input Receiver.

In Fig. 29 we see how the same receiver can be coupled to a simple dipole antenna. You will remember that the characteristic impedance of a simple dipole is 72 ohms. We could use a twisted pair, which also has a characteristic impedance of 72 ohms, or use a specially designed 75-Ohm twin-lead transmission line. 72 ohms and 75 ohms are so close together that any reflections created by the slight mismatch would be negligible.

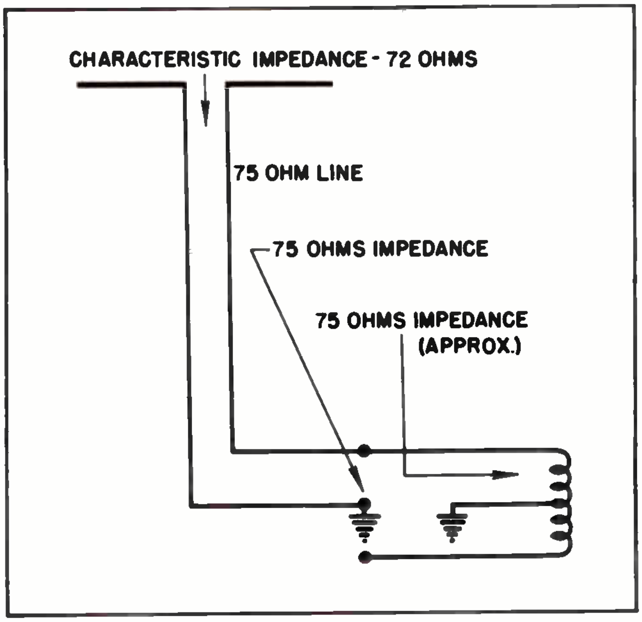

Fig. 29. How a 72-Ohm Antenna is Matched to the Receiver by Using only Half the Primary Inductance.

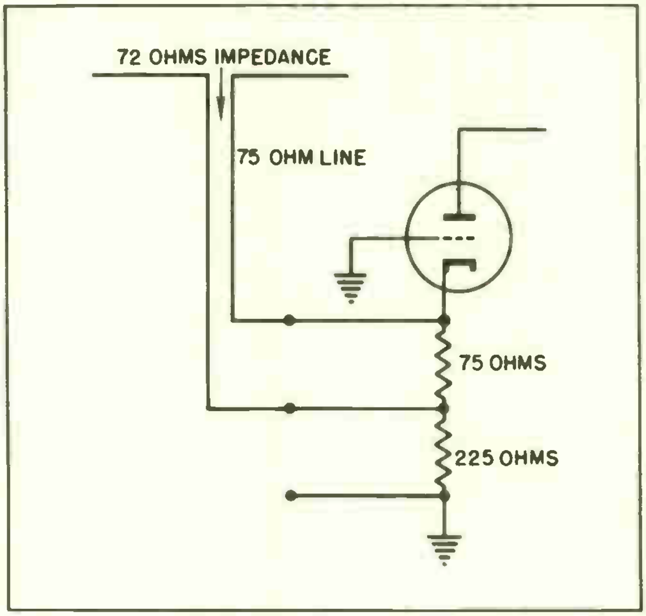

Fig.30. Matching a 72-Ohm Dipole to a Resistive Input Receiver.

The line is then connected to one side of the input to the receiver with the other conductor of the line being connected to the ground of the chassis of the receiver. Since it is frequently the custom to ground the center tap of the input inductance to ground this provides an input impedance of approximately 72 to 75 ohms. Such a coupling between the antenna and the receiver is close enough to provide ghost-free reception insofar as the line itself is concerned.

If the input of the receiver is resistive instead of inductive the termination is usually quite similar. Fig. 30 shows one type of resistive input. It shows a dipole antenna coupled to a resistive-input receiver. The circuit shown is one known as a grounded-grid input. This type of circuit has been discussed at considerable length in previous lessons.

Fig. 31 shows how a folded dipole antenna would be coupled to a resistive-input receiver. The 75-ohm resistor and the 225-ohm resistor in series provides 300 ohms of resistance for the load. The 300 ohms is a perfect match for the transmission line, thus all the energy from the line and from the antenna is absorbed, none is reflected to create ghosts.

Section 17. MATCHING STUBS

Despite all the television serviceman can do by using various kinds of transmission lines and making various changes in the input circuit to the television receiver, it sometimes happens that mismatches will occur. Sometimes these mismatches are so serious as to create ghosts on the screen that cannot be removed by the use of the methods we have described in this lesson.

To overcome these situations, a skillful television technician can frequently create an impedance match by connecting a short piece of transmission line called a "stub". The stub should be connected where the mismatch occurs, but often it will correct the situation by connecting it as shown in Fig. 32. You will recall from your earlier studies that an open-ended quarter-wave transmission line has certain characteristics which duplicate those of a tuned circuit. This is the end we seek by coupling the short stub of line as shown in Fig. 32.

The exact length of the line from slightly less than one quarter-wave length to a full half-wave length has a very strong determining influence on the exact type of impedance the stub will couple into the transmission line. From less than one quarter-wave length to a full quarter-wave length the stub will act like a series resonant circuit. Between a quarter-wave length and one half-wave length the stub will act like an inductance. At exactly

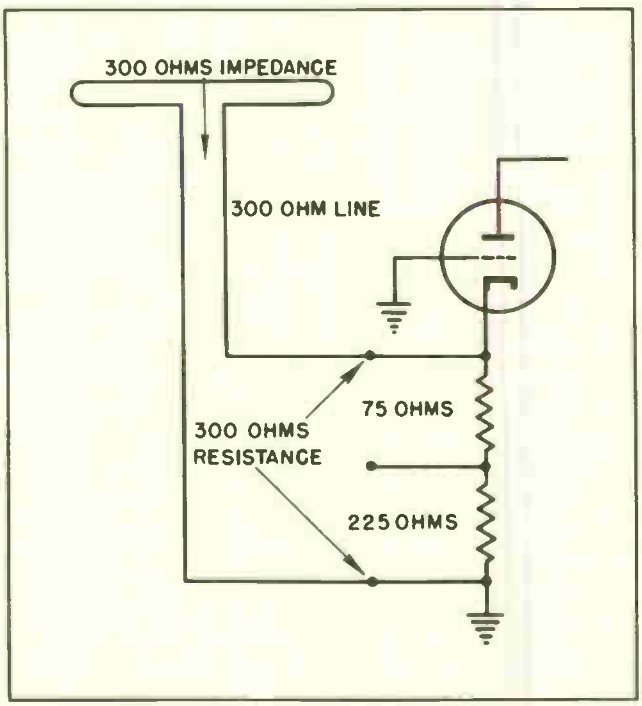

Fig.31. Matching a Folded Dipole to a Resistive Input Receiver.

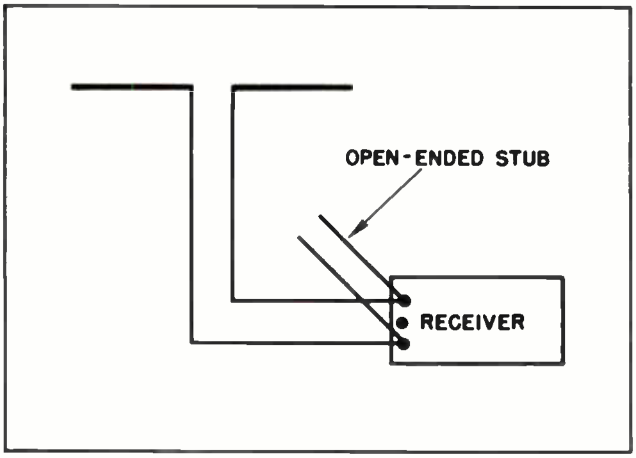

Fig.32. An Open-End Matching Stub.

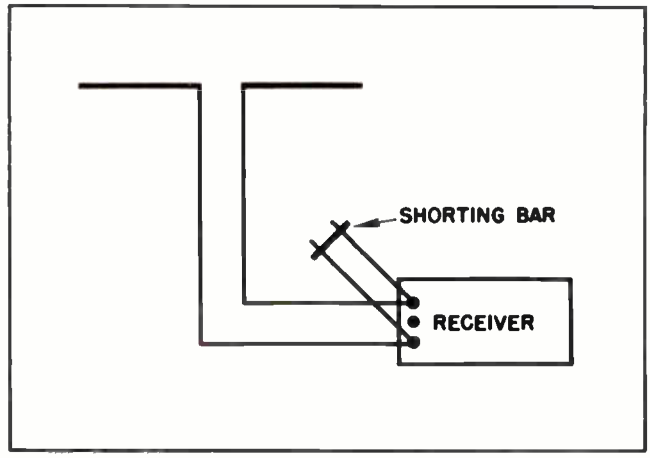

Fig.33. A Shorted Matching Stub.

a half-wave length it will act like a parallel resonant circuit.

Similar, but opposite, effects can be obtained by using a shorted stub. Less than a quarter-wave length of shorted stub tends to add inductance to the line. Exactly one quarter-wave length acts like a parallel resonant circuit. Between a quarter-wave length and a half-wave length acts as though capacity were being added to the circuit. If the shorted stub is exactly a half-wave length long it will act like a series resonant circuit.

Stubs are also used to remove undesirable frequencies from the line. Interference from an unwanted nearby transmitting station can be removed by the use of the proper stub. Other types of interference can be trapped by the use of stubs.

The theory behind the action of trimming, or matching, stubs is rather involved. We would like to give it to you because we think you should know it. But a full comprehension of matching stubs requires a knowledge of mathematics somewhat beyond that we can assume you understand.

Before leaving the subject of matching stubs we might mention that shorted stubs are more generally used than open end stubs. To be properly used the length of the open end stub must be calculated rather closely. The use of the shorted stub makes it possible to find the correct length by experimentation rather than calculation.

Use of the shorting bar makes it possible to find the critical length rather easily. All that is necessary is to scrape some of the insulation from one side of the pair of conductors in the stub. Then a piece of shorting metal -- a "bar" -- is moved along the bare conductors until the desired spot is located. This is shown in Fig. 33.

Section 18. INSTALLATION RECORDS

At the time a television receiver and its antenna is installed, the technicians should make a record of the installation. If you are running the business you should have some forms printed which will make the report and record accurate and factual.

If a complaint is received concerning the installation you will have your records at hand and be able to put your finger on the trouble quickly, or perhaps utilize the records to avoid the same trouble in a later installation.

The type of information that should be noted on the form is given in one of the tables in the back of this lesson. It should include the serial numbers of the receiver, and information concerning the antenna. It should also show the condition of the sweep circuits when unpacked from its crates, and any adjustments which were necessary should be noted.

The names of the technicians who worked on the installation should be noted on the record. Information concerning the distance from the transmitting stations, the location of the receiving antenna, and such like, should also be included in the record. You will find such records invaluable in your work, and will help you to provide your customers with a higher quality of service.

If the installation is in the vicinity of an airport, or if airplanes fly overhead frequently, that information should also be noted on the report. Airplanes flying overhead create short-lived ghosts, but many owners of receivers can make loud complaints unless such owner understands the cause for such ghosts.

NOTES FOR REFERENCE

The selection of the correct type of antenna is an important factor in making a satisfactory television receiver installation.

The selection of the antenna depends upon many factors, including such things as the distance from the transmitter, the number of stations to be received, and the actual location of the receiver.

The type of building where the antenna is to be located is also often a determining factor in the exact kind of antenna which is chosen for any specific installation.

In the fringe areas considerable attention must be directed toward raising the antenna high enough to receive a strong signal.

The location of the mast which supports the antenna is often determined by the height of the mast. Some masts must be so high that it is not wise to depend upon the roof to support the mast.

Antenna masts should be guyed at least every ten feet of their height.

If a guy wire is placed closer than 9 feet to the antenna, (and they often are) the guy should be broken about 3 or 4 feet from the mast and an insulator inserted in the guy. This will avoid ghosts being created by reflections from the guy wire.

The transmission line should be kept from metal pipes, down-spouts, masts and so forth. The metal, if close enough will create a change in the characteristic impedance of the line and set up reflections in the line.

Twin-lead transmission lines can be held away from the metal supporting masts by special stand-off insulators.

The installer should have a firm platform from which to work when working on peaked rooftops.

Care should be exercised in the use of metal ladders. Such ladders can be a source of genuine danger if used near high-voltage power lines.

Light weight metal hook-type ladders are useful on rooftops.

Some type of two-way communications system should be used to enable the man on the roof to talk with the man at the receiver during the installation of a television receiver.

Television antenna masts are often fastened to chimneys. When this is done, care should be taken to see that the antenna does not damage the chimney. The antenna mast should be securely anchored to prevent it whipping in the wind and possibly damaging the chimney.

Every outside antenna installation should be well grounded to prevent lightning damage. A properly installed and grounded antenna system is a protection against lightning; an improperly grounded one can be a source of potential danger.

Do not make the mistake of grounding the twin-lead transmission line while leaving the mast ungrounded. Some antennas are electrically connected to the supporting masts, others are not. A good method is to place the lightning arrester for the transmission line directly on the mast, then ground both the line and the mast at the same time.

By "grounding" a transmission line against lightning it should be understood that we mean grounding through an "arrester", and not grounding the conductors directly. If the conductors of the transmission line are directly grounded you will also ground your signal. By using the arrestors you will ground the lightning but not the signal.

The common 300-ohm twin-lead transmission line should be twisted about once every 12 to 15 inches. This will reduce the amount of noise the line will pick up.

It is possible to connect two receivers to a single antenna if the signal is strong and a properly designed matching network is employed.

Where more than two receivers must be worked from the same antenna, a special antenna amplifier should be used.

The transmission line must be properly matched to the antenna and it must also be properly matched to the input of the receiver.

Most commercial receivers are designed so that either a 75-ohm line or a 300-ohm line will couple directly to the receiver without any additional matching network.

Matching stubs can be used to reduce interference or to affect a good match between the line and the receiver.

Always make a complete record of every antenna and receiver installation. The time spent on the record will more than repay you later on.

Above everything else familiarize yourself with the local ordinances covering the installation of television antennas. There have been so many slip-shod installations that many cities have been forced to enact some rather strict ordinances governing such work. Find out what the ordinances are in your city, then abide by them.

Every effort has been made to make this list of stations accurate at the date of compilation. Changes are occurring constantly; new stations go on the air, existing stations fail to make the grade and go off the air, stations change ownership and their call letters. This means you may find discrepancies between this list and the conditions as you know them to exist. On the whole, however, the list is essentially accurate, complete and reliable.

TABLE I

TV STATION LIST

Station Name		Channel	Station Name		Channel
ALABAMA			KTVK	Phoenix	3
WABT-TV	Birmingham	13	KDWI-TV	Tucson	9
WBRC-TV	Birmingham	6			
WALA-TV	Mobile	10	ARKANSAS		
WCOV-TV	Montgomery	20	KRTV	Little Rock	17
WMSL-TV	Decatur	23	KFSA-TV	Ft. Smith	22
WSFA-TV	Montgomery	12	KARK-TV	Little Rock	4
WEDM	Munford	7	KATV	Pine Bluff	7
WTVY	Dothan	9	KBTM-TV	Jonesboro	8
WAIQ	Andalusia	2			
			CALIFORNIA		
ARIZONA			KMJ-TV	Fresno	24
KVAR	Mesa (Pheonix)	12	KJEO	Fresno	47
KPHO-TV	Phoenix	5	KABC-TV	Los Angeles	7
KOPO-TV	Tucson	13	KHJ-TV	Los Angeles	9
KOOL	Phoenix	10	KCOP	Los Angeles	13
KVOA-TV	Tucson	4	KRCA	Los Angeles	4
KIVA	Yuma	11	KNXT	Los Angeles	2

TABLE I - (Cont'd.)

TV STATION LIST

Station	Name	Channel
KTLA	Los Angeles	5
KTTV	Los Angeles	11
KBIK-TV	Los Angeles	22
KFMB-TV	San Diego	8
KFSD-TV	San Diego	10
KGO-TV	San Francisco	7
KPIX	San Francisco	5
KRON-TV	San Francisco	4
KSAN-TV	San Francisco	32
KVEC-TV	San Luis Obispo	6
KBAK-TV	Bakersfield	29
KERO-TV	Bakersfield	10
KHSL-TV	Chico	12
KIEM-TV	Eureka	3
KSBW-TV	Salinas	8
KITO-TV	San Bernardino	18
KEYT	Santa Barbara	3
KTVU	Stockton	36
KVVG	Tulare	27
KCCC-TV	Sacramento	40
KCRA-TV	Sacramento	3
KQED	San Francisco	9
KOVR	Stockton	13
COLORADO		
KKTV	Colorado Springs	11
KFEL-TV	Denver	2
KBTV	Denver	9
KRDO	Colorado Springs	13
KLZ-TV	Denver	7
KOA-TV	Denver	4
KFXJ-TV	Grand Junction	5
KCSJ-TV	Pueblo	5
CONNECTICUT		
WICC-TV	Bridgeport	43
WKNB-TV	New Britain	30
WGTH-TV	Hartford	18
WATR-TV	Waterbury	53
WNHC	New Haven	8
DELAWARE		
WDEL-TV	Wilmington	12
DISTRICT OF COLUMBIA		
WMAL-TV	Washington	7
WRC	Washington	4
WTOP-TV	Washington	9
WTTG	Washington	5
FLORIDA		
WMBR-TV	Jacksonville	4
WTVJ	Miami	4
WSUN-TV	St. Petersburg	38
WITV	Ft. Lauderdale	17
WINK-TV	Ft. Myers	11
WJHP-TV	Jacksonville	36
WJDM	Panama City	7
WPFA	Pensacola	15
WEAR-TV	Pensacola	3
WIRK-TV	West Palm Beach	21
WDBO-TV	Orlando	6
WSNO-TV	Palm Beach	5
WEAT-TV	West Palm Beach	12
WTVI	Ft. Pierce	19
WGBS-TV	Miami	23
WFLA-TV	Tampa	8
WTVT	Tampa	13
GEORGIA		
WAGA-TV	Atlanta	5
WLWA	Atlanta	1
WSB-TV	Atlanta	2
WDAK-TV	Columbus	28
WMAZ-TV	Macon	13
WNEX-TV	Macon	47
WMAZ-TV	Warner Robins	13
WALB-TV	Albany	10
WQXI-TV	Atlanta	36
WSBF	Augusta	6
WRDW-TV	Augusta	12
WRBL-TV	Columbus	4
WROM-TV	Rome	9
WTOC-TV	Savannah	11
WSAV-TV	Savannah	3
IDAHO		
KIDO-TV	Boise	7
KID-TV	Idaho Falls	3
KBOI	Meridan	2
KLEW	Lewiston	3
ILLINOIS		
WTTV	Chicago	11
WBBM-TV	Chicago	2
WBKB	Chicago	7
WGN-TV	Chicago	9
WNBQ	Chicago	5
WEEK-TV	Peoria	43
WTVH-TV	Peoria	19
WTVO	Rockford	39
WREX	Rockford	13
WHBF-TV	Rock Island	4
WBLN	Bloomington	5
WCIA	Champaign	3
WDAN-TV	Danville	24
WTVP	Decatur	17
WSIL-TV	Harrisburg	22
WGEM-TV	Quincy	10

TABLE I - (Cont'd.)

TV STATION LIST

Station	Name	Channel
ILLINOIS		
WICS	Springfield	20
INDIANA		
WTTV	Bloomington	4
WFBM-TV	Indianapolis	6
WISH	Indianapolis	8
WFAM-TV	Lafayette	59
WLBC	Muncie	49
WSBT-TV	South Bend	34
WSJV	Elkhart	52
WFIE	Evansville	62
WKJG-TV	Ft. Wayne	33
WINT	Waterloo	15
WTHI-TV	Terre Haute	10
WCBC-TV	Anderson	61
IOWA		
WMT-TV	Cedar Rapids	2
WOC-TV	Davenport	6
KVTV	Sioux City	9
WOI-TV	Ames	5
KGTV	Des Moines	17
KQTV	Ft. Dodge	21
KVTV	Sioux City	9
KTIV	Sioux City	4
KCRG-TV	Cedar Rapids	9
WHO-TV	Des Moines	13
KGLO-TV	Mason City	3
KANSAS		
KTVH	Hutchinson	12
KSAC-TV	Manhattan	8
KOAM-TV	Pittsburgh	7
WIBW-TV	Topeka	13
KEDD	Wichita	16
KAKE-TV	Wichita	16
KTVR	Wichita	3
KCKT	Great Bend	2
-------	Goodland	3
KENTUCKY		
WAVE-TV	Louisville	3
WHAS-TV	Louisville	11
WEHT	Henderson	11
WLEX-TV	Lexington	18
LOUISIANA		
WAFB-TV	Baton Rouge	28
WDSU-TV	New Orleans	6
KALB	Alexandria	5
KHTV	Baton Rouge	40
KTAG-TV	Lake Charles	25
KNDE	Monroe	8
KPLC-TV	Lake Charles	7
WBRZ	Baton Rouge	2
WJMR-TV	New Orleans	61
KCIS	Shreveport	12
KTBS-TV	Shreveport	3
MAINE		
WABI-TV	Bangor	5
WCSH-TV	Portland	6
WGAN-TV	Portland	13
WTWO	Bangor	2
WLAM-TV	Lewiston	17
WMTW	Poland Spring	8
MARYLAND		
WAAM	Baltimore	13
WBAL-TV	Baltimore	11
WMAR-TV	Baltimore	2
WBOC-TV	Salisbury	16
MASSACHUSETTS		
WBZ-TV	Boston	4
WNAC-TV	Boston	7
WHYN-TV	Holyoke	55
WWLP	Springfield	61
WTAO-TV	Cambridge	56
WMGT	North Adams	74
WWOR-TV	Worchester	14
WGBH-TV	Boston	2
MICHIGAN		
WPAG-TV	Ann Arbor	20
WBKZ-TV	Battle Creek	64
WWJ-TV	Detroit	4
WJBK-TV	Detroit	2
WXYZ-TV	Detroit	7
WOOD-TV	Grand Rapids	8
WKZO-TV	Kalamazoo	3
WJIM-TV	Lansing	6
WTOM	Lansing	54
WKNX-TV	Saginaw	57
WWTV	Cadillac	13
WKAR-TV	East Lansing	60
WTVM	Muskegon	35
WNEM-TV	Bay City	5
WPBN-TV	Traverse City	7
MINNESOTA		
KDAL	Duluth	3
KSTP-TV	Minneapolis-St.P	5
WCCO-TV	Minneapolis	4
WTCN	Minneapolis	11
KMMT	Austin	6
WDSM-TV	Duluth	6

TABLE 1 (Cont'd.)

TV STATION LIST

Station	Name	Channel
KROC	Rochester	10
KEYD-TV	Minneapolis - St. Paul	9
MISSISSIPPI		
WJTV	Jackson	25
WTOK-TV	Meridian	11
WLBT	Jackson	3
WSLI-TV	Jackson	12
WDAM	Hattiesburg	9
MISSOURI		
WDAF-TV	Kansas City	4
KCMO-TV	Kansas City	5
KSD-TV	St. Louis	5
KETC	St. Louis	9
KWK-TV	St. Louis	4
KTTS-TV	Springfield	10
KYTV	Springfield	3
KFVS-TV	Cape Girardeau	12
KOMU-TV	Columia	8
KHQA-TV	Hannibal	7
KFEQ-TV	St. Joseph	2
KDRO-TV	Sedalia	6
WHB-TV	Kansas City	9
KSWM-TV	Joplin	12
KTVI	St. Louis	36
MONTANA		
KOOK-TV	Billings	2
KXLF-TV	Butte	6
KFBB-TV	Great Falls	5
KGVO-TV	Missoula	13
NEBRASKA		
KVON-TV	Lincoln	12
KOLN-TV	Lincoln	10
KMTV	Omaha	3
WOW-TV	Omaha	6
KHOL	Kearney	13
NEVADA		
KLAS-TV	Las Vegas	8
KZTV	Reno	8
KAKJ	Reno	4
KLRJ-TV	Henderson	2
NEW HAMPSHIRE		
WMUR-TV	Manchester	9
NEW JERSEY		
WRTV	Atlantic City	58
WATV	Newark	13

Station	Name	Channel
NEW MEXICO		
KOB-TV	Albuquerque	4
KGGM-TV	Albuquerque	13
KOAT-TV	Albuquerque	7
KSWS-TV	Roswell	8
NEW YORK		
WNBF	Binghampton	12
WBEN-TV	Buffalo	4
WGR	Buffalo	2
WBUF-TV	Buffalo	17
WCNY	Carthage	7
WABC-TV	New York	7
WABD	New York	5
WCBS-TV	New York	2
WRCA	New York	4
WOR-TV	New York	9
WPIX	New York	11
WHAM-TV	Rochester	5
WHEC-TV	Rochester	10
WVET	Rochester	10
WRGB	Schenectady	4
WTRI	Schenectady	35
WSYR-TV	Syracuse	5
WHEN	Syracuse	8
WKTV	Utica	13
WROW-TV	Albany	41
WKNY-TV	Kingston	66
WIRI	Plattsburg	5
NORTH CAROLINA		
WBTV	Charlotte	3
WFMY-TV	Greensboro	2
WAYS-TV	Charlotte	36
WISE-TV	Asheville	62
WNCT	Greenville	9
WHKP-TV	Hendersonville	27
WPAQ-TV	Mt. Airy	55
WNAO-TV	Raleigh	28
WTOB-TV	Winston-Salem	26
WSJS-TV	Winston-Salem	12
WLOS-TV	Asheville	13
WUNC-TV	Chapel Hill	4
WBTV	Charlotte	3
WTVD	Durham	11
WMFD-TV	Wilmington	6
WNBE-TV	New Bern	13
NORTH DAKOTA		
WDAY-TV	Fargo	6
KCJB-TV	Minot	13
KFYR-TV	Bismarck	5
KXJB-TV	Valley City	4

TABLE 1 (Cont'd.)

TV STATION LIST					
Station Name		Channel	Station Name		Channel
OHIO			WFIL-TV	Philadelphia	6
WAKR-TV	Akron	49	WPTZ	Philadelphia	3
WICA-TV	Ashtabula	15	WCAU-TV	Philadelphia	10
WCPI-TV	Cincinnati	9	WIP-TV	Philadelphia	29
WKRC-TV	Cincinnati	12	WDTV	Pittsburgh	2
WLWT	Cincinnati	5	WENS	Pittsburgh	16
WCIN-TV	Cincinnati	54	WQED	Pittsburgh	13
WEWS	Cleveland	5	WEEU-TV	Reading	33
WNBK	Cleveland	3	WHUM-TV	Reading	61
WXEL	Cleveland	8	WARM-TV	Scranton	16
WCET	Cincinnati	48	WFMZ	Allentown	67
WBNS-TV	Columbus	10	WGLV	Easton	57
WLWC	Columbus	4	WSEE	Erie	35
WTVN	Columbus	6	WCMB	Harrisburg	27
WHIO-TV	Dayton	7	WTPA	Harrisburg	71
WLWD	Dayton	2	WGBI-TV	Scranton	22
WLOK-TV	Lima	73	WTVU	Scranton	73
WSPD-TV	Toledo	13	WBRE-TV	Wilkes-Barre	28
WFMJ-TV	Youngstown	21	WNOW-TV	York	49
WKBN-TV	Youngstown	27	WILK-TV	Wilkes-Barre	34
WUTV	Youngstown	21	WSBA-TV	York	43
WHIZ-TV	Zanesville	18	WKOK-TV	Sunbury	38
WSTV-TV	Steubenville	9			
			RHODE ISLAND		
OKLAHOMA			WJAR-TV	Providence	11
KSWO-TV	Lawton	7	WNET	Providence	16
WKY-TV	Oklahoma City	4			
KWTV	Oklahoma City	9	SOUTH CAROLINA		
KTVQ	Oklahoma City	25	WCOS-TV	Columbia	25
KOTV	Tulsa	6	WIS-TV	Columbia	10
KCEB	Tulsa	23	WNOK-TV	Columbia	67
KVOO	Tulsa	2	WGVL	Greenville	23
KTEN	Ada	10	WAIM-TV	Anderson	40
KGEO	Enid	5	WCSC-TV	Charleston	5
KTVX	Muskogee	8	WUSN-TV	Charleston	2
KMPT	Oklahoma City	25	WBTW	Florence	8
			WFBC-TV	Greenville	4
OREGON					
KPTV	Portland	27	SOUTH DAKOTA		
KVAL	Eugene	13	KELO-TV	Sioux Falls	11
KBES-TV	Medford	5	KDLO-TV	Florence	3
KOIN	Portland	6			
-------	Roseburg	4	TENNESSEE		
			WDEF	Chattanooga	12
PENNSYLVANIA			WJHL	Johnson City	11
WFBG-TV	Altoona	10	WTSK-TV	Knoxville	26
WLEV-TV	Bethlehem	51	WHBQ-TV	Memphis	13
WICU	Erie	12	WMCT	Memphis	5
WHIP-TV	Harrisburg	55	WREC	Memphis	3
WJAC-TV	Johnstown	6	WATE	Knoxville	26
WARD-TV	Johnstown	56	WSIX-TV	Nashville	8
WGAL-TV	Lancaster	8	WSM-TV	Nashville	4
WKST-TV	New Castle	45	WLAC-TV	Nashville	5

TABLE 1 (Cont'd.)

TV STATION LIST

Station Name		Channel
TEXAS		
KFDA-TV	Amarillo	10
KGNC-TV	Amarillo	4
KRBC-TV	Abilene	9
KTBC-TV	Austin	7
KBMT	Beaumont	31
KLRD-TV	Dallas	4
WFAA-TV	Dallas	8
KROD-TV	ElPaso	4
KTSM-TV	ElPaso	9
WBAP-TV	Ft. Worth	5
KGUL-TV	Galveston	11
KPRC-TV	Houston	2
KUHT	Houston	8
KTRT-TV	Houston	13
KCBD-TV	Lubbock	11
KDUB-TV	Lubbock	13
KENS	San Antonio	5
WOAI-TV	San Antonio	4
KCOR	San Antonio	41
KFDX-TV	Wichita Falls	3
KWFT-TV	Wichita Falls	6
KGBT-TV	Harlingen	4
KTVE	Longview	32
KTRE-TV	Lufkin	9
KTXL-TV	San Angelo	8
KVDO-TV	Corpus Christi	22
KFDM-TV	Beaumont	6
KMID-TV	Midland	2
KCEN-TV	Temple	6
KCMC-TV	Texarkana	6
KLTV	Tyler	7
KNAL-TV	Victoria	19
KANG-TV	Waco	34
KWTX	Waco	10
KRGV-TV	Weslaco	5
UTAH		
KTVT	Salt Lake City	4
KSL-TV	Salt Lake City	5
KUTV	Salt Lake City	2
VIRGINIA		
WLVA-TV	Lynchburg	13
WTAR-TV	Norfolk	4
WTVR	Richmond	6
WSLS-TV	Roanoke	10
WBTM-TV	Danville	24
WVEC-TV	Hampton	15
WSVA-TV	Harrisonburg.	3
WACH	Newsport News	33
WTOV-TV	Norfolk	27
WASHINGTON		
KVOS-TV	Bellingham	12
KING-TV	Seattle	5
KHQ-TV	Spokane	6
KXLY-TV	Spokane	4
KTNT-TV	Tacoma	11
KTVW-TV	Tacoma	13
KIMA-TV	Yakima	29
KOMO-TV	Seattle	4
KCTS	Seattle	9
KEPR-TV	Pasco	19
KREM-TV	Spokane	2
WEST VIRGINIA		
WSAZ-TV	Huntington	3
WKNA-TV	Charleston	49
WTAP	Parkersburg	15
WTRF-TV	Wheeling	7
WCHS-TV	Charleston	8
WJPB-TV	Fairmont	35
WOAY-TV	Oak Hill	4
WISCONSIN		
WBAY-TV	Green Bay	2
WTMJ-TV	Milwaukee	3
WEAU-TV	Eau Claire	13
WKOW-TV	Madison	27
WMTV	Madison	33
WHA-TV	Madison	21
WKBT	La Crosse	8
WMBV-TV	Marinette	11
WISN-TV	Milwaukee	12
WCAN	Milwaukee	25
WOKY	Milwaukee	19
WSAU-TV	Wausau	7
WFRV-TV	Green Bay	5
WYOMING		
KFBC-TV	Cheyenne	5
ALASKA		
KFIA	Anchorage	2
KTVA	Anchorage	11
KFAR-TV	Fairbanks	2
KTVF	Fairbanks	11
HAWAII		
KMAU	Wailuku	3
KHBC-TV	Hilo	9
KGMB-TV	Honolulu	9
KONA	Honolulu	11
KULA-TV	Honolulu	4
PUERTO RICO		
WKAQ-TV	San Juan	2
WAPA-TV	San Juan	4

TABLE II

INFORMATION WHICH SHOULD BE INCLUDED IN AN INSTALLATION RECORD

Manufacturer of Receiver ______________________.

Receiver type __________________. Cabinet finish __________________.

Model No. __________________. Serial No. __________________.

Chassis No. __________________. Factory Inspection No. __________________.

C.R.T. Type No. __________________. Tube Serial No. __________________.

Packing No. __________________. Date of Installation __________________.

Chief Installation Technician ______________________________.

Assistant Installer ______________________________.

The following items should be checked at the time the receiver is unpacked from the packing crate. A check mark should indicate if O.K. If an adjustment is needed, that should be indicated.

Raster Height	Horizontal Center
Raster Width	Horizontal Linearity
Ion Trap	Horizontal Hold
Vertical Center	Focus
Vertical Linearity	Contrast
Vertical Hold	Brightness
	Fine Tuning

The following items should be checked after the receiver is installed and the antenna connected.

Hum	Diathermy Interference
Picture Quality	Stubs Installed
Sound Bars	Wave-Traps Installed
Sound Quality	Ignition Noise
Ghosts	Other Noise
Aircraft Ghosts	

A check of the contrast on all channels should be set up.

Kind of antenna used __________________. Height of antenna __________________.

Is antenna mounted on roof or a mast to ground ______________________.

Type of building __________________. Is roof flat or peaked? __________________.

Is roof accessible from building or must a ladder be used? __________________.

Chimney or roof mounting __________________. Is antenna mast grounded? __________________.

Was arrester used on the transmission line? ________. Type of arrester __________________.

How was grounding effected? __________________. Was antenna mast guyed? __________________.

TABLE II - (Cont'd.)

How many sets of guy wires were used? ________. Were top guys insulated? ________.

Direction of receiver from transmitters. ________. In what direction ________.

Are transmitters located in more than one direction? ________.

Was acceptable reception obtained on all channels? ________.

Located in business or residental neighborhood ________.

Is street traffic light or heavy ________. Much ignition noise? ________.

Type of transmission line used ________. Where did line enter building ________.

Extra materials used on the installation ________ ________.

Time spent on installation ________. Traveling time. ________.

Distance from office ________.

Were any unusual circumstances encountered on the installation? ________.

Name them. ________.

Installers Signature ________.

TABLE III

NECESSARY INSTALLATION TOOLS	
Vehicle for hauling tools and equipment. Adjustable ladders. Should be 40 to 50 feet long. Roof ladder with hook. Pipe wrenches. Complete set of open end wrenches. Two sizes of adjustable Crescent wrenches. A complete set of screw-drivers. (Small, medium and large.) Phillips head screw-drivers. (Two Sizes.) Heavy Electricians pliers. Long Nose pliers. Diagonal cutters. Slip-joint adjustable-jaw pliers. (Preferably two pair.) One wood hand saw. One claw hammer. One medium size wood chisel. (About 3/4-inch.) One portable 1/4-inch electric drill. Assorted sizes of drills. Two sizes of masonry drills. 100-foot heavy duty extension cord with multiple outlets. Brace with rachet.	An assortment of wood bits for use with brace. One cold chisel. One nail set. One setting punch for Ackerman-Johnson Anchors. One heavy duty soldering iron. One solder dipping pot. (Can be home-made.) 75-foot 1/2-inch rope. Hack saw and extra blades. Portable inter-communication system. Carpenter's square. Assorted sizes of nails, (8d, 12d, 16d, 20d.) Assorted wood screws. (No. 7, 1-inch; No. 10, 1-inch; No. 12, 2-inch Cadmium.) Two sizes of Ackerman-Johnson Anchors. Two sizes of wood screw Anchors. Level (Preferably torpedo type.) Small masonry tuck-pointing trowel. Can of pitch or other water-proofing compound, (For sealing holes in roof.) A roll of guy wire.

TABLE IV

TRANSMISSION LINE TWINLEAD						
Company	Model No.	Nominal Imp. Ohms	Nominal Cap. μμf/ft.	Attenuation db/100 ft. 100 Mc	200 Mc	400 Mc
Alpha Corp.	1150	300	4.5			
	1151	150	9.5			
	1152	75	20.0			
Anaconda	75	75	23.0	4.7		
	125	125	14.5	3.1		
	150	150	11.0	2.4		
	ATV-300-L	310	4.4	0.85		
	ATV-300-S	315	4.9	0.80		
	ATV-300-H	300	5.9	0.79		
Amphenol	14-056	300	5.8	2.1	3.16	
	14-079	150	10.0	2.7	4.7	
	14-080	75	19.0	5.0	8.3	
	14-023	75		4.8 (144 Mc)		
Ansonia	321-2	300	5.0		5.0	
Beldon	8222	72	20.7	7.7	11.0	15.9
	8223	100	16.3	5.1	7.2	10.3
	8224	150	9.8	2.8	4.2	6.4
	8225	300	4.6	1.1	1.7	2.7
	8235	300	5.0	1.1	1.73	2.74
	8210	72	22.0	3.1	4.4	6.3
Consoli-dated	Rotran 2 cond.	300			2.8 (144 Mc)	
	Rotran 3 cond.	300			2.8 (144 Mc)	
Cossor	SC2126	100			7.5	
Federal	K1046	300	4.0		3.0	
	K200	200	7.8		0.7	
La Pointe Plascomold	X200A	200		1.1		
Whitney Blake Co.	2080	300				
	2081	150				
	2082	75				

TABLE V

CHARACTERISTICS CHART SHIELDED TWIN CONDUCTOR							
Company	JAN No.	Model No.	Nominal Imp. Ohms	Nominal Cap. μμf/ft.	Attenuation db/100 ft. 100 Mc	200 Mc	400 Mc
Amphenol	RG/U22	21-038	95	16.0	3.4	5.2	8.3
	RG/U57	21-039	95	17.0	2.9	4.6	7.3
Anaconda	RG/U22		95	16.0			10.5
	RG/U57		95	17.0			8.8
	RG/U23		125	12.0			5.2
	RG/U24		125	12.0			5.2
		ATV-225	225	6.4	3.2	4.7	6.8
		ATV-150	150	11.6	2.6		
Beldon		8226	100	18.2	8.3	12.0	17.2
		8227	100	22.0	4.1	6.4	10.2
Cossor		SC2128	100		18 db at 600 Mc		
		SC2120	150	9.0		0.8	
Federal		K-117	185	6.8		6.0	
		K-111	300	4.2	3.4	4.6	
Whitney Blake Co.	RG/U22		95	16.0			10.5

JAN numbers refer to Joint Army and Navy Type Number.

TABLE VI

COAXIAL CABLE							
Company	RG/U No.	Model No.	Nominal Imp. Ohms	Nominal Cap. μμf/100 ft.	Attenuation db/100 ft. 100 Mc	200 Mc	400 Mc
Alpha	59	1157	73.0	21.0			
American Phenolic	5	21-001	52.5	28.5	2.65	3.85	5.6
	6	21-002	76.0	20.0	2.65	3.85	5.6
	8	21-004	52.0	29.5	2.10	3.30	4.5
	9	21-005	51.0	30.0	2.10	3.30	4.5
	10	21-006	52.0	29.5	2.10	3.30	4.5
	11	21-007	75.0	20.5	1.90	2.85	4.35
	12	21-008	75.0	20.5	1.90	2.85	4.35
	13	21-009	74.0	20.5	1.90	2.85	4.35
	29	21-018	53.5	28.5	4.10	6.20	9.5
	55	21-023	53.5	28.5	4.10	6.20	9.5
	58	21-024	53.5	28.5	4.10	6.20	9.5
	59	21-025	73.0	21.0	3.75	5.60	8.3
	62	21-026	93.0	13.5	3.05	4.40	6.3

TABLE VI - (Cont'd.)

COAXIAL CABLE							
Company	RG/U No.	Model No.	Nominal Imp. Ohms	Nominal Cap. μμf/100 ft.	Attenuation db/100 ft.		
					100 Mc	200 Mc	400 Mc
American Phenolic (Cont'd.)	71	21-029	93.0	13.5	3.05	4.40	6.3
		21-030		8.2	Cables supplied without center conductor (No. 30 AWG specified.) Recommended kinked for self-support.		
		21-057		7.0			
		21-072		7.4			
	74	21-041	52.0	29.5	1.40	2.15	3.35
Anaconda	A25a		22.5	70.0	7.5 at 50 MC		21.0
	A35a		32.5	47.5	6.7 at 50 Mc		20.0
	83/U		35.0	44.0			9.5
	58/U		53.5	28.5			11.7
	29/U		53.5	28.5			11.7
	55/U		53.5	28.5			11.7
	54A/U		58.0	26.5			7.0
	5/U		52.5	28.5			7.0
	8/U		52.0	29.5			6.0
	10/U		52.0	29.5			6.0
	9/U		51.0	30.0			5.9
	9A/U		51.0	29.0			65.0
	59/U		73.0	21.0			10.5
	6/U		76.0	20.0			7.4
	11/U		75.0	20.5			5.7
	12/U		75.0	20.5			5.7
	13/U		74.0	20.5			5.7
	62/U		93.0	14.5			8.0
	71/U		93.0	14.5			8.0
	7/U		90-105	14.0			5.8
	63/U		125	11.0			5.5
	79/U		125	11.0			5.5
Ansonia	5/U	506	52.5	28.5		3.8	
	10/U	341	52.0	29.5		3.3	
	62/U	CE809	93.0	13.5		4.5	
	59/U	334	73.0	21.0		5.7	
	8/U	CE995	52.0	29.5		3.3	
Belden		8216	72.0	37.0	17.0		
		8229	72.0	20.5	5.0	7.7	
		8228	52.0	28.5	4.5	7.2	
		TV59	72.0	22.0		6.0	
Federal	59/U	K32	72.0	22.0		6.0	
	11/U	K49	75.0	20.0		3.1	
	8/U	Intelin K-45	52.0	29.0		3.2	
General Insulated Wire Works	59/U	Tel/73	73.0	21.0	8.0		
		RG-59/U	73.0	21.0	7.0		
Rome Cable		Coax Rotran	50.0	21.0	5.8		

TABLE VI - (Cont'd.)

COAXIAL CABLE					
Company	RG/U No.	Model No.	Nominal Imp. Ohms	Nominal Cap. μμf/100 ft.	Attenuation db/100 ft. 100 Mc 200 Mc 400 Mc
Whitney Blake Co.	8/U		52.0	29.5	6.0
	29/U		53.5	28.5	11.7
	58/U		53.5	28.5	11.7
	58A/U		50.0	28.5	13.2
	59/U		73.0	21.0	10.5
	62/U		93.0	13.5	8.0
RG/U Number is Armed Forces Type Number.					

TABLE VII

COMPANIES MAKING MULTIPLE ANTENNA SYSTEMS AND BOOSTERS	
Blonder-Tongue Labs., Inc., 526 North Avenue Westfield, New Jersey	Jerrold Electronics Corp., 1401 So. 26th Street, Philadelphia 46, Pennsylvania
The Rauland Corp., 4245 North Knox Avenue, Chicago 40, Illinois.	Regency Division, I.D.E.A., Inc., 55 New Jersey Street, Indianapolis 4, Indiana.
Radio Corporation of America, Camden, New Jersey.	The Astatic Corp., Conneaut, Ohio.
Amy, Aceves and King, 11 West 42nd Street, New York 18, New York.	Trio Mfg. Co., Griggsville, Illinois.

NOTES

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ANTENNA ROTATORS

Contents: Introduction — Receiving Conditions After Freeze Was Lifted — Problems Imposed by TV Signals Arriving From Different Direction — Origin of Antenna Rotators — Basic Requirements of TV Antenna Rotator — Motor Action in Rotator — Rotator Using Double Motor — Action of Limit Switch — Action of Indicating Meter — Single Motor Rotator — The Driving Motor — Circuit for Rotator Requiring Multi-Wire Cable — Mounting the Antenna Shaft — Radial Type Rotators — Installing an Antenna Rotator — Trouble-shooting a Rotator Installation — All-Directional Antennas — Notes for Reference.

Section 1. INTRODUCTION

In the first few years of the television era there were few localities where viewers had any choice of programs. In most cases only one station could be picked up, and the viewer had to be satisfied with whatever program was being telecast.

Chicago, New York and Philadelphia were among the first cities to have TV stations operating on regular schedules. For several years there was only one station in each city. In Chicago, for example, WBKB was the only station on the air for about six years.

That was satisfactory enough. Television was such a novelty the mere experience of being able to hear and watch an audio-visual program coming from empty space was enough to keep a viewer enthralled. Entertainment value of the program was entirely secondary.

Since only one station could be received in most localities, TV receiving antennas were installed so they faced that station. All efforts were bent toward capturing as much of the signal from the single station as was possible.

Even after additional stations began coming on the air in 1947 and 1948 the new stations were

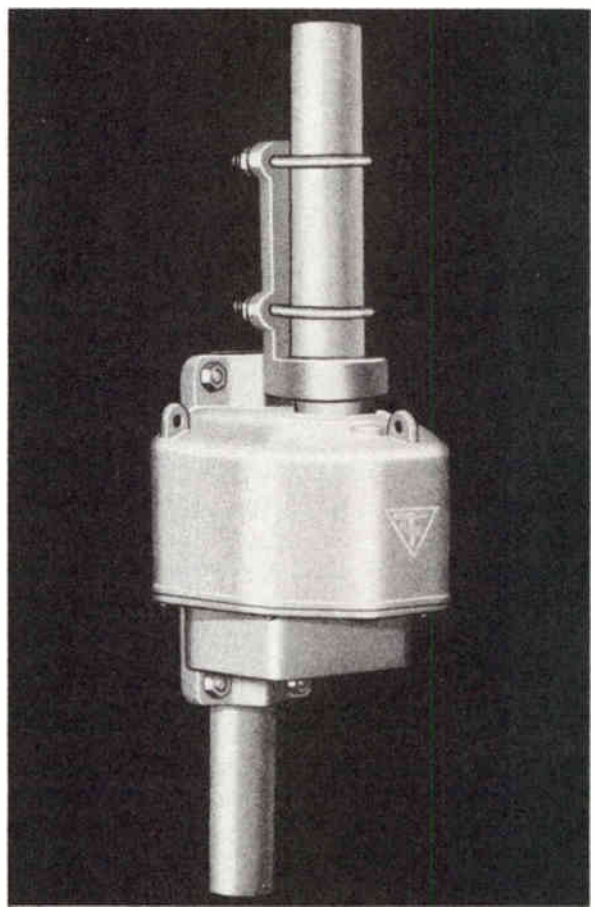

Fig. 1. Antenna Rotator (Courtesy Trio Mfg. Co.)

closely adjacent to those already on the air. The effect was to make it possible for a receiving antenna, which already faced an existing station, to also pick up the new stations.

This was the condition which existed in most localities up until about 1952. The situation was such that a rigidly fixed receiving antenna — fixed to face the principal TV station or stations — was reasonably satisfactory. In most cases there was little need for a receiving antenna to face in more than one direction.

In those few cases where a viewer was situated so it was possible to receive two different stations — stations positioned in different directions from the receiver — the situation could usually be handled by using two antennas. One would be mounted on the antenna mast to face one broadcast station; the other antenna faced the second station.

Section 2. RECEIVING CONDITIONS AFTER FREEZE WAS LIFTED

After the freeze on new TV stations was lifted in 1952, new stations quickly went on the air. Many of these new stations were located in cities within 75 to 150 miles of other cities where one or more stations were already operating.

People who lived between the new stations and those already on the air were now free to choose between several stations located in two or more directions.

An excellent example are those people living in villages and towns in north central Illinois. A reference to the sketch map Fig. 2 will make this more readily understandable.

Before the freeze was lifted, persons living in the vicinity of Ottawa, Illinois, for example, could receive good programs from only one direction — northeast, from Chicago.

Occasionally, a program could be picked up from Rock Island or Davenport, Iowa, to the west, when receiving conditions were just right; but those were exceptional occasions.

After the freeze was lifted new stations went on the air at Champaign, Peoria, and Rockford, while those in Chicago, Davenport and Rock Island improved their transmitting facilities. Res-

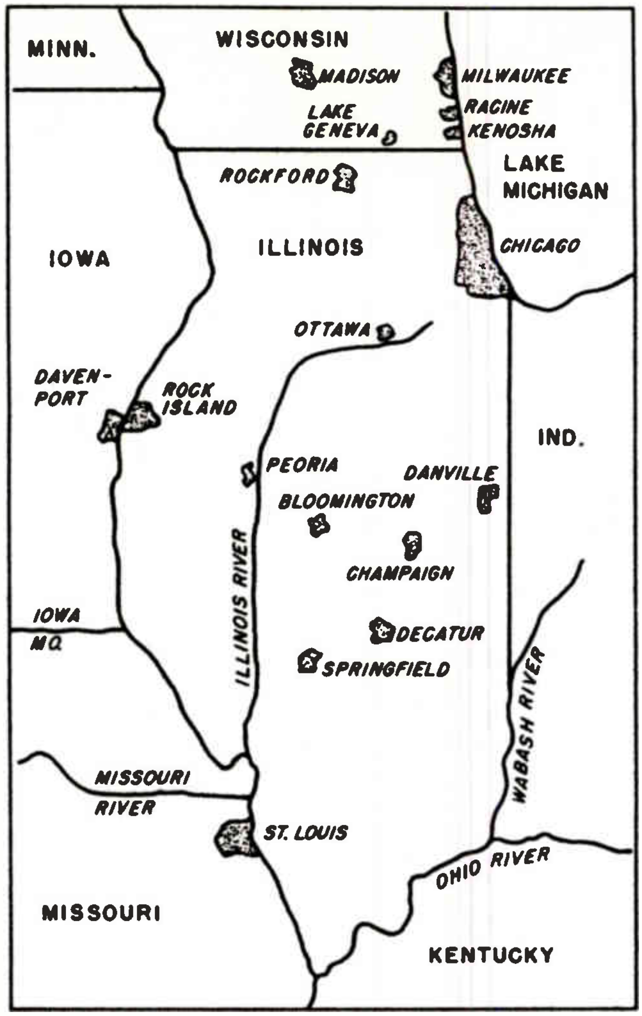

Fig. 2. In certain localities TV programs can be received from several directions.

idents of Ottawa now have a choice of four stations in Chicago, two in Rockford, two at Peoria, one at Champaign, and one each at the twin cities of Rock Island and Davenport. This means programs come from five *different* directions instead of the single direction of a few years ago.

A similar example is that of Lake Geneva, Wisconsin. Prior to lifting of the freeze on new TV stations, residents of that resort city had a choice of one station in Milwaukee and four in Chicago.

At that time they could use one antenna for the Chicago stations and a separate antenna facing toward Milwaukee.

Now the situation has changed. Many can pick up three stations from Milwaukee, two VHF and the third UHF. Some can also pick up one or two UHF stations from Madison. One VHF and one

UHF station can be picked up from Rockford, Illinois, while most viewers can also pick up the four stations from Chicago.

The stations are located in four different directions. In fact, Lake Geneva is almost exactly in the center of cross lines drawn between the cities where the TV transmitters are located.

Bloomington, Illinois presents a similar, although slightly different, situation. UHF signals from Peoria, Springfield, Decatur and sometimes Danville can be picked up there. VHF signals from Champaign, and from the higher powered stations at Chicago can be picked up most of the time, while those from Rock Island and Davenport can be picked up part of the time by many viewers. Here we find signals coming from *six* different directions.

Even the suburban area northwest of Chicago is so situated that strong TV signals can be picked up from three different directions. Two powerful VHF stations in Milwaukee, stations WTMJ-TV and WISN-TV, each with antenna towers more than 1000 feet high, put powerful TV signals into that area. Station WREX-TV in Rockford also puts a strong signal into that area. These are in addition, of course, to the four Chicago stations.

Section 3. PROBLEMS IMPOSED BY TV SIGNALS ARRIVING FROM DIFFERENT DIRECTION

When the stations which can be received lie in a single direction the arrangement of the receiving antenna is a relatively simple matter. The antenna is placed in that particular location which provides the strongest signal, and the best reception.

When the stations lie in two directions, and those in one direction are not too distant, it is practical to use a separate antenna for the two directions.

However, if the stations in both directions are quite distant, and elaborate receiving antennas are needed to bring in sufficient signal, a problem is created. Most of the more elaborate — and more sensitive — antennas used to bring in distant stations are quite heavy.

Not only are they heavy in actual weight, they present considerable resistance to winds; and when the winds are strong a heavy strain is placed on the supporting mast. They also tend to collect heavy accumulations of ice when icing conditions are bad, which places an additional strain on the mast and guy wires.

In such cases, it is not always wise to place two heavy antenna arrays on the same mast, one to face in each of the two directions. It is better to use a single, very sensitive, antenna; then rotate the antenna to face the direction from which the desired signal is arriving at any given instant.

These conditions are accented when the signals arrive from more than two directions, regardless of how far distant the broadcast stations are located. When TV signals arrive from more than two directions it is nearly always better to use a single, high-gain antenna, then rotate it to face the direction from which the desired signal is arriving.

A device to rotate the antenna to the various points of the compass is called a *rotator.* To be technically accurate, the more nearly correct name is an *antenna rotator*, but when the device is referred to in conversation technicians nearly always shorten the name to *rotator*.

A photograph of a modern rotator used with television receiving antennas is shown in Fig. 1.

The one in the photograph is manufactured by the Trio Mfg. Co. This company also manufactures the Zig-Zag antenna which has become so popular in parts of the country where a lightweight, but sensitive, antenna is needed.

Section 4. ORIGIN OF ANTENNA ROTATORS

Antenna rotators are relatively new insofar as their use with receiving antennas are concerned. There was little need for such a device with antennas used to receive radio stations operating in the broadcast band.

However, antenna rotators did come into existence through their use with radio equipment. But they were used with *commercial* radio equipment, and with *amateur* gear, rather than for broadcast reception.

Communication radio equipment, used to transmit and receive radio commercial messages, has used antenna rotators for many years. Especially when the higher radio frequencies were used for that type of service. High frequencies, of course, mean shorter wave length. Shorter wave lengths, in turn, mean smaller antennas.

But radio amateurs are the ones who made the greatest use of antenna rotators, and it was directly from the equipment used by them that TV antenna rotators were developed.

Radio amateurs operating on the 20-meter and 10-meter band made great use of yagi antennas for both transmitting and receiving. This was especially true of those working the 10-meter band, and even more true of those working the 5-meter band and the 2½-meter band. The yagi type antenna is readily adapted for use at those frequencies, and because of its great gain it can shoot out a powerful signal.

However, the yagi is a highly directional antenna. Instead of the signal from a yagi transmitting antenna being broadcast in all directions it goes out in only *one* direction.

Since radio amateurs are a chummy and talkative group, and never intentionally limit their transmissions to a single direction, it became necessary for them to devise ways to rotate antennas to shoot their signals in the direction they want them to go. For that reason they devised methods by which they could rotate the entire antenna.

Many amateurs are reasonably satisfied with mounting their antennas so they can physically rotate the entire mast and antenna by turning a crank at the base of the mast. This method has the advantage of simplicity and low installation cost.

A rough idea of one method that has been used by many amateurs is shown in Fig. 3. In that illustration the antenna is rigidly mounted on the top of the mast. The mast rests loosely in a hole in a slab of concrete or metal, so the mast is reasonably free to rotate.

It is then rotated by applying physical force to the horizontal bar shown near the base of the mast in the figure, or by a crank, or by some other means. Such method is often entirely adequate for rotating the mast to whatever position

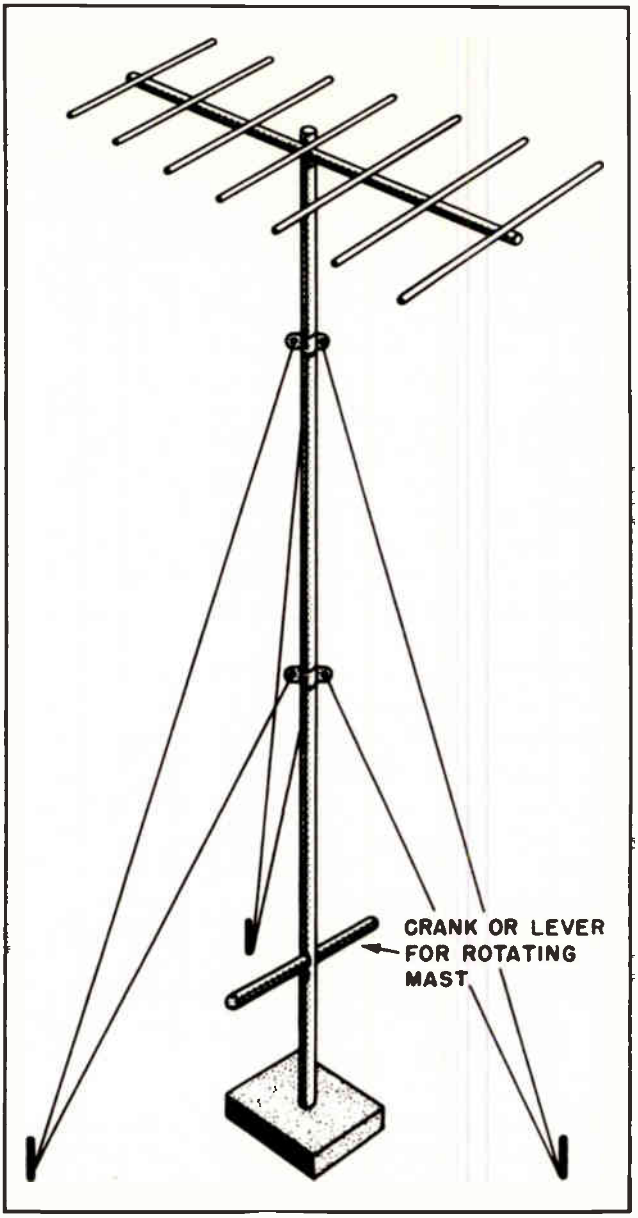

Fig. 3. Antenna and mast arranged so they can be rotated by crank near base.

is desired, especially for those whose finances are limited.

Other amateurs refined their installations by adding certain modifications to the basic design. Some attached a pair of ropes or chains, then ran the ropes or chains inside the house so the mast and antenna could be rotated without going out of doors.

There is a definite advantage in being able to rotate the antenna without going outside. In addition to the matter of convenience, there is the advantage of being able to position the antenna so it points in exactly the correct geographical angle which provides best transmission and reception. It is easier to find the position which provides best reception, if the antenna can be rotated while the operator is listening to an incoming signal.

Amateurs improved their antenna installations in many ways as the years wore on. Some became elaborate.

Some designed and built their own electrical rotators by installing one or more motors high on the mast, then using power from the motor to rotate the topmost portion of the mast. By controlling power to the motor it was possible to rotate the antenna to whatever position provided best reception. It became easier to pinpoint the directional position of the antenna, and the labor involved in actually rotating the antenna was avoided.

Still later, manufacturers adopted the ideas of these inventive amateurs, and began manufacturing commercial rotators for sale to other amateurs and to commercial radio companies.

This was the situation when television came on the scene, and a means for rotating TV antennas became desirable. Companies that had been building antenna rotators for radio work now turned to building similar equipment for TV receivers.

Despite their similarity of purpose, there is considerable difference between the rotators originally designed for use with amateur radio equipment and those intended for use with TV receiving antennas.

Those used with radio antennas were usually required to handle larger, and heavier, antennas than those used in TV work. The rotators were stronger and more massive. Furthermore, since they were intended for use by men well trained in electricity they were not necessarily so trouble-proof as those intended for use by the general public who can not be expected to have technical knowledge.

In this connection it is worthwhile pointing out that TV antennas are still rotated in some rural communities with a device similar to that shown in Fig. 3. But, in general, such a system lacks the convenience demanded by most TV viewers.

Section 5. BASIC REQUIREMENTS OF TV ANTENNA ROTATOR

Rotators intended to work with TV receiving antennas follow a fairly consistent pattern of design. Despite the differing ideas of the individual manufacturers of such devices, their general manner of operation is pretty well standardized.

The prime requirement for such a rotator is, of course, to actually rotate the antenna installation. The rotator must be strong enough to support the heaviest commercial antenna in common use. Since many of these rotators are used in remote signal areas where broadcast stations are quite distant, it means that they will normally be used with massive antennas. Frequently the antennas will be stacked, thus adding to their weight and wind resistance.

Rotators are usually designed to prevent rain, snow and other weather elements getting inside the rotator housing where they would corrode or damage the working mechanism. Since these devices are normally mounted high on antenna masts, they are exposed to the weather, thus must provide their own protection.

Once it is mounted on the mast where it is to operate the only way access can be had to a rotator is to lower the mast to the ground. This is a major job, and is to be avoided if at all possible. This means the rotator should be reliable in its operation, and not require frequent servicing. Once the rotator is mounted on the mast it should be able to remain there for long periods of time without attention.

All commercially built antenna rotators are electrically operated. This means an electric motor is built into the rotator to provide the necessary motive power.

The motor is supplied with electrical power by means of a cable from the ground. Furthermore, the motor is usually designed so it can operate in either direction. In operation it rotates back and forth over an angle of 360 degrees, meaning that it rotates completely around to all directions of the compass.

To prevent tangling the cables to the rotator motor, and also prevent tangling the transmission line from the antenna to the receiver, the rotator is designed so its full swing of rotation is limited to approximately 360 degrees, or only slightly more. Once the rotator has turned to its limit in one direction it must be reversed to face in any new direction. It cannot continue rotating in the same direction without limit.

In practice, the limit of rotation occurs when the antenna points north. If, after reaching its limit, its direction of rotation is then reversed, the antenna rotates all the way around the compass in the other direction until it again points north.

The rotator controller is usually mounted in a small cabinet, similar to those used to house small table model radio receivers. The photograph in Fig. 4 provides a pretty good idea of what such a control cabinet looks like.

The control cabinet is usually located directly on top of the TV receiver, or on a nearby shelf or table. It should be convenient to the TV receiver, since the correct position of the antenna has a direct bearing on the quality of the picture being received.

This means the position of the antenna should be adjustable while the station is being tuned in on the receiver. The more convenient the control cabinet is to the TV receiver the better the control the viewer has over the quality of the picture. Improper positioning of the antenna results in a weak signal. That means "Snow" in the picture.

Designs of the cabinets differ from one manufacturer to another. But all have some arrangement for monitoring the position of the antenna. Figure 4 shows a dial on the face of the control

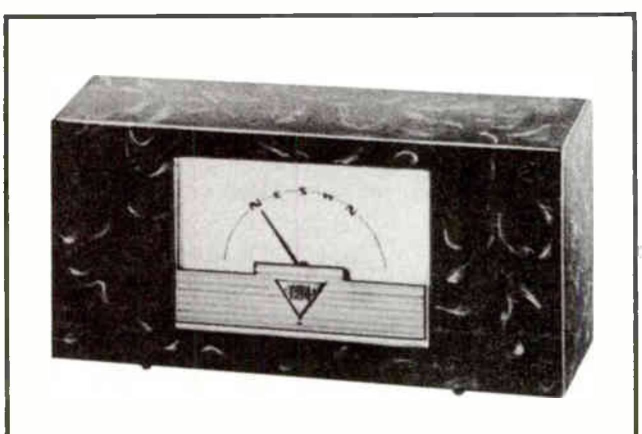

Fig. 4. Control cabinet for antenna rotator. (Courtesy Trio Mfg. Co.)

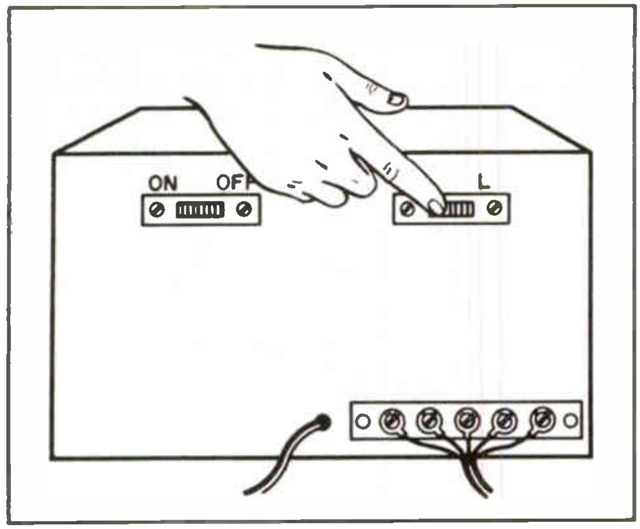

Fig. 5. Control switch mounted on rear panel of control cabinet.

cabinet, with an indicator needle. The dial is marked with the four principal points of the compass — north, east, south and west — with the dial pointer indicating the direction in which the antenna is pointing.

As the antenna is rotated from one position to another the dial pointer on the face of the control cabinet moves from one position to another. This is an item to which the installing technician must pay careful attention at the time installation is made.

The antenna must be mounted on the top section of the mast, and the mast correctly adjusted to the rotator, so the antenna is actually pointing north when the dial indicator on the control box is pointing north. This follows for the other compass directions. When the antenna is actually facing east the control cabinet dial should so indicate. The same is true for south and west.

The manner in which the viewer operates the control cabinet differs from one model to another. Some models have a push-button arrangement similar to those used to tune push-button radios. In most cases there are only two such push-buttons, one to rotate the antenna to the right, the other to rotate it to the left.

The model shown in Fig. 4 uses a sliding switch located on the back panel, just below the top of the cabinet. Figure 5 shows how the switch is positioned.

Moving the sliding switch in one direction causes the antenna to rotate to the right. Sliding it in the other direction causes the antenna to rotate to the left. Since the sliding switch is located in that particular position, the viewer can grasp the top of the control cabinet with his hand, then, with one finger, move the sliding control switch in the direction desired for the antenna.

The rotator revolves at a relatively slow speed. The finger holds the sliding switch in the rotating position until the antenna reaches the desired position. Then the switch is released, and the antenna ceases to rotate.

An "on-off" switch for turning the electrical power on and off is also mounted on the rear panel of the control cabinet. Some control cabinets omit the "on-off" switch. In fact, most models do not have a separate "on-off" switch.

A somewhat different method of controlling the direction of antenna movement is shown in Fig. 6. It shows a control cabinet used with a rotator built by the Radiart Company of Cleveland, Ohio.

Most rotators, and their cabinets, are designed so the two extremes of the antenna movement end in the direction of north. This means that when the antenna is rotated to the left as far as it will go, the movement stops when the antenna points north. When the antenna rotates as far as it will go to the right it also stops when it points toward the north.

This means that when such a rotator is installed the rotator should be rotated as far as it will go in one direction. Then the antenna is mounted on the rotator so it faces north. Then, if the wiring is correctly installed, the antenna will always be pointing in the direction indicated by the pointer dial on the control cabinet.

There is no technical requirement which forces the two directions of rotation to end when the antenna faces north. But that is the custom.

Section 6. MOTOR ACTION IN ROTATOR

While all commercially built TV rotators use electrical motors for motive power, it is also true that the same *kind* of motors are not used by all manufacturers. It is worth devoting a little attention to the motor, since the type of motor — or motors — used in any given situation determines, to some extent, the wiring circuits needed.

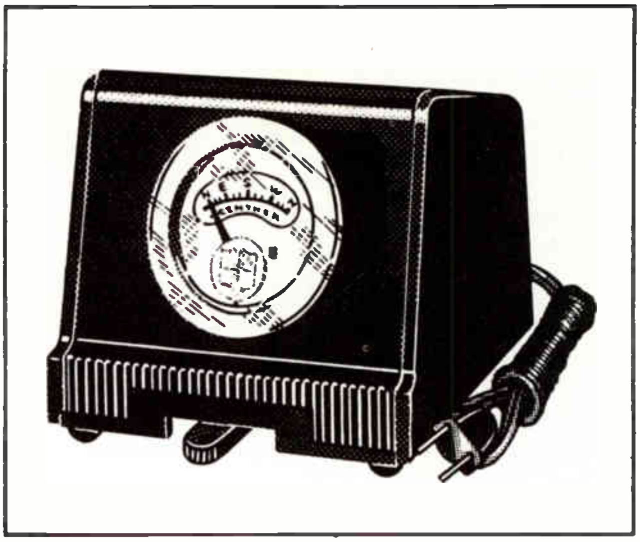

Fig. 6. Control cabinet with controls mounted on front.

Some manufacturers use a single motor as the source of motive power for the rotator. Others use a double motor, meaning a motor with double windings. Still others use two separate motors.

When a single motor is used its field windings are arranged so its direction of rotation can be reversed. When a double motor — or two motors — are used, one motor powers the antenna rotation in one direction while the other powers its rotation in the opposite direction.

The general practice is to design the motor for operation from relatively low voltage. This practice reduces the danger should a short circuit occur between one of the power lines and the metal mast. The lower voltage also reduces the danger of insulation breakdown. The voltage commonly used is 24 volts.

It is almost invariable practice to use AC power in these motors. This makes it easy to obtain the lower voltage. Power from the outside AC line is fed into a transformer in the control cabinet where it is stepped down to the proper voltage for operating the motor, or motors.

Section 7. ROTATOR USING DOUBLE MOTOR

When trying to understand the action of a rotator it is necessary to consider the control cabinet, with its included components, and the external rotator unit, mounted on the antenna mast, as a single operating unit. Neither is able to operate as an isolated, or separate unit. Each is dependent on the other.

In most cases the power for operating the rotator motor is developed inside the control cabinet, usually by transformer action. This means the power from the original AC source must pass through the control cabinet before reaching the motor. It is seldom desirable or possible to operate the rotator motors directly from the AC power line.

Furthermore, the mechanism for controlling the direction of rotation is usually included in the control cabinet, although this is not universal practice.

The indicating device on the control cabinet which shows the direction in which the antenna is pointing at any given instant is controlled by signals fed back from the rotator motor, or from some component within the motor housing. This means that the indicating signal is actually fed back from the motor action; it does not result from merely monitoring the electrical power fed to the motor from the control unit.

One type of rotator, which uses a double motor, is controlled from a control cabinet like the one shown in Fig. 7. The antenna is rotated by depressing the control lever shown on the front of the control cabinet.

The antenna is rotated in one direction by depressing the control lever to the right. It is rotated in the opposite direction by depressing the control lever to the left.

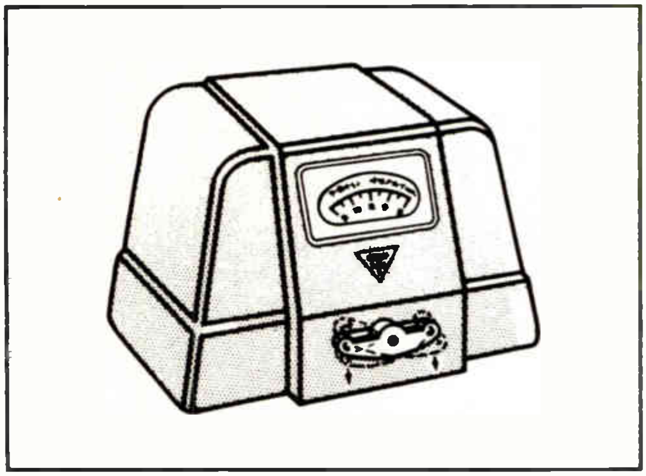

Fig. 7. Control cabinet with lever to be depressed to right or left.

Depressing the control lever in either direction closes an electrical switch which supplies electrical power to the operating circuits. Depressing it to the right causes one set of electrical actions, while depressing it to the left sets up a different train of actions.

But the main "on-off" switch is closed regardless of which way the control lever is depressed. This makes it possible to use a single control lever to turn the AC electrical power on and off, while simultaneously controlling the direction of rotation of the antenna.

The electrical wiring inside the control cabinet is shown in pictorial-diagrammatic form in Fig. 8. The electrical power needed to operate the entire rotator assembly is obtained through the AC line cord from any convenient 117-volt AC source.

AC power is fed into the primary winding of a step-down transformer. Control over the AC power is maintained by means of a leaf-type switch in the primary circuit. The leaf-type AC switch is actuated, or controlled, by the control lever mounted on the end of a shaft which extends outward through the front panel.

The mechanism of the control lever, and its shaft, are not shown in Fig. 8. But its action is not difficult to visualize. Both the *actuator*, which controls direction of rotator movement, and the on-off switch are operated by the shaft on which the control lever is mounted.

To better understand the circuit it is well to turn our attention to the terminal strip shown at the bottom of the diagram. The terminal strip is mounted on the back of the chassis where it is accessible for making wiring connections. It is to the terminal strip that wires of the control cable are connected. The control cable connects the control cabinet inside the house with the motor unit mounted high on the antenna mast.

The No. 2 terminal on the terminal strip can be looked upon as the "common" connection. This does not mean it is the "ground" connection; it is merely the *common* connection. In this particular system *no part of the circuit is grounded.*

When the *actuator* is moved by the control lever to the left a continuous circuit is made between the transformer and the No. 1 terminal on the terminal strip. When the wiring is all properly

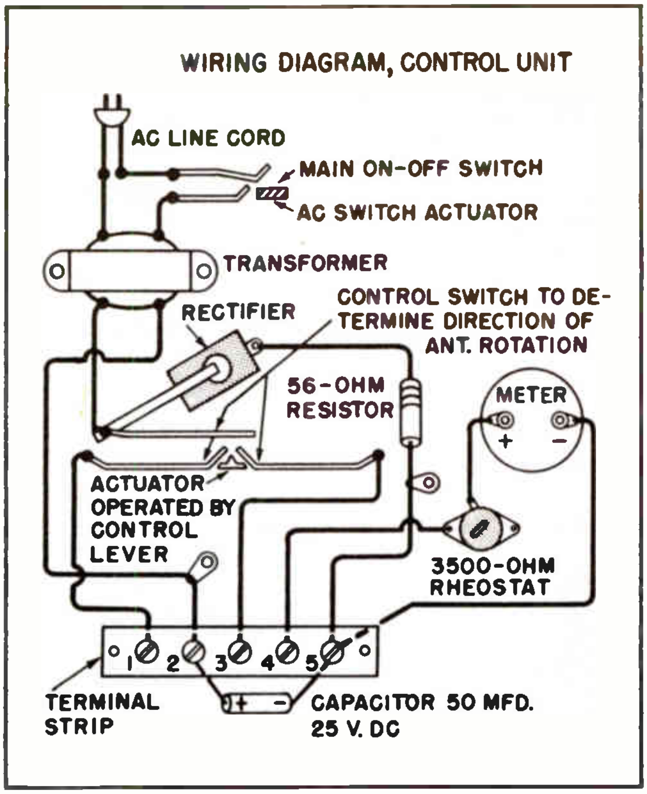

Fig. 8. Wiring inside control cabinet.

connected a complete circuit is then made from the transformer through the control switch to terminal No. 1, then through wire No. 1 to one of the motors in the rotator unit, then back through the "common" wire to terminal No. 2, and on back to the transformer.

That closes the circuit to that motor, and the antenna is rotated in one direction.

When the *actuator* is moved to the right a circuit is made between the transformer and the No. 3 terminal, and through the No. 3 wire to the second rotator motor, and back through the common wire to the transformer. That rotates the antenna in the opposite direction.

Whichever way the control lever is depressed acts to close the main AC on-off switch, thus supplying AC power to the transformer. Depressing the lever to the left causes the antenna to rotate in one direction; depressing it to the right causes it to rotate in the opposite direction.

How the act of energizing these two circuits affects the motors in the rotator unit on the antenna mast can be understood better by studying Fig. 9.

When the circuits shown in the figure are studied it can be seen that the circuits to terminals 1 and 2 of the control unit are connected directly to terminals 1 and 2 on the rotator unit. Following the circuits in the rotator unit it can be seen that when power is sent to terminals 1 and 2 of the control unit it acts to supply power to the motor shown in the upper left part of the diagram.

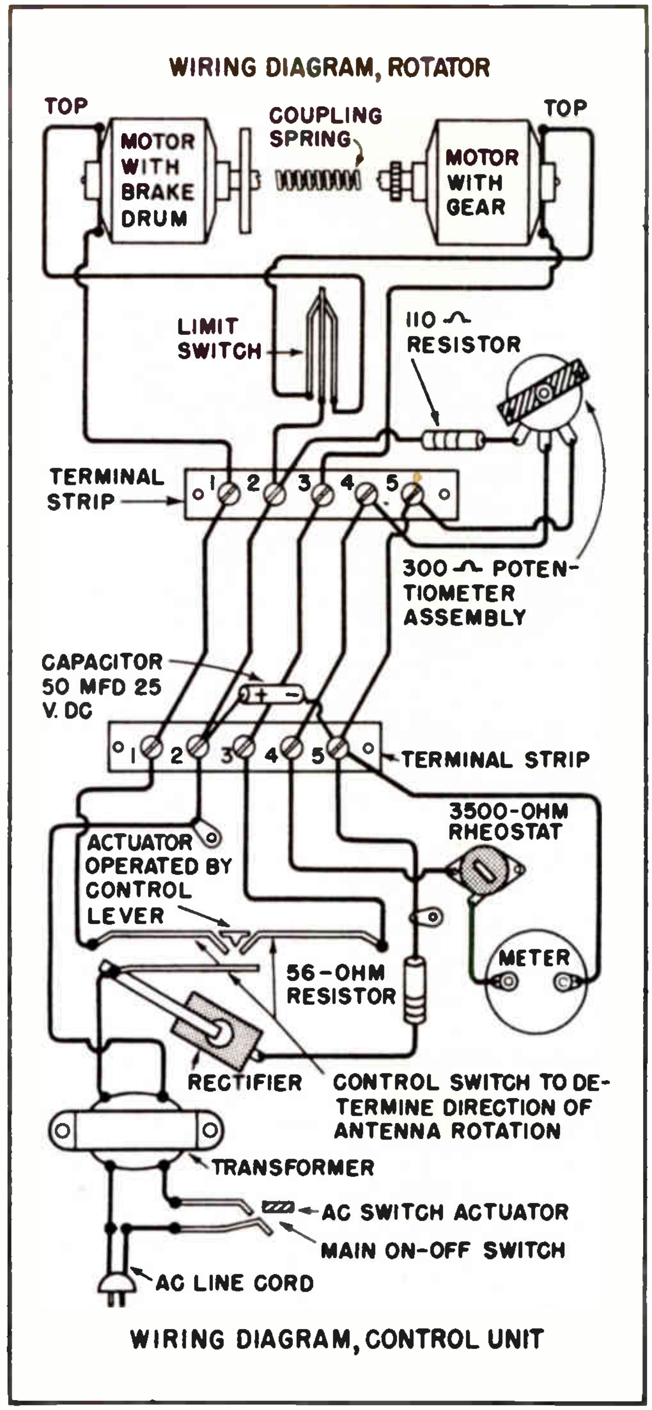

Fig. 9. Wiring to rotator unit.

To summarize this action, we can see that when the *actuator* is moved to the left by the control lever it closes the circuit to terminals 1 and 2, and supplies power to the motor on the left and causes it to operate. The motor will continue to operate so long as the control lever remains depressed, or until the limit switch is opened.

Section 8. ACTION OF THE LIMIT SWITCH

In this connection it should be noted that the return circuit from the left motor to the "common return" at terminal No. 2 is through the *limit switch*. The limit switch is normally closed, and so long as it remains closed electrical current can flow through it.

But that limit switch performs an important and useful service. It is well worth devoting a little attention to it.

A limit switch is an electrical device widely used with industrial equipment to limit the movement of a machine—or a machine part—when the movement is created by an electric motor. The limit switch is positioned at such a location that the movement created by the motor will cause the machine to strike the limit switch when the movement reaches or exceeds some predetermined limit.

The purpose of the limit switch is to prevent the motor moving the machine—or the machine part—farther in a given direction than is safe, or desired.

When the moving part strikes the limit switch, the switch is opened. When it is opened the circuit to the motor is broken, no more electrical power is supplied to the motor, and the motor stops.

The limit switch shown in Fig. 10 is one regularly used with the rotator whose action is being described. Its purpose is to prevent the antenna being rotated too far in either direction.

The limit switch is so positioned that when the antenna is rotated to point north a *stop* on the rotator strikes the limit switch, and it is opened. This breaks the circuit to that motor, and the rotator cannot be rotated in that direction any further.

It will be noticed that the type of limit switch used in this particular application is actually a double one. Normally both of the outside leaves of the limit switch press against the center one, and thus both sides of the circuit are closed. It is against the center leaf that pressure is exerted by the *stop* on the rotator.

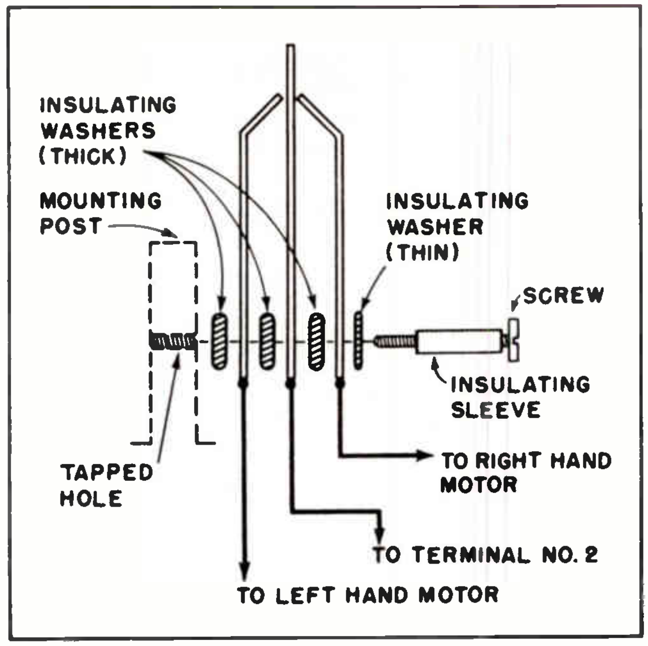

Fig. 10. Limit switch assembly.

When pressure is exerted on the center leaf from the left, the pressure acts to open the circuit between the center leaf and the left leaf. By referring back to Fig. 9 it can be seen that this opens the circuit to the motor on the left.

However, opening the circuit to the *left-hand* motor has no effect on the return circuit of the *right-hand* motor. That circuit is still closed.

The net effect is this: When the control lever on the control cabinet is depressed to the left it causes the left-hand motor in the rotator to rotate the antenna. The antenna will continue to rotate until the control lever is released or the *stop* on the rotator strikes the limit switch. If the stop on the rotator opens the limit switch the motor will stop, and the antenna cannot be rotated any further in that direction.

However, the return circuit from the *right-hand* motor is still closed. Therefore, if the control lever is then depressed to the right the antenna will start rotating in the opposite direction. It will continue to rotate in the opposite direction until the control lever is released or the *stop* strikes the center leaf of the limit from the opposite side after making a complete revolution from its previous position.

This means that when the limit switch is struck from one side it breaks the circuit from the left-hand motor but does so without interfering with the circuit from the right-hand motor. When it is struck from the opposite direction it breaks the circuit from the right-hand motor, but does not interfere with the circuit from the left-hand motor.

Section 9. ACTION OF INDICATING METER

The indicating device in this particular antenna rotator is a simple D'Arsonval meter. But instead of the dial being calibrated to read ohms, or amperes or volts, or other electrical unit, it is calibrated to read *compass directions.*

In order for the meter to indicate directions it is necessary to supply it with electrical power in such a manner that the magnitude of the current is varied as direction of the antenna is varied. This can be done by so mounting a potentiometer that it is rotated simultaneously with the rotation of the antenna, and so connected electrically that current to the indicating meter must flow through the potentiometer.

Since the meter uses a simple D'Arsonval movement it is necessary to supply it with a DC source of power. This is accomplished by placing a dry-disk rectifier across the AC line and rectifying a portion of the AC power into DC, then filtering it with a low voltage electrolytic capacitor.

The rectifier, indicating meter and filter capacitor are all mounted in the control cabinet. The potentiometer is mounted inside the housing which encloses the motors of the rotator unit. Connections between the potentiometer and the other components of the circuit is by means of two wires in the connecting cable. Wires 3 and 4 are used for this purpose. This can be seen by studying the diagram in Fig. 9.

Perhaps the electrical action can be understood somewhat better by studying the schematic diagram in Fig. 11. In that diagram the wiring is limited solely to those circuits directly involved with the indicating device.

The load on the rectifier consists of the 56-ohm

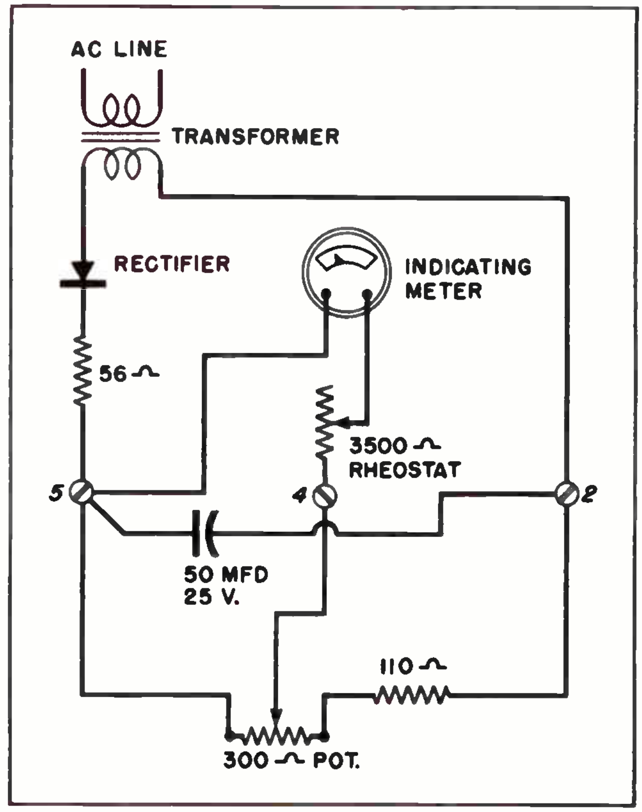

Fig. 11. Wiring to indicating meter.

fixed resistor, the 300-ohm potentiometer, and the 110-ohm fixed resistor connected in series. The meter is connected across a portion of the potentiometer.

It can be seen from this circuit that most of the voltage drop in the circuit is across the 300-ohm potentiometer. It can be further seen that the two fixed resistors are arranged so one is on each side of the potentiometer. Thus the fixed voltages at each end of the potentiometer are such that they never drop completely to zero, nor do they ever reach the maximum developed by the rectifier and transformer.

To get back to the voltage applied to the meter. That is a portion of the voltage developed across the potentiometer. Meaning—the indicating meter is connected across the potentiometer in such manner when the slider of the potentiometer is moved from one end to the other the voltage on the slider varies over a relatively wide range. That voltage, thus developed at the slider, is applied to the meter movement through the 3500-ohm rheostat.

The rheostat is mounted on the rear panel of the control cabinet. Its function is to act as an adjustment for the meter, to aid in its proper calibration.

The slider arm of the potentiometer is mechanically coupled to the shaft of the rotator. Sometimes this coupling is direct; in other cases it is through gears.

When the rotator is at its extreme position in one direction the slider of the potentiometer is at zero. At that instant there is no voltage across the meter, and its pointer reads zero.

The meter dial is so calibrated that the pointer indicates "North" when in zero position.

As the rotator shaft is rotated, under the influence of its motor, the slider of the potentiometer moves toward the right. As it moves it causes a higher voltage to be placed across the meter movement. This, in turn, causes the meter dial to swing slowly across the dial.

If the rotator is designed so the antenna is rotating from north to northeast, then east, then southeast, and so forth, around to northwest and finally to north again, the dial of the meter would be calibrated in like manner.

As the antenna is rotated to face east the pointer on the meter dial swings a quarter of the distance across its face so it points to the word "East." As the antenna is rotated further, to face south, the voltage across the meter is also increased and the pointer swings further across the dial to the word "South."

And so it goes. By the time the rotator has swung the antenna in a complete revolution so it again faces north, the pointer on the meter swings to the extreme right side of the dial to face the marking "North." All of which means that such a dial would normally have five words on the dial. Beginning at the left side they would read "North-East-South-West-North."

There is no reason why the forward movement of the antenna could not be in the opposite direction. In that case the dial would be calibrated "North-West-South-East-North." But this latter method is not used so widely as the first mentioned.

Occasionally, the more elaborate control cabinets have their dials calibrated to read eight

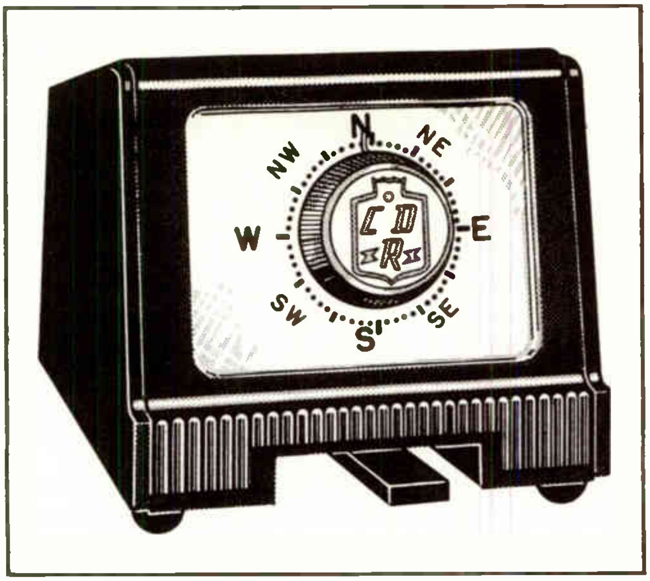

Fig. 12. Indicator calibrated for 8 compass positions.

points of the compass instead of only four (see figure 12), but such are exceptional.

One noteworthy feature of the complete rotator circuit just illustrated is that the connecting cable between the control cabinet and the rotator unit contains five wires. Some other types of rotators require only four wires, and this fact is often hailed by the manufacturer as an advantage.

It is hard to work up much interest whether the cable contains four wires or five, or more, but some installation technicians are influenced in favor of the fewer wires needed for proper installation.

Section 10. SINGLE MOTOR ROTATOR

Instead of using two completely separate motors—one to rotate the antenna in one direction, the other to rotate it in the opposite—another method is to use a single motor with *two* different windings. In this latter case one set of windings is used to rotate the motor in one direction, the other set to rotate it in the opposite direction.

It is possible, of course, to use a single set of windings; then mechanically reconnect them for the purpose of reversing the motor. This method is entirely possible from an electrical point of view, and is the method followed in reversing electrical motors in many other kinds of applications. But it is scarcely practical under the conditions in which rotator motors operate.

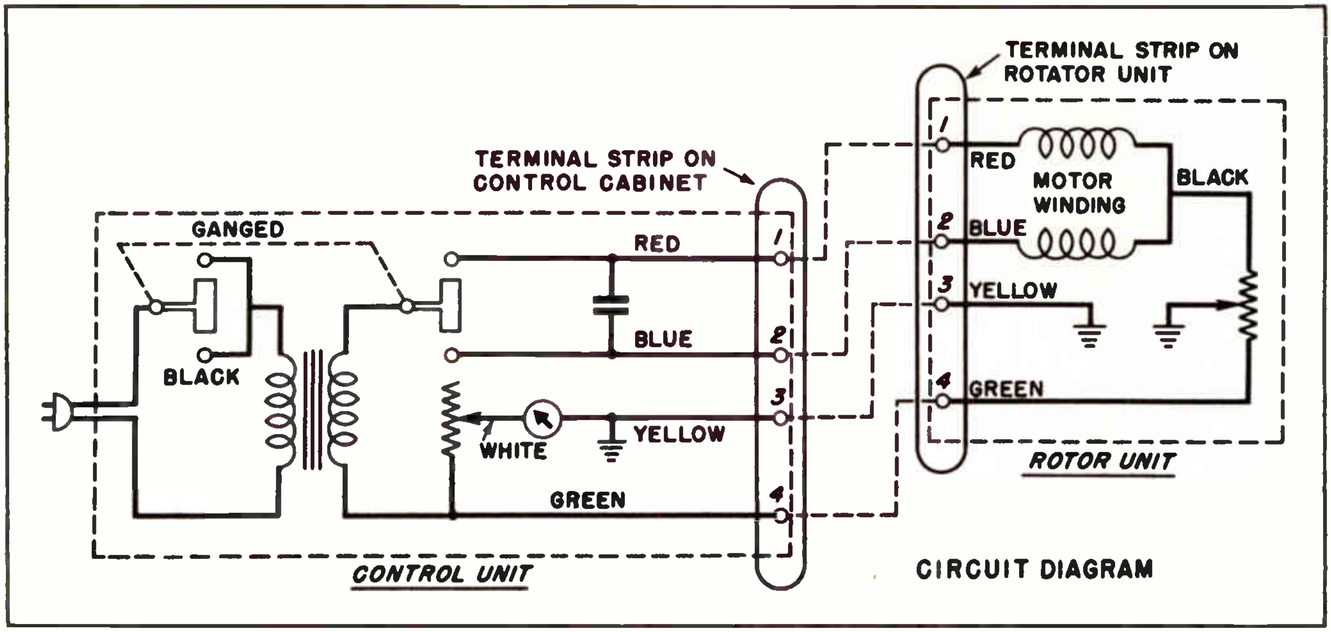

Fig. 13. Four-wire connections to single motor with double windings.

The more practical method is to use a single motor with two separate sets of windings. The wiring to such a motor is shown in Fig. 13.

The circuit (figure 13) shows that only four wires are needed in the control cable between the control cabinet and the rotator unit. A careful study reveals little difference in the manner in which power is sent to the motor. But there is a difference in the wiring between the potentiometer in the rotator unit and the meter in the control cabinet. Such a wiring circuit requires a different type of meter.

The meter used in the circuit in Fig. 13 must be either an AC meter, or a D'Arsonval meter with built-in rectifier. The rectifier and filter are not separate, as was the case with the circuits shown in Figs. 8 and 11.

Section 11. THE DRIVING MOTOR

When a motor for an antenna rotator is first considered one might easily suppose a relatively powerful motor is necessary. A little thought brings the realization that such is not necessarily true.

Most motors have a relatively high revolutions per minute (r.p.m.). In small motors the rpm is quite regularly in excess of 1000. Motors used in this kind of work usually have a speed close to 1800 rpm.

It is neither necessary nor desirable that the antenna be caused to rotate at a high rate of speed. In fact, it is much more desirable that it rotate quite slowly; in most cases at not more than a single revolution per minute.

This means there must be a radical reduction in speed between the motor shaft and the rotator shaft. Such reduction in speed automatically multiplies the force which even a small fractional horsepower motor is able to apply to the antenna shaft.

Figure 14 provides a pretty good idea of the appearance of one type of motor used in many rotator units. Power from the motor is delivered by the small pinion shown on the end of the shaft.

When the motor is firmly mounted on its mounting plate the pinion extends through the large hole shown in the center of the assembly plate. There it engages a large intermediate gear for the first step in the speed reduction process.

Some idea of the position of the intermediate gear can be obtained by studying Fig. 15.

After passing through reduction gears, the power is applied to the worm gear. The worm gear engages with a helical-cut gear mounted on the shaft which holds the antenna mast.

When the motor supplies power through the

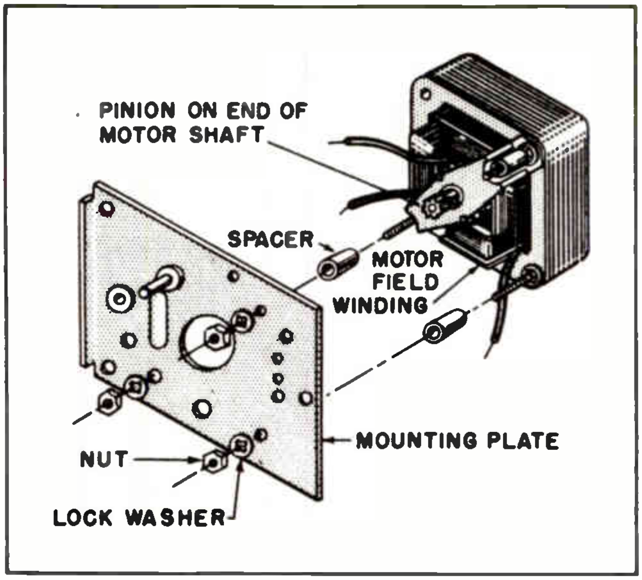

Fig. 14. Rotator motor and its mounting assembly.

reduction gear train to the vertical shaft, the shaft is rotated. As the shaft rotates, the antenna also rotates.

Section 12. CIRCUIT FOR ROTATOR REQUIRING MULTI-WIRE CABLE

One type of antenna rotator which avoids use of an indicating meter and potentiometer is shown in Fig. 16. It uses a series of dial lamps, one positioned at each of the four principal points of the compass.

Instead of a potentiometer being mounted on the rotator shaft for the purpose of sending a signal back to the indicator meter, a series of switches are located around the shaft. As the shaft rotates under the action of the motor a moving contact makes electrical contact successively with one after another of the contacts.

Each of the contacts is connected electrically with a dial lamp on the control panel. By observing which of the lamps is lighted the viewer can tell in which direction the antenna is pointing.

There are both advantages and disadvantages with this system. The dial lamps are less expensive than the meter; and cost of the contact switches is probably less than that of the potentiometer. Furthermore, when properly connected, and everything is working properly, the cabinet is probably somewhat more attractive and interesting than one using a meter.

On the other hand, this arrangement requires a cable with at least eight wires, instead of the four or five used with other systems already described. Unless the technician making the installation is quite careful there is always the danger of getting wires connected to the wrong terminal. The eight-wire cable also costs more than the four-wire cable.

A fairly good idea of the appearance of the control cabinet can be obtained by studying Fig. 16. The cabinet has some resemblance to the base of a French-type telephone, with the indicating dial having some points of similarity to a telephone dial.

The exact manner in which the dial is marked or decorated varies from one manufacturer to another, and from one model to another. But the one shown is taken from an actual working model and can be considered as being reasonably typical.

Section 13. MOUNTING THE ANTENNA SHAFT

The antenna shaft, which actually carries the antenna, is rigidly fastened into the receptacle on

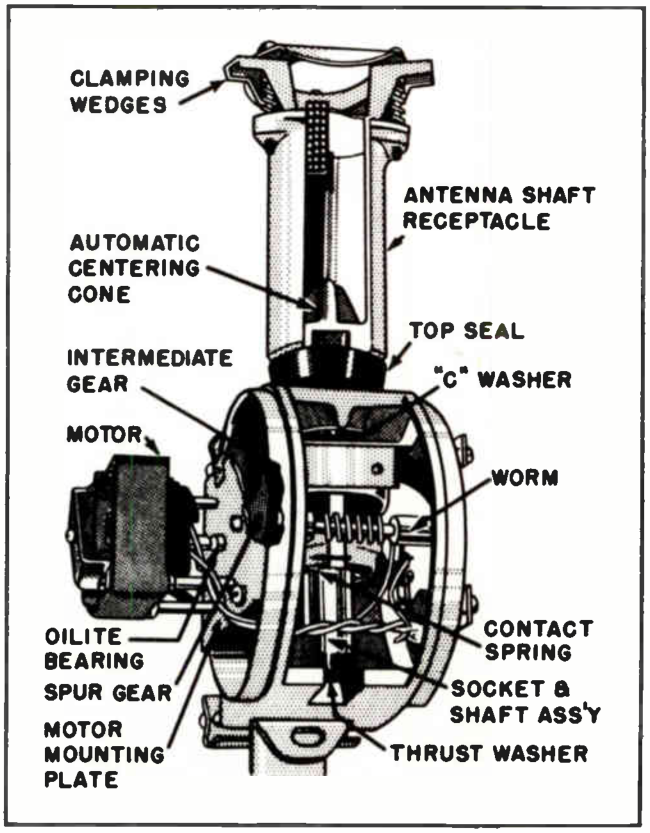

Fig. 15. Motor and reduction gear assembly.

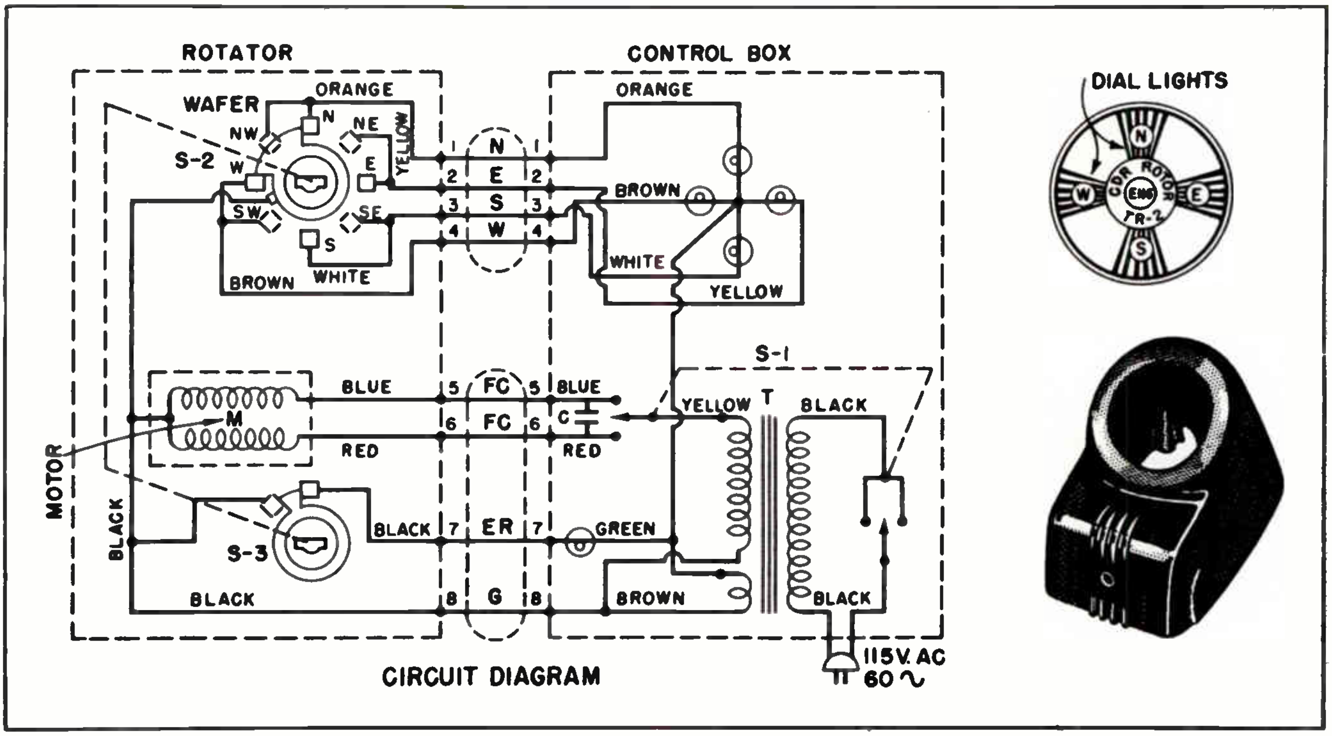

Fig. 16. Circuit needed with rotator indicator using dial lamps.

top of the rotator unit provided for that purpose. If the antenna is not too elaborate or too heavy the shaft is simply dropped into the shaft receptacle shown in Fig. 15, and the clamping wedges tightened to hold the shaft tightly in place.

When the antenna is quite heavy, such as those used in remote fringe areas, especially where stacked arrays are necessary, added precautions are frequently taken.

Instead of mounting the rotator at the extreme top of the supporting mast, it is mounted some three to five feet below the top. The antenna shaft is then dropped into the shaft receptacle in the normal manner, but a supporting bracket is mounted at the top of the mast to support the antenna shaft.

The drawings in Fig. 17 show better than words how this is done. The support bearing for the antenna shaft is shown in detail.

Clamps of the bearing are adjusted to support the antenna shaft, but are not tightened sufficiently to interfere with the free rotation of the shaft. The bearing itself is rigidly clamped to the supporting mast to provide firm support. Use of the supporting bearing provides added support to take the extreme thrusts to which the antenna shaft is subjected when the antenna is exceptionally heavy.

Since such antennas are often raised to extreme heights, and are subjected to the full force of winds, rain and ice, the antenna shaft is often

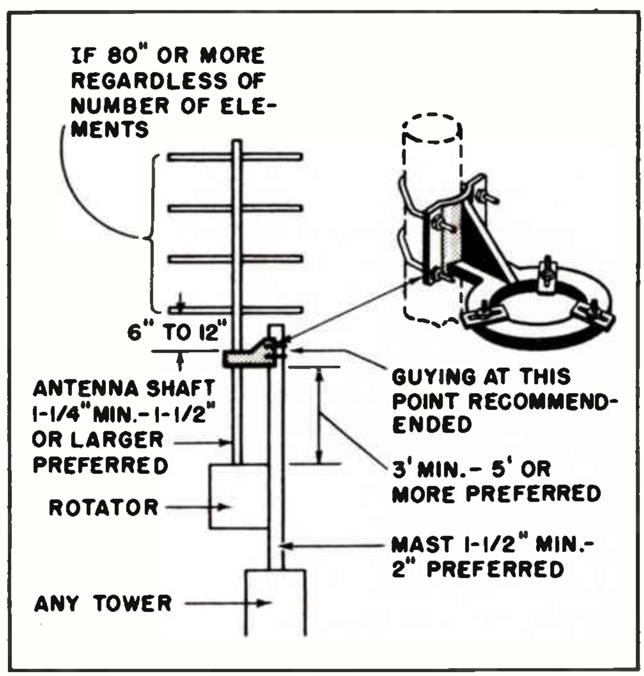

Fig. 17. How added support is given heavy antenna.

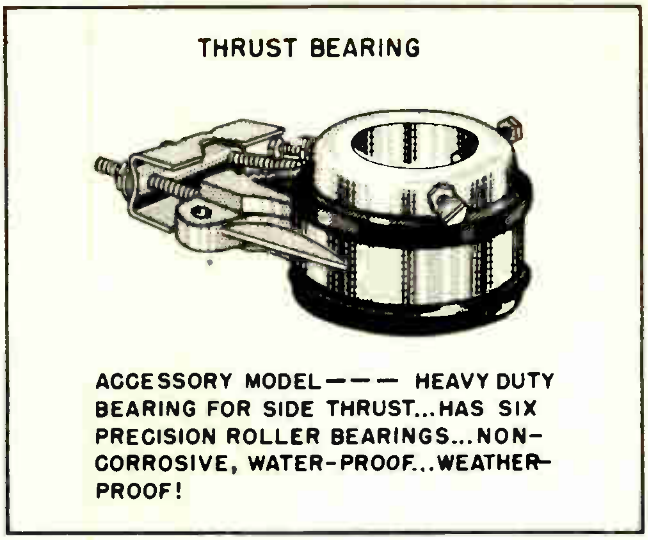

Fig. 18. Ball-bearing support.

called upon to withstand terrific strains. The support bearing helps the shaft withstand such strains.

A somewhat more elaborate thrust bearing for supporting the antenna shaft is shown in Fig. 18. This is a ball bearing type.

The thrust bearing shown there is clamped rigidly to the antenna mast with three set-screws. The outer part of the bearing is rigidly mounted to the supporting frame, which is clamped to the supporting mast resting on the ground. The two parts are friction-free from each other because of the ball bearings between them.

Section 14. RADIAL TYPE ROTATORS

Some persons object to the offset between the supporting mast and the antenna shaft. They prefer the antenna shaft be mounted directly above the supporting mast.

This can be arranged by using a rotator with a different type of design. The LaPointe Electronics Company, manufacturers of several types of well known antennas, builds such a model. Rotators having similar appearance are also built by other companies.

A cutaway drawing, which shows the working mechanism of such a rotator, is shown in Fig. 19. The speed reduction gear chain is shown to good advantage in the drawing.

The driving motor in this model is rigidly mounted below the gear reduction train. Power from the final reduction gear is applied through a pinion to a large spur gear mounted under the rotating socket into which the antenna shaft fits.

Note the provisions for centering the rotator. The rotator itself is centered on the supporting mast by the cone-shaped *aligner* located beneath the motor. Being cone shaped, the supporting mast automatically slips into it until it finds the exact center. Once positioned, the chuck-type clamps are tightened around the supporting mast to hold the rotator rigidly in place.

The method of aligning the antenna shaft on top of the rotator is quite similar. A cone-shaped guide is molded into the bottom of the hole into which the antenna shaft fits. When the antenna shaft is slipped into the mounting hole it is auto-

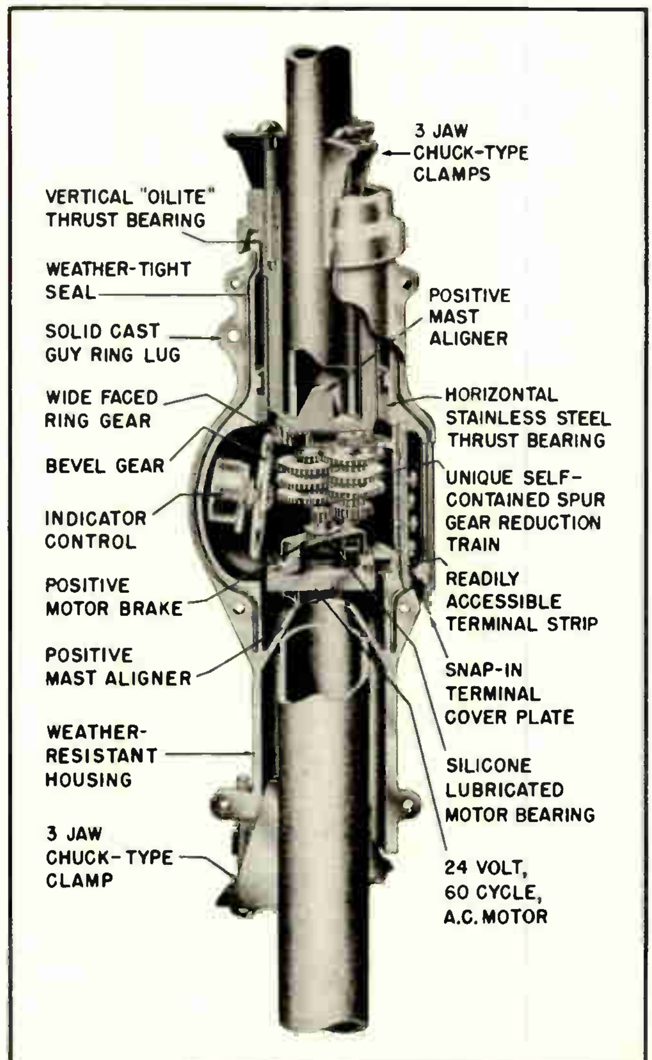

Fig. 19. Cutaway drawing of Radial type Rotator.

matically guided to a position which is exactly in the center of the hole.

Once positioned, the chuck-type clamps are tightened by screws until the antenna shaft is locked rigidly in place.

The indicator control, which supplies the varying voltage for the indicating meter in the control cabinet, is shown to the left of the motor. The potentiometer is directly geared to the spur gear on the bottom of the antenna shaft socket. The gearing has a 1:1 ratio; meaning there is only one revolution of the potentiometer for each revolution of the antenna shaft.

All wiring from the potentiometer and motor is brought out to a terminal box on the side of the housing which encloses the motor and gear train. A removable cover over the terminal strip provides ready access for installation purposes, and also for checking conditions of the circuits should that ever be necessary.

Section 15. INSTALLING AN ANTENNA ROTATOR

A few generalized instructions for installing an antenna rotator can be given. But the exact manner in which any given rotator should be installed often depends on characteristics which are peculiar to that particular model. Therefore, before installing any specific antenna rotator the instructions applying to it should be carefully studied.

The manufacturer of each unit knows better than anyone else the manner in which it performs best. The instructions he provides for its installation are the result of experience, and are well worth heeding.

The supporting mast on which the rotator is mounted should be as large as possible, or as large as practical. The stronger the mast the less likely the antenna will be damaged by wind and ice.

The cable to the rotator should have sufficient freedom to move as the antenna is rotated, but should not be permitted to flap freely in the breeze. If the mast is quite high it is usually advisable to support the cable firmly by attaching it to the mast.

During the process of installation care should be taken that the antenna actually faces north when the indicator on the control cabinet indicates "north." This point is emphasized because it is quite easy to make a mistake, especially on the first installation, and wind up with an antenna which rotates counter to the indication of the dial, or which actually faces in a different direction from that shown by the indicator.

Always use the type of cable recommended for use with each specific rotator. In many cases the correct cable is furnished with the complete rotator, but this is not universal practice. Do not use a cable which does not have sufficient wires to handle the rotator.

Section 16. TROUBLE-SHOOTING A ROTATOR INSTALLATION

Antenna rotators are strongly and ruggedly built. Every effort is made to build them so they will be practically free from trouble.

Nevertheless, they are exposed to the weather. Winds strain at them; ice forms on them; they are subjected to alternate extremes of heat and cold, dry weather and rain. Winds tug at the operating cable, and sometimes causes it to fray and become detached from the terminals to which its wires are connected.

Near the seacoast, salt air sometimes penetrates to the inner working parts of the rotator and sets up corrosion. In some industrial areas chemical fumes have a deteriorating effect on the outer covering, and sometimes penetrate to the inner working parts.

All of which means, that despite the best intentions and care of the manufacturer and the installer, antenna rotators do occasionally require servicing attention. In which case it is always convenient for the servicing technician to know something of the manner in which the rotator operates, and for him to be able to diagnose the symptoms to determine which component is most likely causing improper operation.

Trouble-shooting a rotator and its control circuits when trouble develops follows much the same common sense principles which must be followed when trouble-shooting any other electrical or electro-mechanical device. The first thing to determine, of course, is just exactly what is causing the malfunctioning action.

In most cases the symptoms displayed go a long way toward pinpointing the cause of the trouble. The symptoms listed below are certainly not the only ones found in servicing this type of equipment. However, they probably occur more often than any others.

Some symptoms, and what to look for when each of them is present, are listed below:

Symptoms:	Possible trouble and its correction:
Rotor does not operate. Indicator lights do not operate.	a. Line cord may not be plugged in. b. Fuse may be blown in AC power line. c. Cable wires may not be correctly connected. d. Transformer primary may be open. e. Possible open circuit in line cord. f. "On-off" switch may be defective.
Rotor does not operate, but indicator works properly.	a. Open circuit in indicator wires in cable. b. Broken gear in reduction train. c. Burned out rotor motor. d. Motor shaft frozen by cold weather.
Rotor operates, but indicator does not operate.	a. Defective leads in indicator circuit. b. Defective indicator potentiometer. c. Meter, or pilot lamps, burned out. d. Open resistor in meter circuit.

In connection with the above list of symptoms it must be kept in mind that all rotators do not use the same type of circuits, nor do they employ exactly the same kinds of mechanical parts. This means that a type of symptom which might apply in one situation would not necessarily apply in another.

Furthermore, the electrical and mechanical construction of some rotators is somewhat more elaborate and complex than those in other brands or models. It is possible in such cases for a malfunctioning of some type to occur which would not be possible in a more simple piece of equipment.

In most cases, the manufacturer of the rotator provides operating manuals showing exactly how the apparatus is constructed, how it is to be installed, and what to look for when it does not function properly. If such a manual is available it should be studied to learn if there is any peculiar circuit or component used which is not commonly used on all rotators.

In the final analysis, ordinary good common sense, coupled with a knowledge and understanding of electrical apparatus, is the best guide to locating a defective part, or an improperly functioning piece of equipment.

Most of the commercial rotators now on the market do a remarkably good job, and are reasonably free from trouble. But all such rotators are a part of the antenna installation; they are located outside where they are subject to all the fury that weather elements can impose on them.

Winds and ice formations impose tremendous stresses on them. This is especially true when the antenna is a multi-element array, and is raised to extreme heights. The strain is multiplied in those localities where the wind velocities occasionally reach extremes of 80 to 100 miles per hour.

No matter how good a rotator is used, it can do its job no better than the quality of the installation. If the installation is sloppy, if there

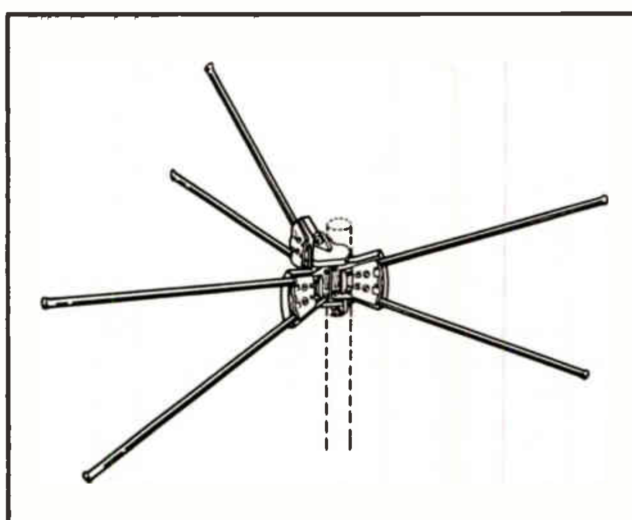

Fig. 20. All-directional Antenna.

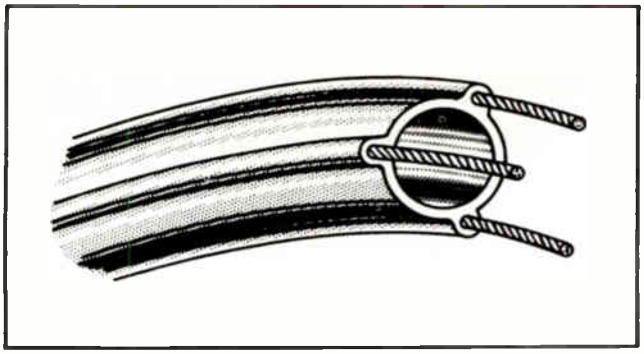

Fig. 21. Three-wire transmission line used with All-Directional antenna.

are not enough guy wires or if they are too small, if the rotator is too small for the type of antenna array with which it is used, one can expect trouble sooner or later.

Section 17. ALL-DIRECTIONAL ANTENNAS

In an effort to design a TV antenna capable of picking up signals from all directions, yet avoid the trouble and expense of installing an antenna rotator, several manufacturers came up with what they called "All-directional" antennas. Various names have been used by various manufacturers. One is called the *Directonic* antenna; another is simply called *"All-direction,"* others have been called by other names.

Basically, all operate on similar principles. They utilize the principle of the tilted conical. But instead of having the conical face in only one direction, it is built in three sections so it faces in three different directions. The sketch in Fig. 20 gives a pretty good idea of the arrangement of the arms of the antenna.

Instead of the antenna having only two arms, as is customary with most conical antennas, the all-directional arrays use three arms. The three arms are set at angles of 120° with each other, as is indicated in the figure.

The transmission line lead-in from the antenna uses three or four wires rather than the two wires commonly used in most 300-ohm transmission line. At the receiver is a switching arrangement which makes it possible for the viewer to select which two-arm combination he desires to use for any given reception.

The theory is that the antenna, having three faces, is actually able to receive signals from all directions. The direction from which a signal is being received at any given instant is determined by the specific pair of wires in the transmission line which are used at that instant.

The drawing in Fig. 21 shows one type of three-wire transmission line used with this type of antenna. At the antenna one wire is connected to each of the three sections of the antenna.

The manner in which the antenna is expected to pick up signals from various directions is shown

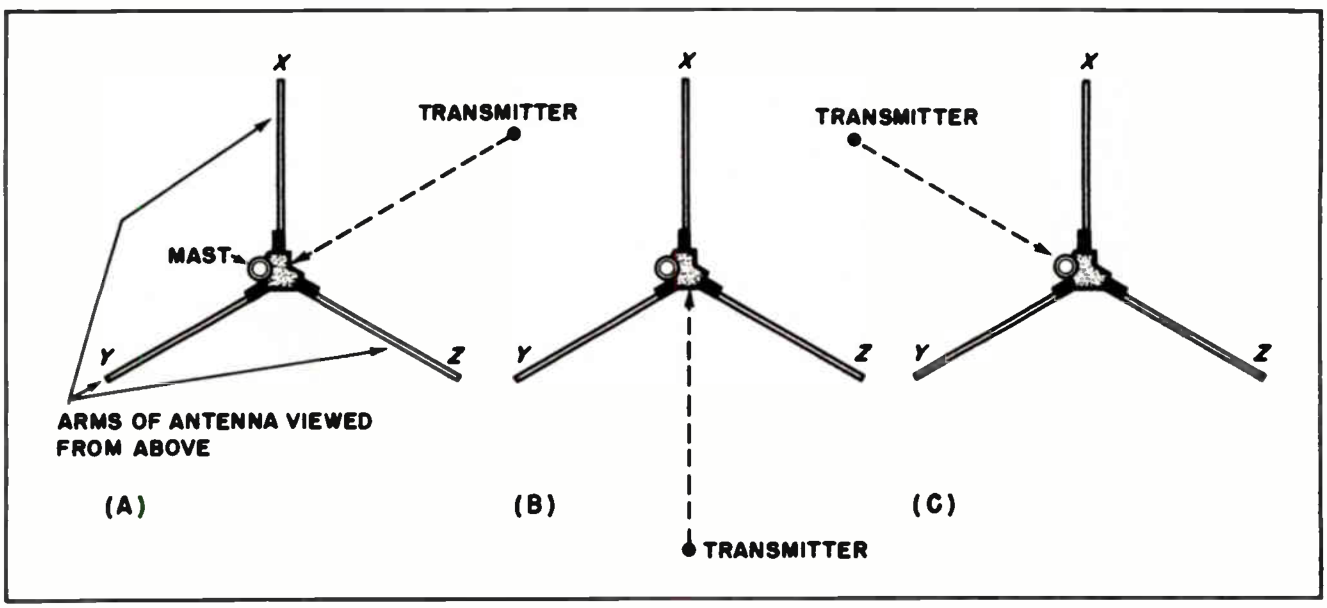

Fig. 22. How antenna picks up signals from different directions.

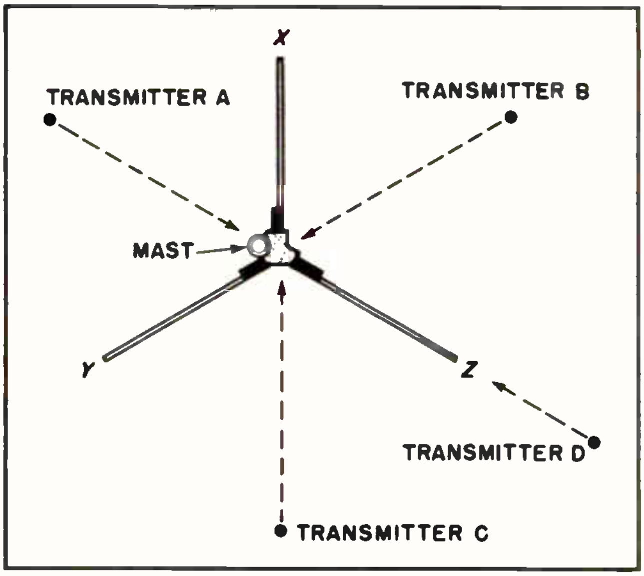

Fig. 23. Sometimes transmitters are positioned so all are not readily receivable.

in Fig. 22. The three arms of the conical antennas are designated by the letters X and Y and Z. The arms are in the position they would occupy if viewed from above.

In part *A* of Fig. 22 we see a signal arriving from a transmitter so the signal strikes arms X and Z broadside. In this case the wires in the transmission line connected to those two arms are connected through the switch at the receiver so they feed directly into the tuner. When so connected arms X and Z of the antenna act as any other conical antenna.

If the signal were arriving from a transmitter in another direction, such as shown at *B* in Fig. 22, the wires in the transmission line would be connected differently at the receiver. The signal would be arriving so that it strikes arms Y and Z broadside, and thus those two arms act as an ordinary conical antenna. In that case the switch at the receiver would be readjusted so the wires from those two arms feed directly into the tuner of the receiver.

Much the same is true if the signals arrived from still a third direction as shown at *C* in figure 22. In that case the wires in the transmission line leading from arms X and Y are so connected as to feed directly into the tuner of the receiver.

In theory this all works out very well. And, in many practical installations the antenna is reasonably satisfactory.

Occasionally, however, transmitters are so positioned with respect to the location of the antenna that all cannot be received broadside. In that case, one or more transmitters do not come in with full strength at the antenna. One such situation is indicated in Fig. 23.

If the antenna in Fig. 23 were positioned to favor the first three transmitters the signal from transmitter *D* would not be received well. If all stations were quite distant, one or more may not be received at all.

One other drawback to this type is its lack of sensitivity. The conical, by its characteristic nature, is a broadband antenna. But it does not have the gain, or sensitivity, of some of the other types. Nor does it have the high front-to-back ratio of sensitivity. This makes it less desirable for use in remote fringe areas where all signals are weak.

The all-directional antenna has one advantage in its comparative low cost. It has considerable usefulness where the signal strength from all receivable stations is relatively high. But it is defi-

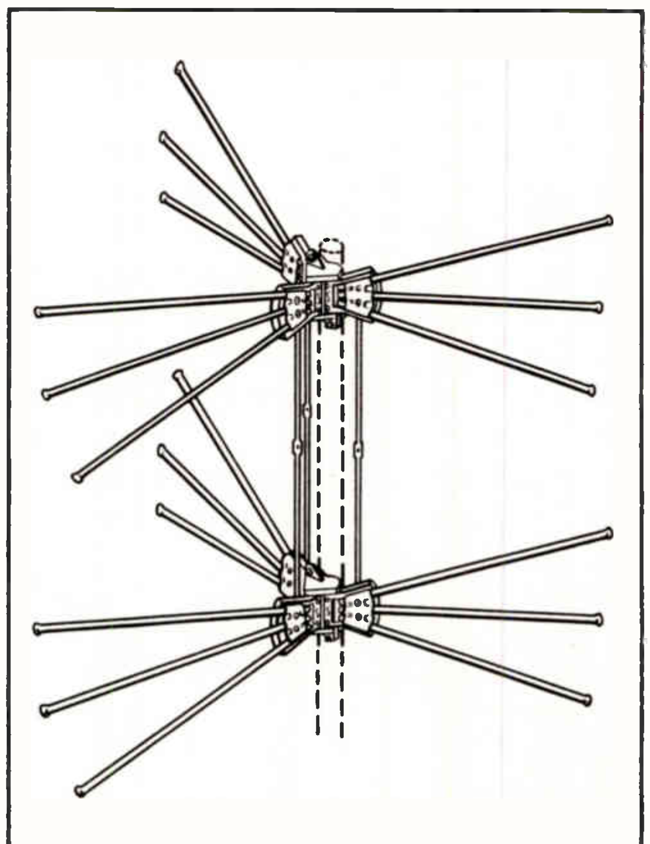

Fig. 24. Dual-Bay All-direction Antenna.

nitely a compromise type of antenna, and its selection in remote fringe areas where all signals are weak is not generally recommended.

On the other hand, in those areas where reasonably strong signals can be received from several directions, the antenna has proven its utility. It has the advantage of low cost, reasonable sensitivity, no need for rotator and its wiring, and reasonable freedom from service problems.

Some increase in the sensitivity of all-directional antennas has been achieved through use of dual-bay types. A dual-bay all-direction antenna consists of two active antenna elements stacked so one is above the other, then both connected together electrically before feeding into the transmission line. Some idea of the appearance of such antenna is shown in Fig. 24.

A dual-bay antenna is more sensitive than a single-bay, but is still not comparable in sensitivity to some of the higher gain antennas of other types. It is even possible to stack a pair of dual-bay antennas to increase the sensitivity still further. But it is debatable if anything is actually gained by such multiple stacking.

The cost of a pair of dual-bay all-direction antennas, stacked to present four active antenna elements in each direction, is not greatly different from the cost of a more sensitive antenna operated with a rotator. The all-direction antennas do not have a very high front-to-back ratio of sensitivity, meaning that signals from the back are closely comparable in strength to those received from the front. In areas where ghost conditions are bad this is not desirable.

Furthermore, in those areas where it is possible to receive signals from two stations operating on the same channel, but in opposite directions, the all-direction antenna is not especially desirable.

Whether or not an all-direction antenna is desirable in any specific location depends on a number of factors. These factors should be carefully considered.

Distance to the transmitters, strength of the incoming signals, comparative levels of the signal strength from several stations, direction of the transmitters, ghost conditions, and cost of installation. All these are determining factors, and all must be taken into consideration.

NOTES FOR REFERENCE

When television was new broadcast stations were few, and usually grouped fairly close together. There was little need for a receiving antenna to face in more than one direction.

After the freeze on new broadcast stations was lifted by the FCC it became possible for viewers in many localities to receive programs from several directions. Then it became necessary to provide some means for rotating the antenna to face the direction from which a desired program was coming.

A device to rotate a receiving antenna to make it face in any desired direction is called an *antenna rotator.*

Antenna rotators were used by commercial radio operators, and by radio amateurs, for many years before they were adapted for use with TV antennas, but were rarely used for ordinary radio broadcast reception.

An antenna rotator consists of an electric motor, a train of speed reduction gears, and some kind of control and indicating device.

A train of reduction gears is needed because the motor is usually small in size, and operates at relatively high speed, whereas it is desirable that the antenna rotate slowly.

An indicating device is needed so the viewer can determine in what direction his antenna is facing without having to go outside to visually inspect the antenna.

In many rotators, devised for the commercial market, the indicating device is an ordinary D'Arsonval meter with the dial calibrated with the points of the compass. A few rotators use dial lamps to indicate the direction.

Most rotators use a control cabinet with the control lever mounted on the front panel; but at least one model uses a sliding switch mounted on the back panel, just below the top, where it can be manipulated by the viewer's fingers when the cabinet is grasped in the hand.

Most rotator controls have the "on-off" switch mechanically coupled with the direction control lever, but a few models use a separate "on-off" switch.

A few rotators use one motor to rotate the antenna in one direction and a second motor to rotate it in the opposite direction—but most rotators use a single motor with separate windings for the two directions of rotations.

Most rotators prevent the antenna rotating too far in either direction by using some type of *limit switch* to shut off power to the motor when it has rotated as far in one direction as is desirable.

It is general practice to have limits of rotation arranged so the antenna is facing north at each limit. There is no technical reason why any manufacturer cannot deviate from this practice should it seem desirable.

It is usually necessary to limit the rotation of the antenna to one complete revolution. Rotation of the antenna much further in either direction would result in tangling or twisting of the power cable and signal transmission line.

The antenna shaft between rotator and antenna can be strengthened by offsetting the mounting of the rotator from the supporting mast, then providing additional bracing for the antenna shaft. Such mounting is often desirable in extremely high antenna installations.

Placing a rotator on the upper part of a high antenna mast places an increased weight on the mast. This makes it even more important than normal to have the mast well guyed.

A high antenna mast, with a rotator and an array of several elements, is an expensive installation. Wind or ice damage can mount into the hundreds of dollars. It does not pay to skimp on the cost of such an installation.

All-directional antennas which do not require a rotator are available.

Sensitivity and directivity of all-directional antennas limit their usefulness so they are impractical in some localities. In other localities they work well

NOTES

SYMBOL OF PROFICIENCY