2-WAY MOBILE RADIO handbook

by JACK HELMI

INCLUDING COMPREHENSIVE SECTIONS ON:
Basic Systems • Receivers • Transmitters • Control Systems • Power Supplies • Servicing • Setting Up The Shop

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2-WAY MOBILE RADIO handbook

by JACK HELMI

2-Way Mobile Radio Handbook presents the complete story on mobile radio for the benefit of those interested in mobile-radio servicing, as well as buyers and users of the equipment. The author, who has had years of experience in mobile radio, has thoroughly covered his subject by presenting the operational theory of basic systems, receivers, transmitters, control systems, and power. An extensive discussion on servicing, plus pointers on setting up the shop for servicing, are also given. His down-to-earth explanations of circuits you will actually encounter in the field, along with the numerous illustrations he has included, are a boon to anyone interested in mobile radio.

HOWARD W. SAMS & CO., INC.
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$3.95

Cat. No. MRS-1

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HOWARD W. SAMS & CO., INC.
THE BOBBS-MERRILL COMPANY, INC.
Indianapolis • New York

FIRST EDITION

FIRST PRINTING—MARCH, 1960

2-WAY MOBILE RADIO HANDBOOK

Library of Congress Catalog Card Number: 60-8905

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INTRODUCTION

The Federal Communications Commission has granted authority to equip more than one million vehicles with two-way radiotelephone equipment. The art, known as *mobile radio,* is expanding at an unprecedented rate. It has been spurred on by the recent revision of FCC rules which opens regulated radio communications to almost every type of lawful commercial enterprise—to all branches of local and national government, and even to every citizen of the United States. Equipment sales are running close to $100,000,000 a year.

Two-way radiotelephone communication is not really new. However, it was not until after World War II that the industry became of significance. At this time, the FCC allocated frequencies to various types of businesses and local governments. Equipment manufacturers immediately turned seriously to the development and manufacture of commercial two-way radio equipment.

Since 1946, much progress has been made. Yet, much of the equipment manufactured between 1947 and 1950 is still in use.

The demand for radio communications grew so fast that it was not long before the available radio channels became overcrowded. Recently the FCC expanded the radio spectrum by dividing the available bands into narrower channels, with less guard space between channels.

Although the FCC is allowing time for licensees to get further use from existing equipment (which is not suited to the new narrow-band, split-channel techniques), equipment being purchased by new licensees and for replacement of old equipment is designed for immediate split-channel use, or for modification to meet the higher technical standards.

More channels have been made available by narrowing of channels and crowding them closer together, but this is only a temporary solution. Even more channels will have to be made available in the future. SSB (single sideband) is one solution; it squeezes the channel space occupied by a transmitted signal to even less than that of present narrow-band FM and conventional AM transmitters. Or it may be necessary to develop new bands of frequencies not now in use. They are to be found in that portion of the radio spectrum above 89 megacycles.

At the present time, commercial mobile radio systems are operated in the 25-50, 152-174, and 450-470 mc (megacycle) bands. Certain industries and government agencies can also operate mobile radio systems in the 1.6-8.0 mc portion of the radio spectrum. Mobile units at airports are often operated in the 108-132 mc aviation radio band. Radio amateurs may operate their own mobile radio units, using commercial two-way radio equipment in the 50-54 and 144-148 mc bands.

For greater privacy and more economical utilization of the available radio channels, the use of selective calling is expanding. This enables base stations to selectively signal mobile units individually or in groups without alerting the others. Similarly, mobile units can select specific base stations or control points, again without alerting others not concerned.

Vacuum tubes are employed in most mobile radio equipment. However, in some recent types, transistors are used in the power-supply and audio-amplifier sections. Some manufacturers are already producing fully transistorized receivers.

Servicing and installing mobile radio equipment can be a lucrative and interesting occupation. Many TV-radio service technicians have turned to mobile radio servicing as a full-time endeavor or to supplement their income.

This book is dedicated to them and to anyone else interested in servicing mobile radio.

CHAPTER

1 Basic Systems

A TWO-WAY radio communications system consists of two or more mobile units, or a base station and one or more mobile units, or a combination of two or more base stations and any number of mobile units.

A *mobile unit* (Fig. 1-1) is a radio station on board a vehicle or other conveyance, or one carried by a person. The compact radiotelephone in Fig. 1-1 contains a transmitter, receiver, and power supply. Another mobile unit is shown in

Fig. 1-1. Mobile unit on board a fork-lift truck. (Courtesy of Motorola Communications and Electronics, Inc.)

Fig. 1-2. Basic components of a mobile unit. (Courtesy of Radio Corporation of America.)

Fig. 1-2. It consists of the antenna, speaker, microphone, control head, and the communications unit. The latter contains the transmitter, receiver, and power supply. Also considered a mobile unit is the man-carried, portable radio station in Fig. 1-3. Weighing less than ten pounds, this compact "walkie-talkie" can be carried by hand or strapped to the back. Either dry or wet batteries, in the snap-off lower compartment, power the transmitter and receiver.

A base station is a radio station permanently installed at a fixed location and used primarily for communicating with mobile units. A *fixed station* is also a radio station installed at a fixed point, but one which is used primarily for communicating with other fixed stations. The basic components of a fixed station are shown in Fig. 1-4. They are the microphone, speaker, and communications unit. The communications unit is in a wall-mount cabinet containing the transmitter, receiver, and power supply. The microphone is combined with the control head. An external antenna (not shown) is used.

The art of communicating between mobile units, or between a base station and mobile units, is called *mobile radio*. A mobile radio system may be either one-way or two-way.

A *one-way* mobile radio system consists of a base-station transmitter and any number of portable receivers. It may also consist of portable transmitters and one or more base receivers.

A *two-way* mobile radio system may consist of two or more mobile units, each equipped with a transmitter and receiver for two-way

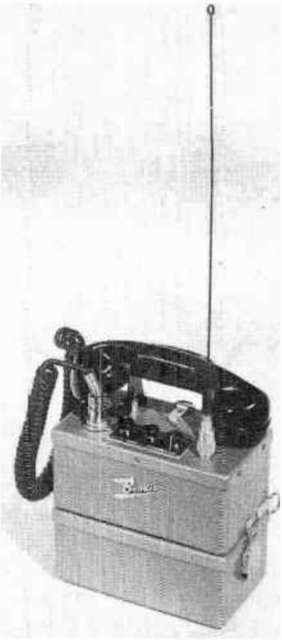


Fig. 1-3. "Walkie-talkie." Easily carried or strapped to one's back. (Courtesy of Bendix Radio.)

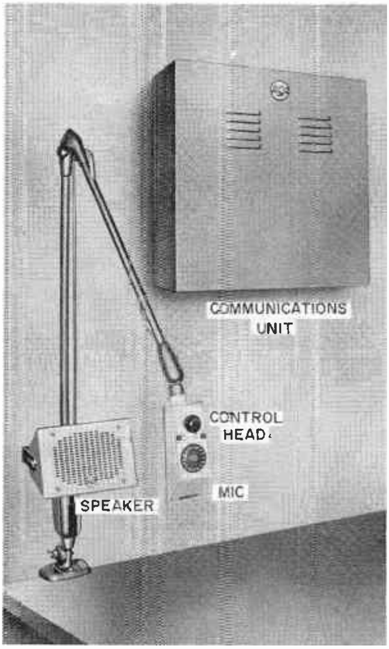


Fig. 1-4. Basic components of a base station. (Courtesy of Radio Corporation of America.)

communication. Or it may consist of one or more base stations and one or more mobile units equipped for two-way communication with each other.

A single- or two-frequency system may be employed in mobile radio. In a *single-frequency* system (Fig. 1-5), mobile units and base stations transmit and receive on the same frequency. This is generally on a *simplex basis,* in which mobile units and base stations transmit sequentially (one station transmitting and the other listening).

In a *two-frequency,* or *duplex,* system, the base stations transmit on one frequency (F_1) and receive on another (F_2). (See Fig. 1-6.) Mobile units transmit on F_2 and receive on F_1. They do not communicate *directly* with each other. Communication between mobile units is not ordinarily possible unless they have two-channel receivers that can be switched to receive on either F_1 or F_2, or unless the transmitters are equipped for transmission on these two channels. Communication may be sequential or, in some instances, full duplex (in both directions at the same time).

As we have said, in a duplex system the base station transmits on F_1 and receives on F_2, while the mobile units transmit on F_2 and receive on F_1. The base-station transmitter is so connected to the base-station receiver that signals from the mobile units on F_2 are rebroadcast by the transmitter on F_1. Communication between mobile units, therefore, is via the base station and is sequential.

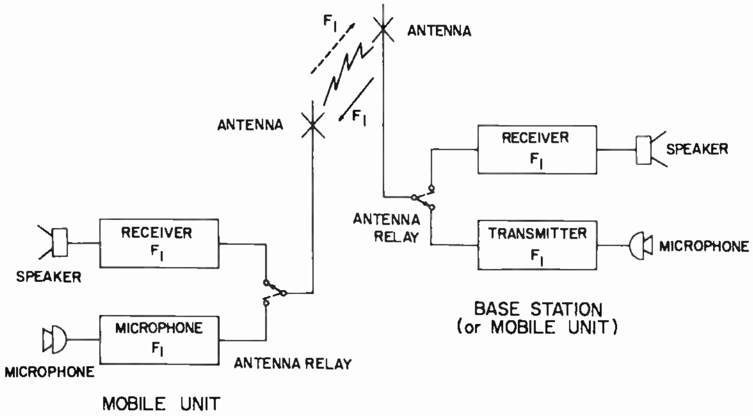


Fig. 1-5. Single-frequency (simplex) mobile radio system.

The typical mobile radio system operates on a single-frequency basis, however, in which mobile units and base stations transmit and receive sequentially on F_1. In some services, such as taxicab dispatching, direct mobile-to-mobile communication is not desirable. In fact, it is impossible because the base station transmits on F_1 and receives on F_2, while the mobile units do just the opposite.

When mobile-to-mobile communication via the base station is required in a two-frequency system, the audio output of the base-station receiver is fed to the audio input of the base-station transmitter (Fig. 1-7). Separate antennas are required for transmitting and also receiving. The base-station transmitter may be turned on automatically by a carrier-operated relay when a signal from a mobile unit is intercepted

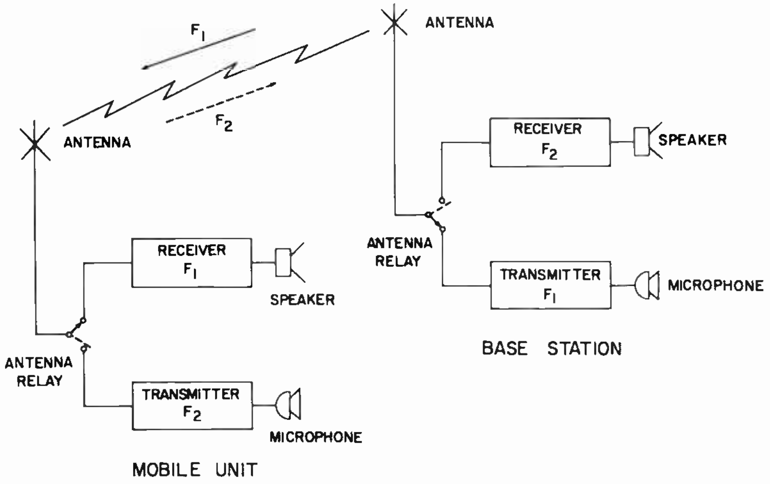


Fig. 1-6. Two-frequency (duplex) mobile radio system.

on F_2, or when the operator manually activates the base-station transmitter. The base station retransmits on F_1 the intelligence it receives on F_2.

It is sometimes desirable to limit communications so that mobile units can communicate with the associated base station only, but not with each other (as in a taxicab system). In other systems, mobile-to-mobile communication, whether direct or via the base station, is desirable.

COMMUNICATING RANGE

The base-to-mobile communicating range is considerably longer than the mobile-to-mobile range on a direct basis. This is due to the greater effective elevation of the base-station antenna.

Communicating range in VHF (very high frequency) and UHF (ultra high frequency) bands is considered line-of-sight. If the base-station antenna is 100 feet above the surrounding terrain and the

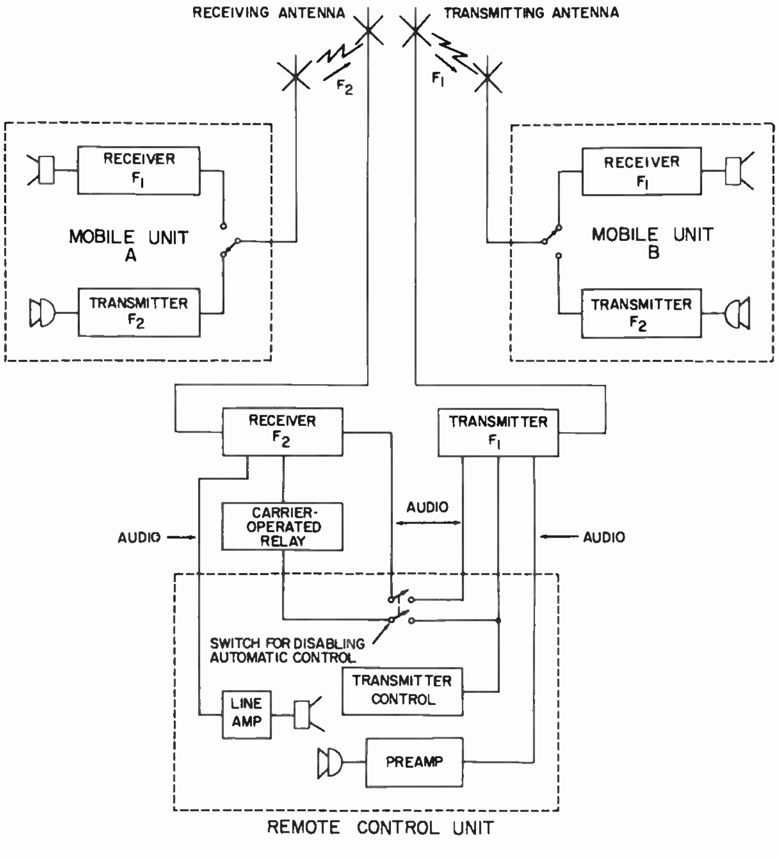


Fig. 1-7. Mobile-to-mobile communication via base station. (Circuits are illustrative, not actual.)

mobile-unit antenna is 6 feet, the communicating range is considered to be about 15 miles, based upon the following formula:

$$\text{Range in miles} = 1.23\,(\sqrt{H_1} + \sqrt{H_2})$$

where,

H_1 is the effective elevation of the base-station antenna,

H_2 is the effective elevation of the antenna of the mobile unit.

These calculations are based upon flat terrain. In hilly terrain, where the mobile unit may be elevated, the anticipated range is considerably greater. However, intervening hills and other solid objects, as well as foliage (which has an absorption effect) can greatly reduce the calculated range.

Range also depends upon frequency. When a mobile radio system is operated in the 25-50 mc HF-VHF (high frequency—very high frequency) band, greater range than that in the 152-174 mc VHF (very high frequency) band can be anticipated. In the 450-470 mc UHF (ultra high frequency) band, the communicating range is considered to be about two-thirds of that in the 152-174 mc band.

Under typical conditions, the communicating range between a base station and mobile units operating in the 25-50 mc band vary from 25 to 50 miles. In the 152-174 mc band, the typical communicating range is 15 to 25 miles. In the 450-470 mc band, communication with mobile units within a 10- to 15-mile radius of the base station is typical.

The range is greater at lower frequencies because there is less absorption by foliage. However, the superior reflection characteristics of the higher frequencies help fill in spots where communication at lower frequencies is impossible.

EFFECTS OF POWER

Power also affects the communicating range, but not as much as one would think. A three-watt mobile unit in Ashland, Wisconsin, operating in the 152-174 mc band, has communicated regularly with a base station in Duluth, Minnesota—60 air miles away. However, such ranges are not common. In this situation the base station is on a hilltop, well above surrounding terrain, and part of the transmission path is over Lake Superior. Line-of-sight conditions do not exist, however, because of the earth's curvature.

A one-watt (output) mobile unit can talk with another mobile unit or base station of the same power rating, within a radius of one to two miles, when both antennas are less than ten feet above the ground. When one antenna is raised, the range increases dramatically.

The Islip (N. Y.) police force uses mobile radio equipment of the

Fig. 1-8. Low-power radiotelephone. Can be licensed in the Business, Manufacturers, or Citizens Radio Service. (Courtesy of Kaar Engineering Corporation.)

type shown in Fig. 1-8. This equipment is rated at less than one-watt output, for communicating between patrol cars and headquarters within a five-mile radius. The AM unit is rated at three watts input to the final RF stage of the transmitter. The plug-in antenna is a Tele-Beam *Magic Wand.* A loading coil at its base permits use of a much shorter antenna whip than is ordinarily required for operation in the 25-50 mc band. The base-station antenna is less than 25 feet above the ground, but is above adjacent trees.

For community-wide coverage, however, higher power is needed. To cover a medium-sized city, mobile-unit transmitters rated at 10 to 30 watts output are required in the 152-174 mc (VHF) band. Mobile radio systems in the 450-470 mc (UHF) band are also used primarily for community-wide coverage. Their transmitters are rated at five watts or more output. For covering larger areas, such as entire counties or even several small counties, mobile radio systems are often operated in the 25-50 (HF-VHF) band, using transmitters rated at 30 to 100 watts output.

EXTENDED RANGE SYSTEMS

More than one base station is often used where coverage of an extended area or a long, narrow right-of-way is required. These base stations may be operated independently; or they may be controlled from one or more control points individually, in groups, or all at once.

The base station often uses a transmitter with a power rating identical to that of the associated mobile units, since both must transmit the same distance. However, a more powerful transmitter is sometimes used at the base station. The base station can thus transmit a stronger signal, which will carry farther than the signals from the lower-powered mobile units. This technique is advantageous, it is claimed, because the base station is usually in an area where less electrical noise is apt to prevail. The mobile units move in and out of noisy areas. Therefore, the stronger signal is needed from the base station to override any noise at the mobile unit. The effective sensitivity of the base receiver is greater than that of the mobile units, because the lower noise level at the base station permits satisfactory reception of weaker signals.

Some systems use a single high-power base-station transmitter and two or more base-station receivers. One of these receivers may be at the transmitter. The others, known as satellite receivers, are located at distant points. Their outputs are fed over wire lines or radio links to the base-station control point, as illustrated in Fig. 1-9. Thus, the base transmitter blankets the area. The mobile units have to transmit only to the nearest fixed receiver.

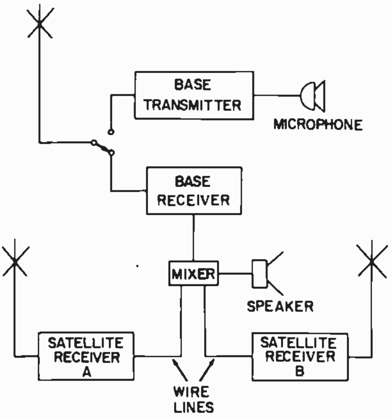


Fig. 1-9. Base-station system with two satellite receivers.

RELAY SYSTEM

The mobile-to-mobile communicating range can be increased drastically by employing an automatic relay or repeater station on a hilltop or with its antenna well above surrounding terrain. Two-frequency operation is required for this system. (See Fig. 1-10.) The relay station receiver picks up signals from the mobile units on F_2, and its transmitter rebroadcasts the intercepted intelligence to all mobile units within range on F_1.

The transmitter is normally off. It is turned on automatically by a carrier-operated relay when the receiver picks up a signal of suitable intensity from a mobile unit. (A timer shuts off the transmitter, should the system remain on after a predetermined period.) When mobile unit *A*, for example, wants to talk to mobile unit *B*, the signal from *A* on F_2 is intercepted by the relay station, which retransmits the intelligence to mobile unit *B* on F_1. In the same manner, the signal from *B* is transmitted to the relay station on F_2, and thence to *A* on F_1.

POINT-TO-POINT RADIO

Two or more base stations can communicate with each other when permitted by FCC rules. When used exclusively for point-to-point communication, these base stations are called operational fixed stations.

RADIO PAGING

A radio paging system consists of a base transmitter and any number of mobile receivers. A subscriber to a radio paging service is alerted by a radio voice transmission from a

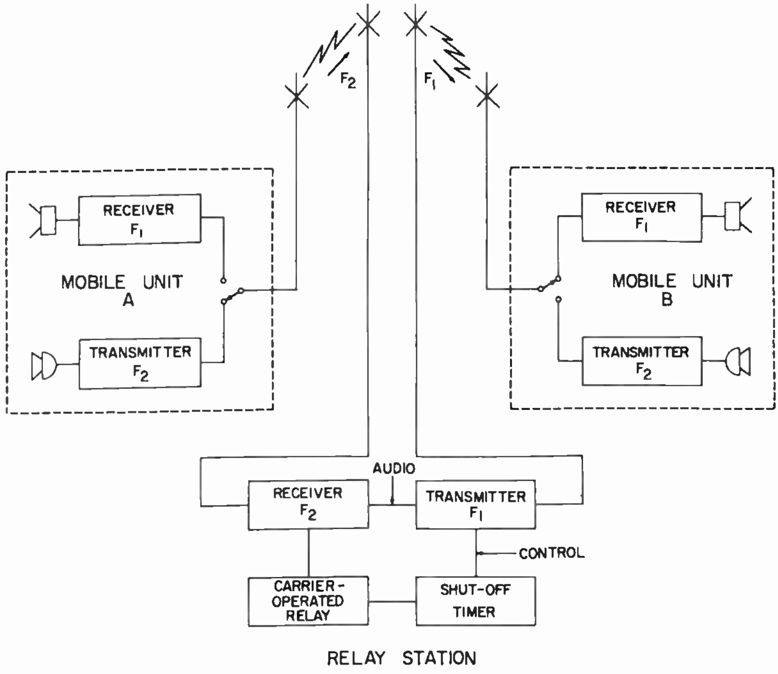


Fig. 1-10. Relay system for mobile-to-mobile communication.

Fig. 1-11. Radio paging system in a telephone answering service. (Courtesy of Kaar Engineering Corporation.)

central office (see Fig. 1-11), often a telephone answering service. The subscriber then goes to a telephone and calls the office, to acknowledge receipt of the call and get the message.

The calls are repeated, either manually or by a tape recording, until the subscriber is heard from. A small, pocket-sized radio receiver is furnished to the subscriber. At frequent intervals he holds the receiver to his ear, presses a button which turns it on, and listens to determine whether there is a call for him. Instead of pocket radios, mobile radio receivers are sometimes installed in the subscriber's vehicle. No receiver is required at the transmitter, since subscribers do not have transmitters. A CONELRAD monitor (at the top left of the switchboard in Fig. 1-11) is required by FCC regulations.

The range of a radio paging system depends upon the power, location, and antenna system of the base transmitter, as well as upon the sensitivity of the receivers. In some areas, subscribers can be paged up to 50 miles from the base transmitter.

A new type of radio paging system has recently been devised. The subscriber is furnished a pocket-sized radio receiver like the one in Fig. 1-12. The tiny transistorized receiver does not reproduce voice signals; instead, it gives out a "beep."

Fig. 1-12. Selective "beep" receiver that can be easily concealed by strapping it to the user's leg. (Photo by Ronald Ambler.)

The receiver is kept turned on. When the base-station operator wants to signal a certain subscriber, she transmits a coded tone signal to which only that subscriber's receiver will respond. The receiver ignores all signals except the one whose code matches the receiver decoder actuating the alarm. Now the subscriber no longer has to listen frequently to determine whether he has a call.

RADIO DISPATCHING SERVICES

In addition to private communications systems, radio dispatching services also use mobile radio. These services operate base stations for communicating with the mobile units of their subscribers. The radio equipment in the vehicles is owned by the subscribers, or leased to them by the operator of the radio dispatching service.

These independent common carriers provide dispatching service for a monthly fee or on a per-call basis. In most instances the base station relays messages to subscriber vehicles. Some operators, however, provide their subscribers' offices with remote-control units connected by wire lines to the base station. This enables the subscribers to talk directly to the drivers of their radio-equipped vehicles.

Some telephone companies also provide radio paging, radio dispatching, and one-way signaling services. The latter consists of actuating, by radio, a visual or audible signal in a subscriber's vehicle. Each vehicle responds to its own code signal, which is selectively generated at the central office.

MOBILE TELEPHONE SERVICE

Mobile telephone services use essentially the same equipment that private mobile radio systems do, except for the addition of a selective ringing decoder, and sometimes a dial. In a typical mobile installation, a speaker is used. It is kept turned on, to enable occupants of the vehicle to intercept all conversations transmitted on the channel to which the radio equipment is tuned. In regular telephone service this practice would be unthinkable, because subscribers demand privacy.

The subscriber listens with a conventional telephone handset instead of a speaker. Ordinarily, nothing is heard when the handset is on the hook. To ring a specific vehicle, the central office operator sends a coded tone signal. This signal is intercepted by all mobile units within range whose receivers are tuned to the proper central-office transmitter frequency. A decoder is actuated in all vehicles; but only one of the decoders, the one whose code was transmitted, responds. It closes its contacts and rings a bell or buzzer momentarily, as well as turning on a call-indicator lamp. The lamp remains lit until the call is answered.

None of the other mobile telephone subscribers are signaled; in fact, they are unaware that the "party-line" telephone channel they share is busy. They can, however, listen in with the telephone handset.

TWO-WAY DIALING

Dial telephone service is being extended to vehicles in some areas. A dial control head (Fig. 1-13) is equipped with a mobile telephone which enables a subscriber to dial calls directly, without the aid of an operator. When the handset is lifted from its cradle, coded tone pulses are automatically transmitted. These pulses identify the mobile unit to the automatic central-office equipment. The subscriber dials the desired number. When the called party answers, ticketing and billing machines are actuated. As soon as the calling mobile telephone is hung up, these machines record the number of the calling mobile telephone and the number of message units or amount of toll charges involved.

Thus, it is now possible to dial even long-distance calls directly from a mobile telephone. Similarly, mobile telephones can be dialed directly from regular telephones.

Fig. 1-13. A two-way dialing system installed in an automobile. (Courtesy of Secode Corporation.)

AM *VERSUS* FM

Both AM (amplitude modulation) and FM (frequency modulation) are employed in mobile radio systems. FM is by far the more popular. A system may employ AM or FM, but not both, since they are not compatible.

FM offers certain advantages, the most significant being a reduction of noise. However, noise becomes less of a problem as the operating frequency increases. In the 450-470 mc band, for example, there is little or no noticeable difference between AM and FM as far as noise is concerned. As far as distance is concerned, tests indicate that both AM and FM offer comparable ranges.

CHAPTER

2 The Basic Receiver and Front-End Circuits

RECEIVERS at mobile, base, fixed, relay, and satellite stations are essentially identical electrically as well as physically. In mobile applications and in some small base-station installations, the receiver chassis is packaged with the transmitter and power supply. Fig. 2-1 shows such a unit. The receiver is in the chassis at the right, the power supply is in

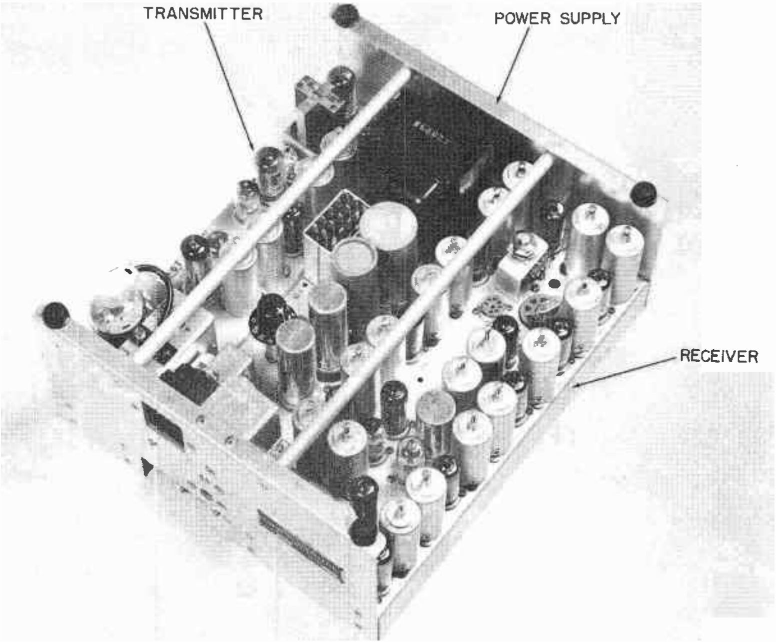


Fig. 2-1. Package unit for mobile operation and some small base stations. (Courtesy of Communications Company, Inc.)

the middle, and the transmitter is at the left. Although on separate chassis, the three units are packaged as a single unit. In larger base, fixed, and relay station assemblies, the receiver chassis is usually installed in a rack or cabinet. Receivers are also used independently at unattended satellite receiving stations, in vehicles, and at attended fixed locations. The AC-operated receiver in Fig. 2-2 is often used as a monitor or auxiliary receiver where reception of more than one channel is required. This receiver can be tuned over the entire 152-174 mc band.

The receiver is a necessarily complex device because it must meet exacting standards not required of home radio receivers. It must (1) have extreme sensitivity, so that it will perform with signal inputs of one microvolt or even less; (2) be very selective, to avoid interference from adjacent- and co-channel signals; and (3) be stable, so that it will stay tuned to the desired operating frequency, and so that its sensitivity and selectivity will not be affected by changes in environment.

SUPERREGENERATIVE RECEIVERS

Some receiver requirements can be met by a fairly simple circuit. For a few purposes, a simple superregenerative receiver like the one in Fig. 2-3 will do. Both tubes in this circuit are filament-type subminiature pentodes. V1 (which is triode connected) is the detector, and V2 is an audio amplifier. This pocket-sized receiver is used in one-way radio paging systems. It can pick up signals in the low band (25-50 mc), up to 50 miles under some circumstances.

Fig. 2-4 shows a tunable superregenerative receiver with an RF stage ahead of the detector to limit the radiation caused by the oscillating detector. Tuning within a narrow band is done by C2. L1 and L2 are adjusted to select the desired

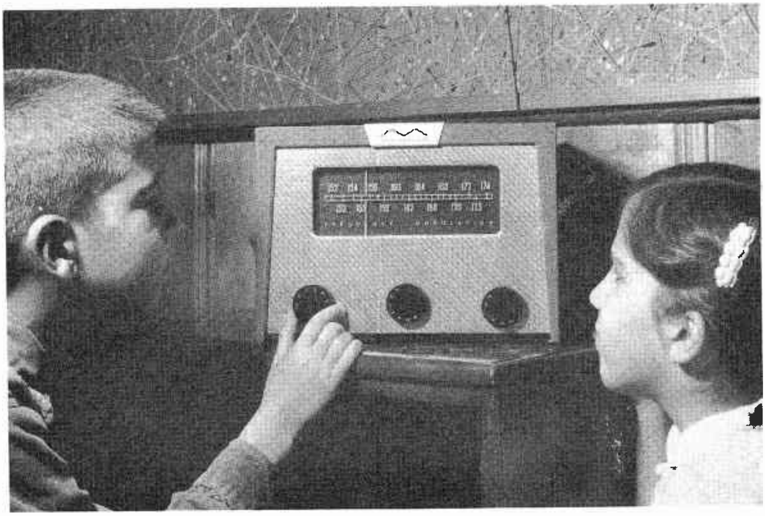


Fig. 2-2. VHF receiver, often used as a monitor or auxiliary radio. (Courtesy of Monitoradio, Division of I. D. E. A.)

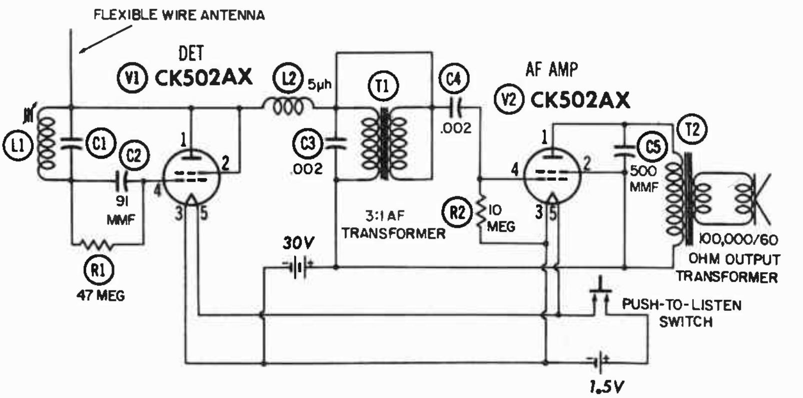


Fig. 2-3. Simple superregenerative receiver for 25-54 mc band.

segment of the band. R7 is the regeneration control. Note that resistor R5 is connected to the detector plate to provide self-quenching action. This prevents the detector stage from oscillating during the reception of strong signals.

The superregenerative detector is not new. It has been known for a long time as an extremely sensitive device, capable of providing as much sensitivity with a single tube as a multitube receiver with more conventional circuitry. Fig. 2-5 is a schematic of a fixed-tuned superregenerative detector for 465-mc, Class-B Citizens Radio Service. C3 and C4 are used to adjust the tuned line to the desired frequency. The antenna is connected through L1. C7 and L2 are tuned to 425 kc, which is the quench frequency.

The superregenerative detector has many unusual advantages. It not only is extremely sensitive, but can also demodulate both AM and FM

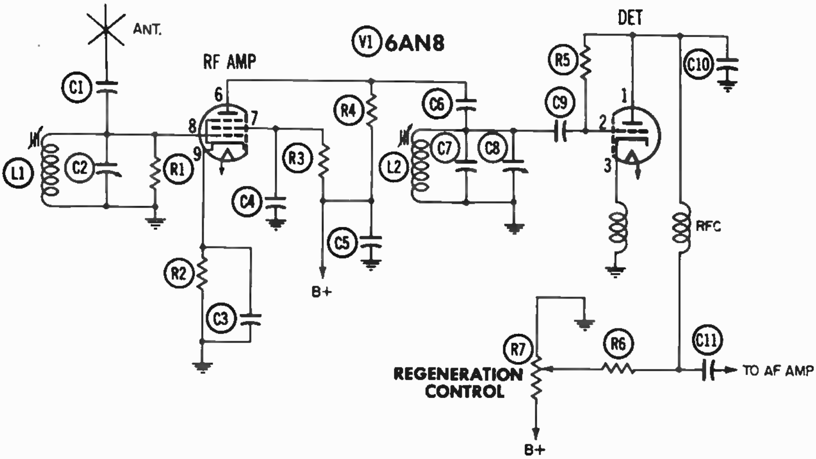


Fig. 2-4. Superregenerative receiver with RF stage ahead of detector.

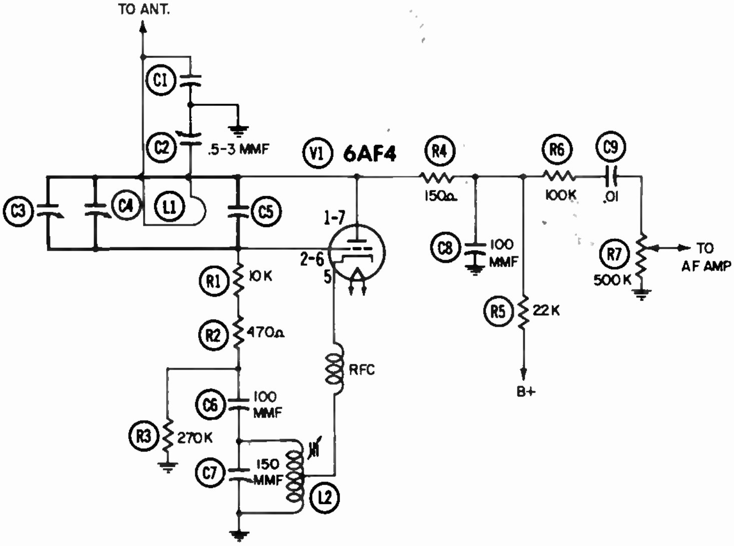


Fig. 2-5. Fixed-tuned superregenerative detector for 465-mc, Class-B Citizens Radio Service.

signals. The superregenerative detector also has inherent limiting action which makes it less susceptible to impulse-type noise (ignition, etc.), and provides almost the same audio output for weak as it does for strong signals. On the negative side, it is not selective enough for most applications (which sometimes is an advantage), its frequency cannot be readily stabilized, and there is background hash when no signal is being received.

Although a squelch circuit (discussed in Chapter 4) eliminates background noise from the audio output in the more complex receivers, the design of a practical one for a superregenerative receiver poses some formidable problems. Vocaline has developed a squelch circuit which is used in its CUB-1 base station, Class-B Citizens Radio unit. RCA has also developed a squelch circuit for use in its Radio-Phone Class-D Citizens radio, as an optional feature, which is controlled by the quieting of receiver background noise when a signal is received.

SUPERHETERODYNE RECEIVERS

All commercial mobile communications receivers except Class-B and some Class-D Citizens Radio units employ superheterodyne circuits. The earliest fixed-tuned receivers employed single conversion, as shown in the block diagram in Fig. 2-6. This is the same basic circuitry used in a home FM receiver, except that the local heterodyne oscillator is fixed-tuned and a squelch has been added.

The single-conversion superheterodyne does not provide the required sensitivity and selectivity. It is possible to design an IF amplifier that will have considerable selectivity if the intermediate frequency is low enough, but other problems arise. Therefore, the industry has turned to double- and triple-conversion circuits. A double-conversion circuit

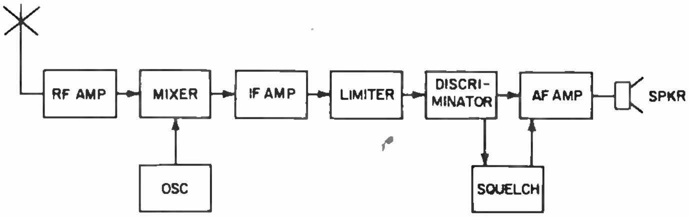


Fig. 2-6. Single-conversion superheterodyne receiver.

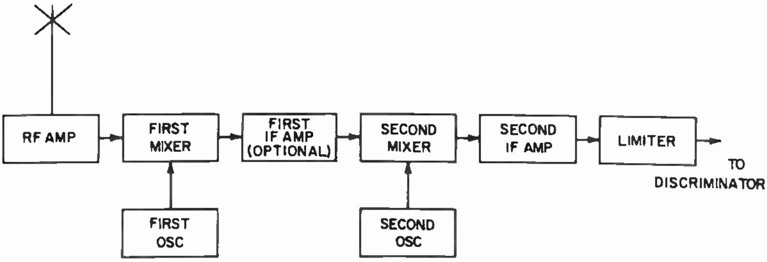


Fig. 2-7. Double-conversion superheterodyne receiver.

has two heterodyne oscillators and two different intermediate frequencies. For triple conversion, three heterodyne oscillator signals and three different intermediate frequencies are required.

Fig. 2-7 is a partial block diagram of a double-conversion receiver. In an FM receiver, the second-IF amplifier is followed by one or more limiter stages and a demodulator. In an AM receiver, limiter stages are not used.

Fig. 2-8 shows the additional stages required in triple-conversion circuits. The RF amplifier may be one or more stages. The first-IF amplifier is omitted in some receivers; and the IF signal from the first mixer is fed directly to the second mixer, which is tuned to the first-IF signal frequency. The second-IF am-

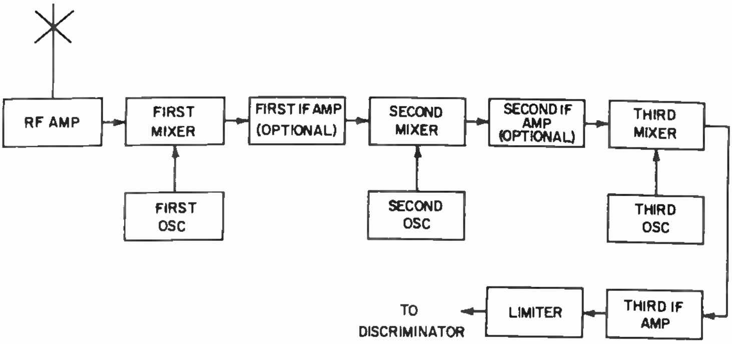


Fig. 2-8. Triple-conversion superheterodyne receiver.

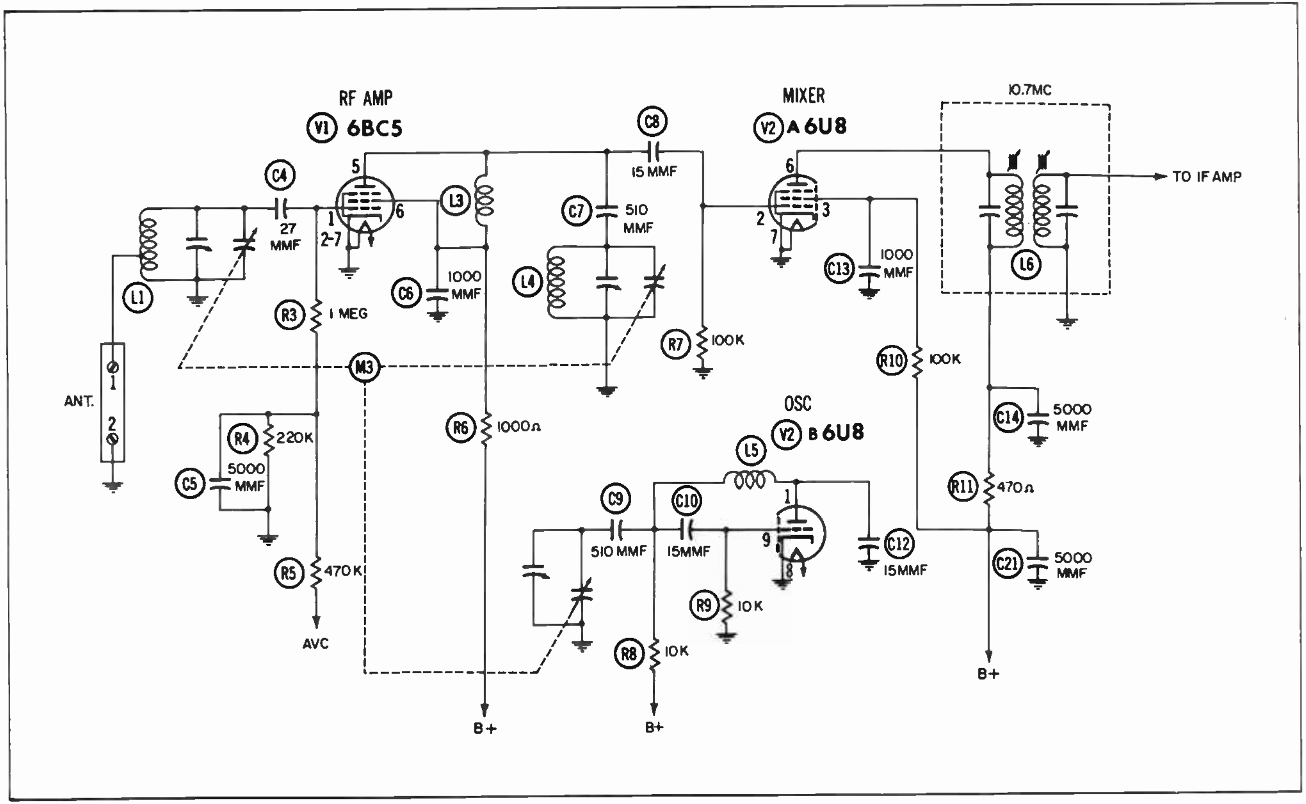
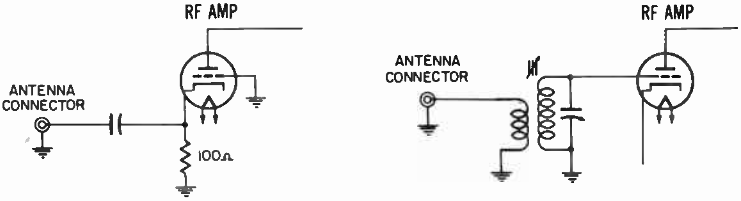
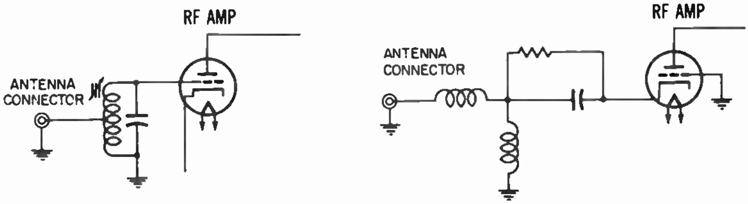


Fig. 2-9. RF amplifier, mixer, and oscillator of the Monitoradio MR-10 receiver.



(A) Resistive, untuned input.

(B) Inductively-coupled input.



(C) Tapped-coil input.

(D) Low-impedance input.

Fig. 2-10. Typical receiver input circuits.

plifier may consist of one or more stages; if it is omitted, the second-IF signal from the second mixer is fed directly to the third mixer. The last IF amplifier (second in double-conversion sets, and third in triple-conversion sets) consists usually of two or more stages.

In some receivers, each mixer has its own crystal-controlled heterodyne oscillator. In others, one of the oscillators serves two mixers. Crystal-controlled oscillators are used in all fixed-tuned receivers because their operation is more stable. Tunable oscillators are used only in receivers designed for hand tuning across a band. One such receiver is the Monitoradio MR-10, which tunes from 152-174 mc. The RF amplifier, mixer, and oscillator are shown in Fig. 2-9. A single conversion superheterodyne circuit is used.

INPUT CIRCUITS

Most receivers are designed for connection to the antenna through an unbalanced (one side grounded) 50-ohm transmission line. In mobile units and at base stations arranged for simplex operation, the antenna transmission line is fed to a relay which normally connects the antenna to the receiver. When energized, this relay connects the antenna to the transmitter.

Input circuit designs vary as to the requirements of the low, high, and ultrahigh bands, and according to the manufacturer's preference. Fig. 2-10 shows some typical input circuits, all of which accomplish the same purpose—transfer of energy from antenna to receiver. The input may match a 50-ohm line, although the match is not critical.

Input-Circuit Troubles

The antenna relay is part of the receiver input circuit, even though not always installed on the same chassis. This relay is a possible source of trouble, since it has moving parts which can fail to make proper contact. Many relays have enclosed contacts to protect them from coarse dust and mechanical damage. However, as long as air, moisture, and gases can reach the contacts, they can become contaminated.

Contact contamination may cause the equivalent of inserting a resistor in series with the antenna. Although this may not impair reception, it can greatly deteriorate transmitter performance. More harmful to reception is erratic contact, which can cause noise and varying sensitivity. A quick check can be made by tapping the relay assembly when a signal is being received, and noting whether any noise is produced in the receiver output.

When the relay coil is not energized, a continuity check with an ohmmeter should indicate zero resistance between the center contacts of the relay antenna connector and the receiver connector. When the relay *is* energized, the circuit between the transmitter connector and the antenna connector should be closed, and the one between the antenna and receiver connectors should be open.

Although the resistance is not really zero under any circumstances, it should be low enough that it will measure zero with a conventional ohmmeter. Even if such a continuity check does show that the relay contacts make and break properly, there still may be contact trouble.

The moving contact, or armature (which is connected to the antenna) and the stationary contact (which is connected to the receiver) make and break what is known as a "dry" circuit. This is one in which voltages and currents are in the *micro* and *micromicro* range. Doing this successfully is more difficult than handling heavy currents, which cause relay sparking. Relay sparking, in turn, burns off the dust film. Thus, the contacts must be really clean, and contact pressure must be adequate.

"Dry" circuit switching problems can be avoided by using relays in which the contacts are in a vacuum. However, such relays are still quite expensive. Their use as replacements for conventional relays can be justified only at base, fixed, and relay stations, and in military equipment.

Although persons skilled in the repair of delicate mechanisms can clean and adjust relays, it is often faster and less expensive to replace a doubtful relay with a new one. The replacement relay must match the impedance of the original coaxial cables, to avoid increasing the VSWR (voltage standing-wave ratio). Such an increase can affect the transmitter performance, even if the receiver performance does not seem to be adversely affected. Inaccessible relay contacts, within an enclosure which has some openings, can be cleaned by immersing the entire relay into a suitable detergent in the cleaning tank of an ultrasonic cleaner. The ultrasonic cleaning treatment will generally remove all accumulated dirt and film. Obviously the relay should be dried, with forced air or other means, before being placed back in service.

Component failures can also occur in the antenna circuit. Trimmer capacitors, tuning slugs, ceramic fixed capacitors and coils, and cavities or tuning lines should be checked visually. However, these components have such a range of electrical values that most conventional test equipment is inadequate for checking their electrical characteristics, except for continuity. Moisture, dirt, and temperature can alter the electrical characteristics of input-circuit components enough to degrade the receiver performance.

RF AMPLIFIERS

The RF amplifier performs several functions. By adding to the over-all selectivity of the receiver, its tuned circuits reduce the intensity of unwanted adjacent-channel, co-channel, and spurious signals which reach the first mixer. The RF amplifier also minimizes radiation of the signal generated by the first heterodyne oscillator and fed into the first mixer. In addition, it provides gain, amplifying the input signal before it is fed to the first mixer. Most receivers have either one or two RF stages ahead of the first mixer. Various tube types and tuned circuits are used, depending upon the frequency band and design choice.

When a receiver is used for reception on one channel only, the RF amplifier is tuned for best performance at the frequency of that channel. When reception on two or more channels is required, tuning is optimized for all channels.

25-54 Mc Band

Since the frequency span of the 25-54 mc band is more than two to one, it becomes impractical to provide trimmers which will tune through the entire range. This requirement is met by connecting various combinations of capacitors across the slug-tuned coils to divide the band into four sections. Fig. 2-11 is a schematic of a two-stage RF-amplifier section (shunting capacitors not shown). Fig. 2-12 shows how the capacitors are connected to provide coverage of the band in four different sections. (The example shows coupling between the first and second RF stages.) Tuning to the exact frequency within each of the four sections is done with the tuning slugs. For coverage of the low-frequency end of the band (25-30 mc), an additional, 0.1-mmf capacitor is shunted across each of the two interstage coupling capacitors.

The circuitry is straightforward and uses known, proved techinques. In the low band (25-54 mc), the standard capacitor and coil still prevail. Servicing and alignment are easier at lower than at higher frequencies, since lead dress and small changes in capacitance and inductance are not as critical. Manufacturers employ somewhat different approaches, but all produce essentially the same end result. Some manufacturers, for example, use a separate antenna coil, as opposed to the single tapped coil.

152-174 Mc Band

In some receivers, tuned lines or resonant cavities are used in high-band RF amplifiers. Fig. 2-13 shows a Motorola *Iso-Q* cavity, which is a tuned line derived from a tuned cavity. It is a hollow cylinder with an internal tuning cylinder. The position of the internal cylinder determines the frequency. The *Iso-Q* provides high *Q*; it can be tuned to any frequency within the 152-174 mc band. Many receivers use a coil and capacitor. The LC circuits of the RF stages and mixer in Fig. 2-14 are tuned with trimmer capacitors. The cathode of the first grounded-grid amplifier is fed from a tap on antenna coil L1. The low-impedance antenna is fed to the cold end of the coil. This coil is isolated from ground by capacitor C1 (33 mmf).

Both the primary and the secondary of interstage RF transformers (L2-L3) and (L4-L5) are individually tuned by variable capacitors. Because of the low-impedance input of the grounded-grid amplifiers, the second RF stage (as well as the

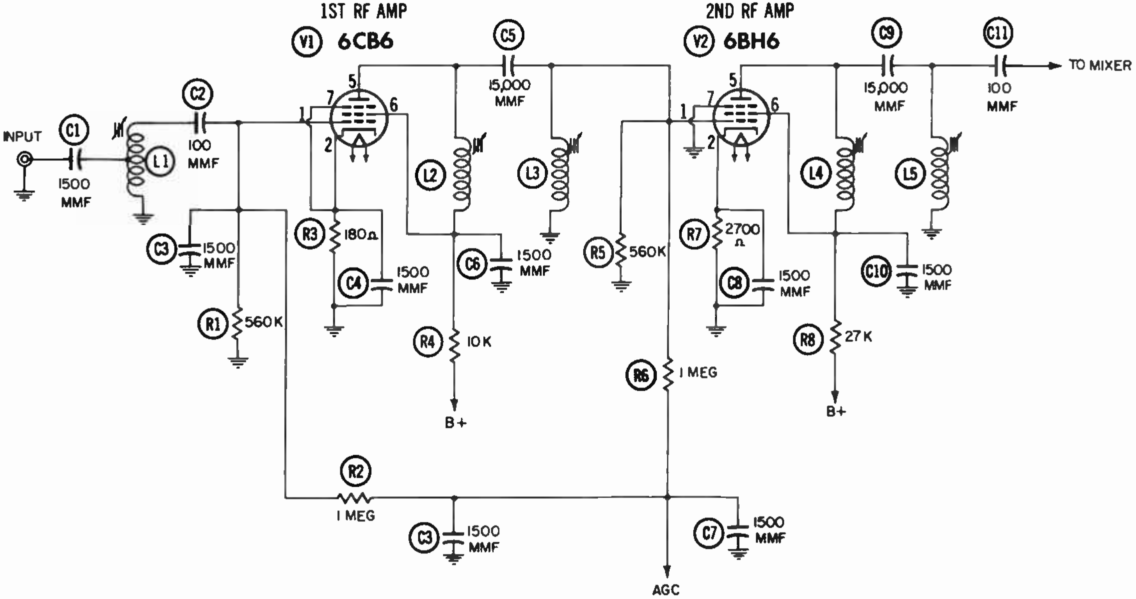


Fig. 2-11. RF-amplifier section of RCA MI-31302 receiver for the 25-54 mc band.

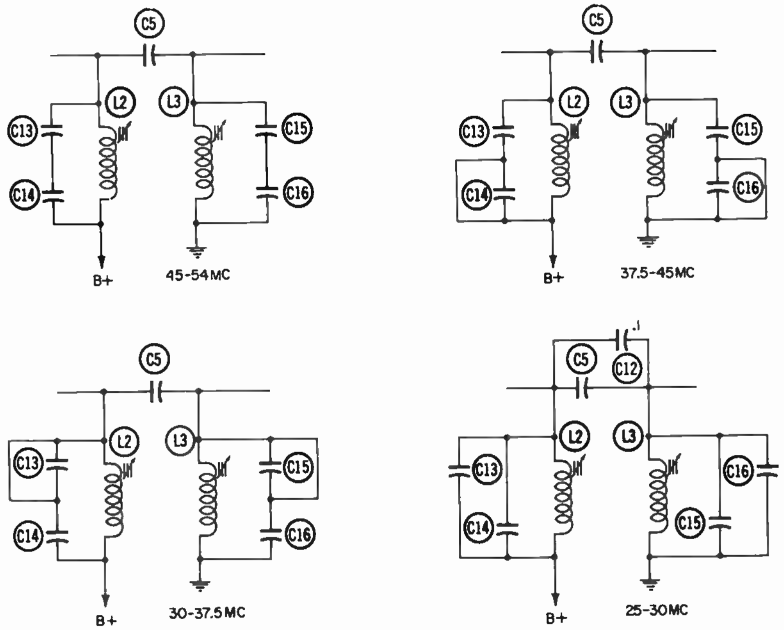


Fig. 2-12. Coupling between RF stages in Fig. 2-11 for the four divisions of the 25-54 mc band.

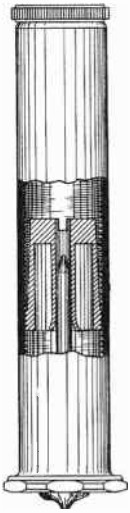


Fig. 2-13. X-ray view of the Iso-Q cavity. (Courtesy of Motorola Communications and Electronics, Inc.)

mixer) derives the signal developed across a 47-mmf capacitor at the cold end of the coil. The RF chokes in series with the cathode-bias resistors have a high RF impedance. For this reason, they prevent the resistors from shunting the signal to ground. This unusual circuit is used with others in this chapter to illustrate the variety of techniques employed in commercial equipment.

450-470 Mc Band

In the 450-mc region it is possible to use efficient resonant devices which, because of their dimensions, would be rather cumbersome at lower frequencies, but which are of practical size in this band. Typical is the 4.3-inch long cavity filter used in the circuit of Fig. 2-15. The resonant frequency of the cavity is determined by its internal dimen-

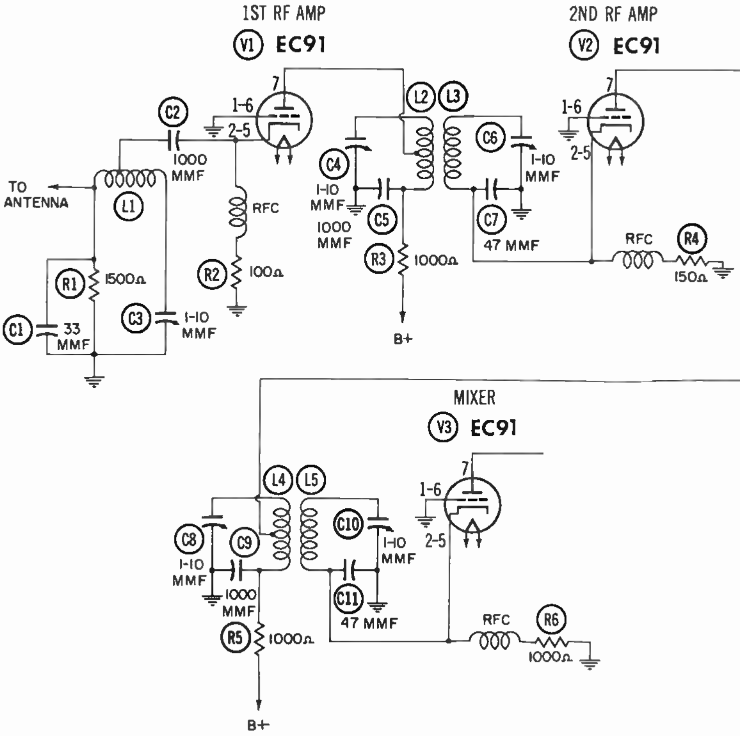


Fig. 2-14. Pye FM-8102 RF amplifier for the 152-174 mc range.

sions. These dimensions can be adjusted by tuning C1, which varies the resonant point of the cavity.

Here again, a grounded-grid amplifier is used, the input signal being taken from a jack on one side of the cavity at a low-impedance point. The plate circuit of the RF amplifier employs a small wire loop tuned by trimmer capacitor C2.

MIXERS

In the first mixer, the signal from the RF amplifier is mixed with a signal from the first heterodyne oscillator. Here these two signals are converted to form the intermediate-frequency (IF) signal, which is fed to the IF amplifier (or second mixer in some receivers). In order to convert these signals to produce beats (the sum and difference of these two frequencies), the mixer must function as a nonlinear device, or detector. Hence, this stage of a superheterodyne receiver originally was called the first detector, later the converter, and now is known as the mixer.

Although a crystal or semiconductor diode can be used as a mixer, tubes are most widely used commercially. In microwave and radar receivers, however, crystals are used extensively for this function.

If a 30- and a 20-mc signal are fed to a mixer, the output will contain a 50-mc signal (30 + 20) and a 10-mc signal (30 — 20). The choice can be made by tuning the output to

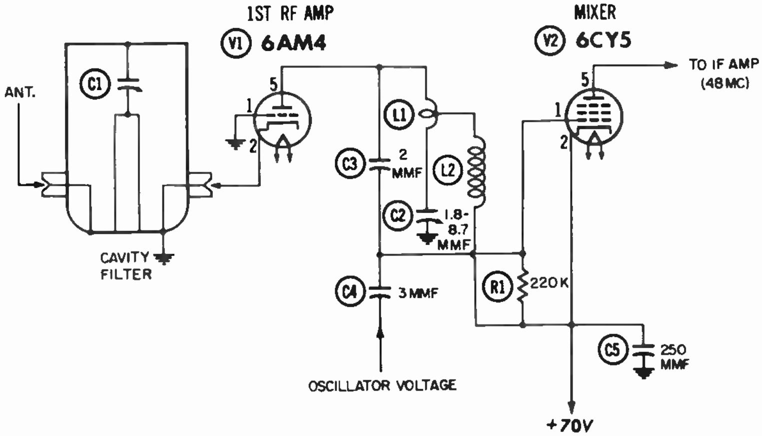


Fig. 2-15. RF section of General Electric Model 4ER26B2 receiver for the 450-470 mc range.

one of these signals: the tuned circuit will reject the unwanted signals.

The mixer stage of a receiver for the 25-54 mc band in Fig. 2-16 uses a 6AK5 tube. This tube has cathode as well as grid-leak bias developed across R2. The local-oscillator signal is fed to the screen of the mixer tube. Capacitor C8 is of such low value that it does not function as a bypass; instead, it forms a voltage divider with C9. Input tuning at the operating frequency is provided by L1 and L2, which are shunted by C2 and C3 respectively. Coupling from L1 and L2 is via the voltage divider formed by C2 and C4. Since C4 is of relatively high capacitance (4700 mmf), only the small RF voltage developed across it is fed to the grid of the mixer through C3. L3 and L4 are tuned to the first intermediate frequency.

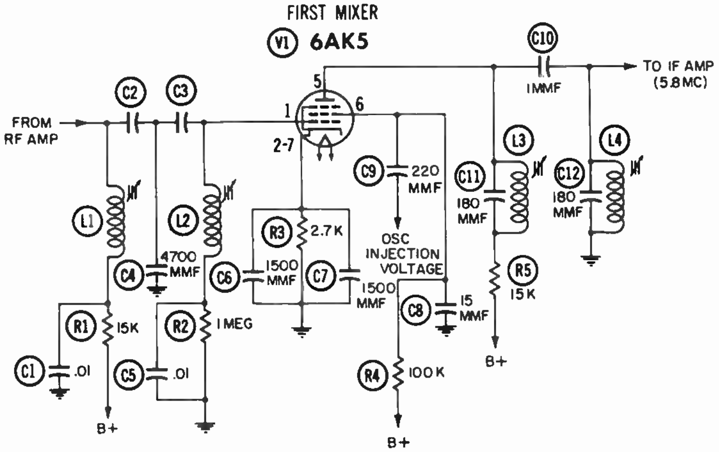


Fig. 2-16. First mixer circuit of Bendix Model 10RS-2A receiver for the 25-54 mc band.

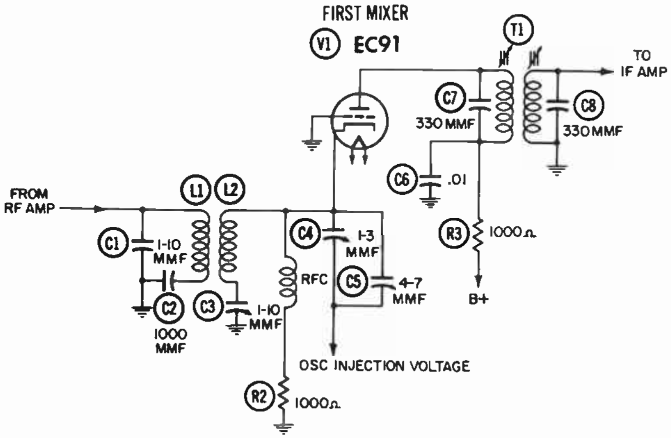


Fig. 2-17. First mixer circuit of Pye Model FM-8102 receiver for the 68-88 mc range.

A grounded-grid circuit is used in the mixer stage shown in Fig. 2-17. The signal from the RF stages is inductively coupled by L1 and L2 to the cathode of the EC91 tube. Note that L2 and C3 form a series-resonant circuit which presents a low impedance at resonance. Bias is developed across R2. An RF choke in series with R2 prevents this resistor from acting as an RF shunt across the tuned circuit. The local-oscillator signal is injected into the cathode in parallel with the received signal. The mixer output is tuned to the intermediate frequency, as would be expected.

In the circuit of Fig. 2-18, a 6BH6 pentode is used in the mixer stage. Conventional LC, capacity-coupled tuned circuits are used in the input and output. The local-

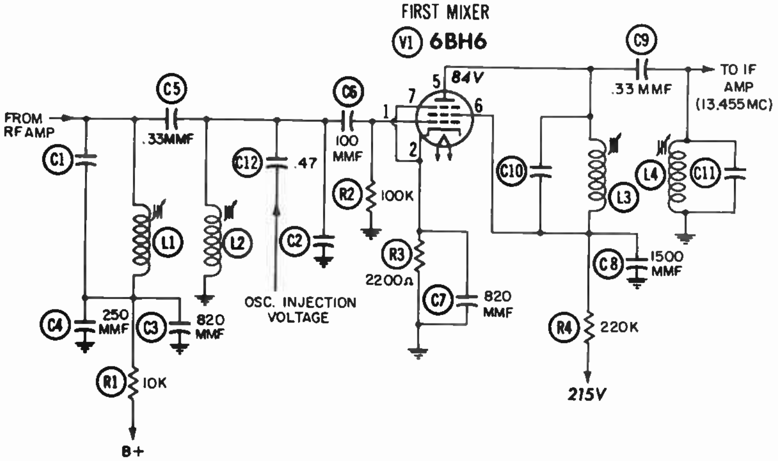


Fig. 2-18. First mixer circuit of the RCA Model MI-31202-C receiver for the 148-174 mc range.

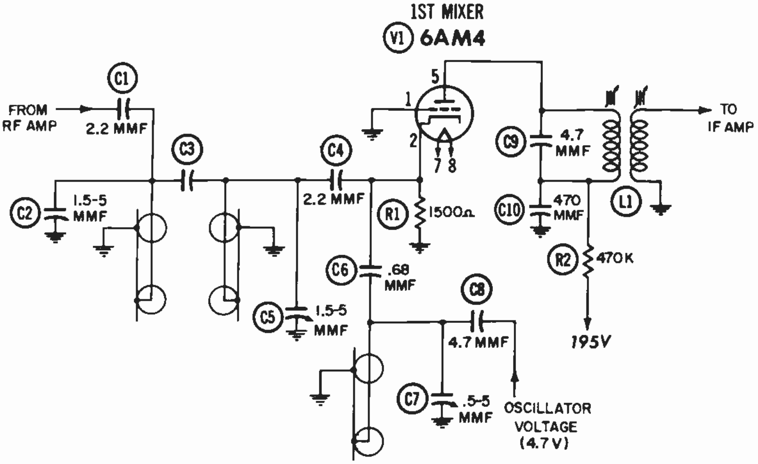


Fig. 2-19. First mixer circuit of the Kaar Model 8818 receiver for the 450-470 mc band.

oscillator signal is fed to the mixer grid through C12.

In the mixer circuit in Fig. 2-19, quarter-wave tuned lines are used for RF output and mixer input tuning. A conventional tuned IF transformer is used in the output. The local-oscillator signal is fed to the mixer cathode through a very small capacitor, C6. Note in Fig. 2-19 that the oscillator input is also tuned by a quarter-wave line.

FRONT-END TROUBLES

The RF amplifier and mixer are considered the front-end of a receiver. These are critical circuits in which the lead dress and placement of components, if altered, could affect the tuning, or could cause unwanted feedback. Identical parts should be used when replacements are made.

Tubes in these stages can be critical. When a tube is replaced, the circuits should be retrimmed because there is likely to be some difference in interelectrode capacitance among tubes. A tube afflicted with grid emission may check "good" in a general-purpose tube tester, but may not function properly as an RF amplifier, particularly in a circuit where the DC grid return is through a high-value resistor.

FIRST HETERODYNE OSCILLATOR

The local oscillator for the first mixer produces an unmodulated RF (CW) signal which beats with the received signal to form the first intermediate-frequency signal. It is important that the local-oscillator signal be stable in frequency. Any frequency variation can cause loss of sensitivity, as well as unwanted reception of signals on an adjacent channel. Because of the frequency-stability requirement, the local oscillator is always crystal-controlled, except in such tunable receivers as the Monitoradio MR-10. (The variable local-oscillator circuit of this receiver was shown in Fig. 2-9.)

A single 6BH6 tube functions as both the oscillator and the frequency multiplier in the circuit of Fig. 2-20. The crystal is used in a modified Pierce circuit. It is connected between the control grid and the screen, which acts as the oscillator plate. Capacitor C3 permits

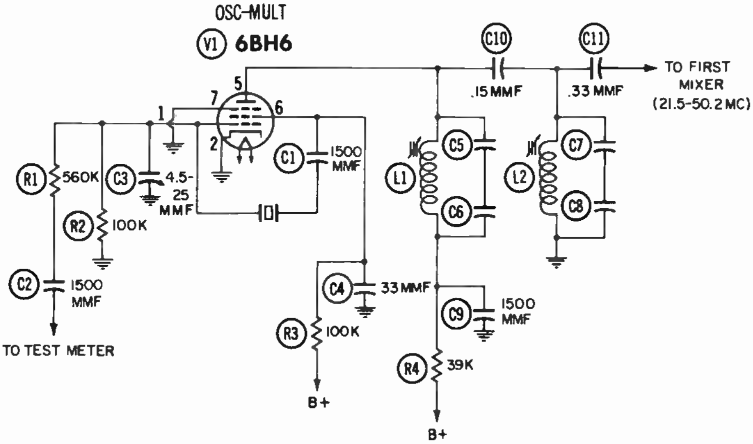


Fig. 2-20. Oscillator-multiplier of the RCA Model MI-31302 receiver for the 25-54 mc range.

trimming of the crystal to the exact desired frequency. The crystal is ground to some frequency between 7,050 and 12,500 kc, depending upon the operating frequency. The crystal frequency is tripled, and L1 and L2 are tuned to the third harmonic. This harmonic lies between 21.5 and 50.2 mc, depending upon the operating frequency.

The local oscillator in the circuit of Fig. 2-21 employs a 12AT7 dual triode. The crystal is between the cathodes of the tube. The crystal frequency is equal to:

$$\frac{\text{operating frequency (mc)} - 10.7\text{ mc}}{4}$$

The output is tuned with the slug of L2 to the fourth harmonic. This gives a local-oscillator signal 10.7 mc (intermediate frequency) lower than the received signal.

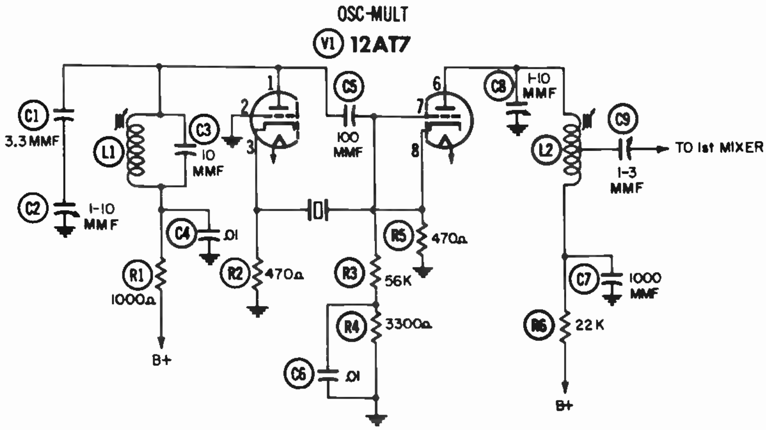


Fig. 2-21. Oscillator-multiplier of the Pye Model FM8102 receiver for the 132-174 mc range.

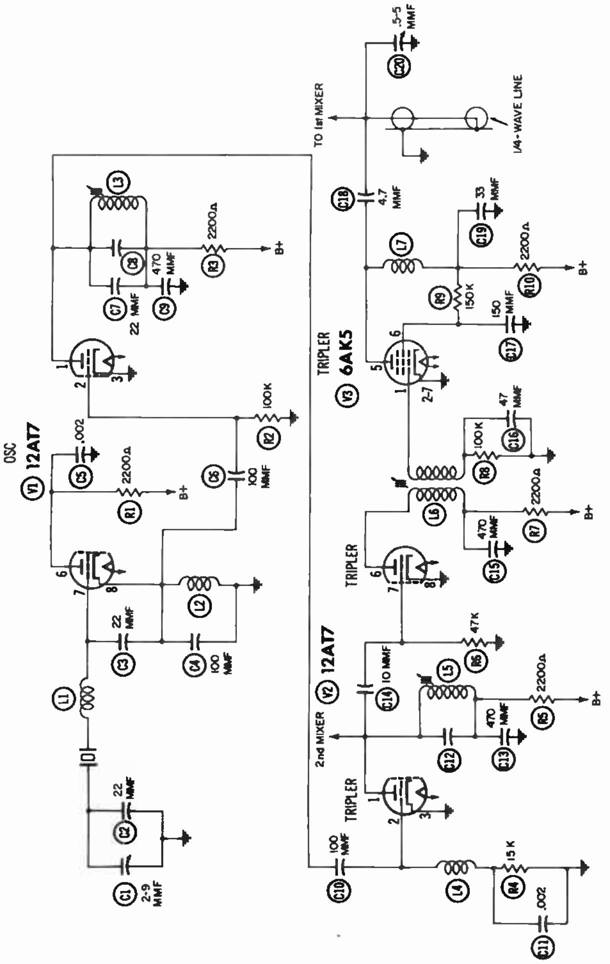


Fig. 2-22. Oscillator and tripler circuits for the first and second mixers in the Kaar TR500 receiver.

In the circuit of Fig. 2-22, only one crystal is required for both the first and the second mixer-oscillator functions. The crystal is in the grid circuit of the oscillator stage, V1. The output is cathode coupled to the other half of the oscillator stage. Three tripler stages follow. The signal from the plate of the first tripler is fed to the second mixer. The first mixer, however, is fed from the third tripler. Thus, only one crystal is required for the first two mixers. A separate crystal is used, in the oscillator, for the third mixer.

MULTIPLE-FREQUENCY OPERATION

The same receiver can be used for reception on two or more frequencies, one at a time, by employing a separate crystal for each frequency and selecting the desired one with a switch-controlled relay. Most receivers, however, employ individual first heterodyne oscillators for each receiving frequency. The desired oscillator is switched into action by a remote-controlled relay.

OSCILLATOR TROUBLES

If there is no oscillator signal, the receiver obviously will be dead. If the oscillator signal is too strong, it can overload the mixer; if too weak, it can impair the sensitivity. Although the level is not critical, the frequency is. As stated earlier, any variation in the oscillator frequency is highly undesirable.

Some variation in the oscillator frequency will occur because of changes in temperature. In most instances, the frequency is stable enough that the crystal does not require a temperature-controlled oven. Where experience shows that oscillator-frequency changes due to temperature variations actually degrade the performance, a crystal oven should be installed. Many receivers are so designed that a crystal oven can be easily added. Fig. 2-23 shows the connections to a crystal oven which plugs directly into the crystal socket of the receiver. (Two sizes are shown.) The oven accommodates two crystals. The temperature is maintained at 75° C. The oven heater consumes four watts.

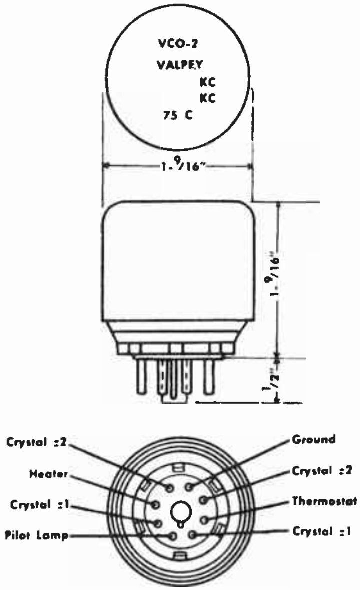


Fig. 2-23. Plug-in crystal oven. Accommodates two crystals. (Courtesy of Valpey Crystal Corporation.)

A frequency meter makes it easy to measure the crystal and multiplier frequencies. A lead from the input terminal of the frequency meter is brought near the crystal-oscillator circuit or is capacitance-coupled to it, to pick up enough signal for detection by the frequency meter.

A defective crystal can cause erratic operation. The quickest way to determine if this is true is to try a new crystal.

CHAPTER

3

IF Systems in Receivers

IN SOME receivers, the first mixer is followed by an IF amplifier. In others, it is followed by the second mixer. The input is tuned to the first IF, and the output is tuned to the second IF. The local-oscillator signal for the second mixer is sometimes derived from the same oscillator multiplier as the first, but more often a separate oscillator is used.

SECOND MIXER-OSCILLATOR

In the circuit of Fig. 3-1, one triode section of a 12AT7 tube is used as the second mixer and the other as the crystal-controlled local oscillator. The 5,537.5-kc crystal signal, when heterodyned at the second mixer input against the 5,800-kc IF signal from the first mixer, results in a 262.5 kc (5800-5537.5 = 262.5) IF signal at the output. A packaged bandpass filter is interjected between the cathode-follower output of the second mixer and the cathode input of the grounded-grid IF-amplifier stage. The same crystal is used in the local oscillator of the

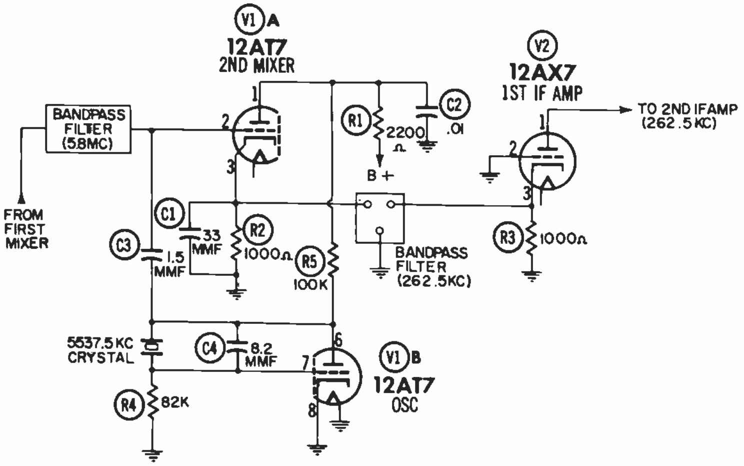


Fig. 3-1. Second mixer-oscillator of the Bendix Model 10RS-2C receiver for the 25-54 mc range.

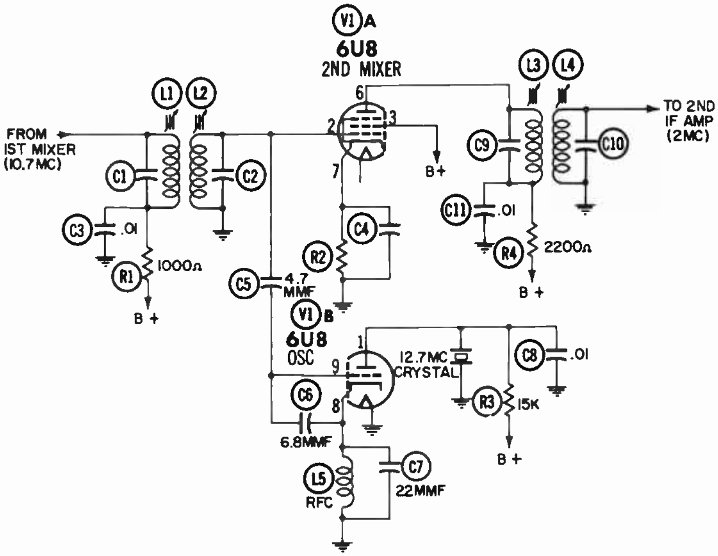


Fig. 3-2. Second mixer-oscillator of the Pye Model FM8102 receiver for the 132-174 mc range.

second mixer, regardless of the operating frequency. However, a different crystal is used in the local oscillator of the first mixer whenever the operating frequency is changed.

A 6U8 tube functions as both a second mixer and local oscillator in the circuit of Fig. 3-2. The pentode section serves as the mixer, and the triode section as a 12.7-mc crystal-controlled oscillator. The oscillator signal is injected into the grid of the pentode section through 4.7-mmf capacitor C5. The 12.7-mc oscillator signal beats against the 10.7-mc signal from the first mixer, resulting in a 2-mc second-IF signal (12.7 — 10.7 = 2).

Both halves of a 12AT7 dual triode are used in the second mixer-oscillator section of the circuit in Fig. 3-3. Capacitors C9 and C10 form a voltage divider from whose midpoint the oscillator signal is fed through C5 to the grid of the mixer. The 48-mc first-IF signal is heterodyned against the 44.8-mc oscillator signal to provide a 3.2-mc (48 — 44.8 = 3.2) beat signal. This signal is then fed through a bandpass filter to the third mixer.

THIRD MIXER-OSCILLATOR

The 3.2-mc filter between the second and third mixers is shown schematically in Fig. 3-4. Here again, a 12AT7 dual triode is used as a mixer and a crystal-controlled oscillator. The 3.2-mc IF signal, when heterodyned against the 3,490-kc oscillator signal, results in a 290-kc beat (3490 — 3200 = 290). The 290-kc signal is fed through another filter to an IF amplifier.

In the circuit of Fig. 3-5, a pair of 6BH6 pentodes are used in the third mixer-oscillator circuits. The output of the Pierce crystal oscillator is fed through small capacitor C8 to the input of the mixer. The resulting 1500-kc beat signal is then

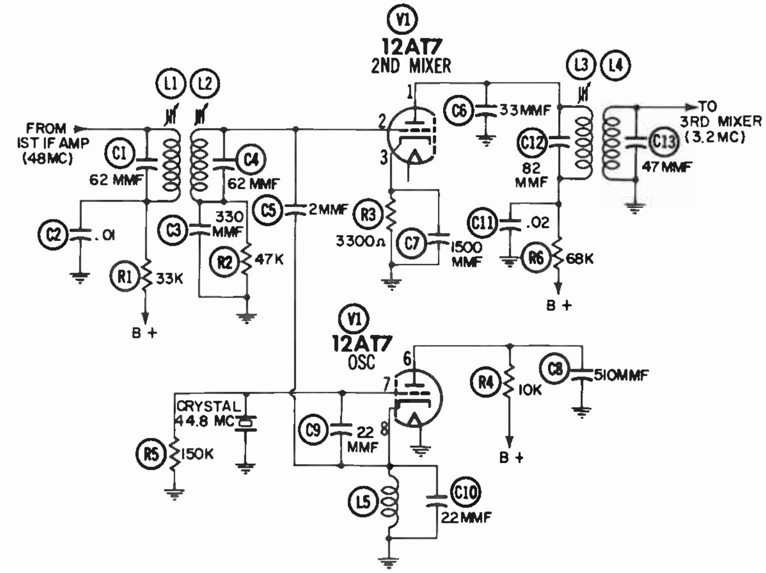


Fig. 3-3. Second mixer-oscillator of the General Electric Model 4ER26B2 receiver for the 450-470 mc range.

fed to an IF amplifier through a bandpass filter.

Instead of the conventional third mixer-oscillator, the circuit in Fig. 3-6 is used in some receivers to yield a third IF signal. The 262.5-kc second-IF signal is fed from the first to the second limiter, which also

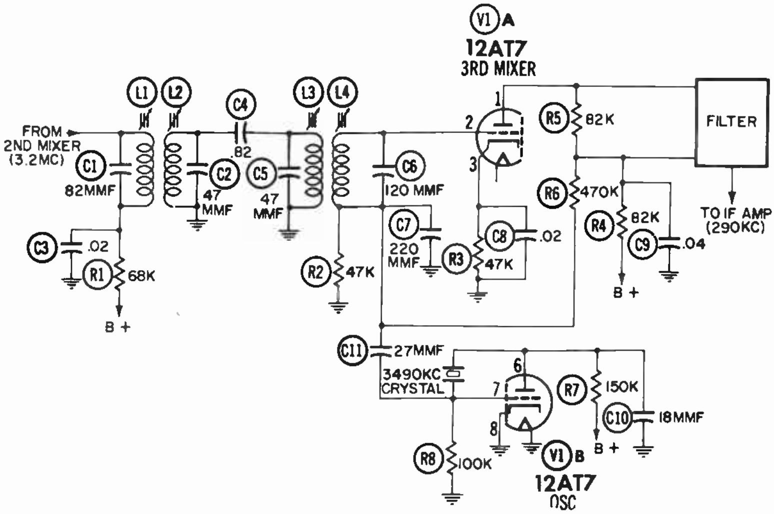


Fig. 3-4. Third mixer-oscillator of the General Electric Model 4ER26B2 receiver for the 450-470 mc range.

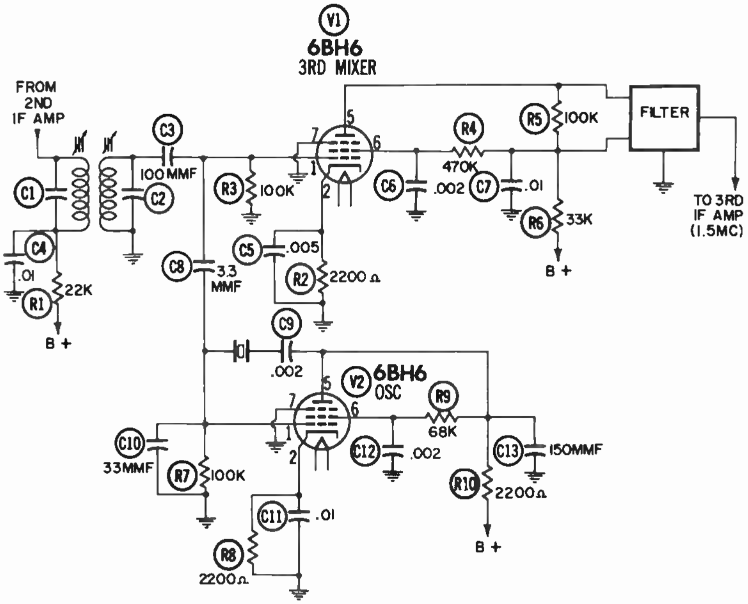


Fig. 3-5. Third mixer-oscillator of the Kaar Model 8818 receiver for the 450-470 mc range.

functions as a frequency doubler. The input of the second limiter (V1) is tuned to 262.5 kc. The output is tuned, by L2 and C6, to 525 kc. Because of the distortion which results from overdriving the tube, a strong second harmonic of the 262.5-kc input signal is present in the output. When the output is tuned to the second harmonic, a new IF signal at twice the input frequency is obtained. Both the fre-

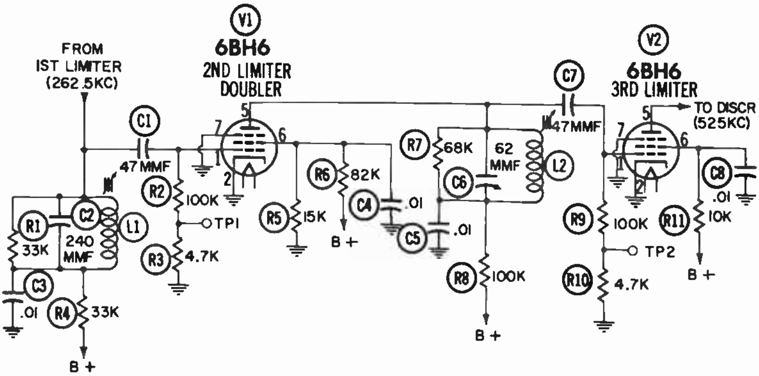


Fig. 3-6. Second limiter-IF frequency doubler of the Bendix Model 10RS-2C for the 25-54 mc range.

quency and the frequency deviation are doubled. The latter makes it easier to demodulate the FM signal at the discriminator that follows the third limiter stage.

Mixer-Oscillator Troubles

Since the signal frequencies fed in and out of the second and third mixers are very low compared to the frequencies at the receiver front-end, the circuits are less critical. Generally the only tuned elements in the second and third local oscillators are the crystals. At these frequencies, conventional signal-tracing techniques can be employed. Troubles are usually caused by defective tubes or crystals.

IF AMPLIFIERS

Most of the required gain and selectivity are obtained in the IF-amplifier stages. Double or triple conversion permits a lower intermediate frequency to be obtained. It is easier to design selective IF transformers and filters for lower frequencies than for higher ones. However, it is not feasible to use a low-IF immediately after the first mixer.

If the first local oscillator were tuned to give a 200-kc IF signal, for example, severe interference would result. The reason is that the front-end (RF amplifier and first mixer), operating at VHF or UHF, is not selective enough to adequately reject image signals only 200 kc away from the operating frequency.

If the RF and mixer stages were tuned to 150 mc and the IF's to 200 kc (0.2 mc), the oscillator frequency would be 149.8 mc. The desired 150-mc signal, when picked up by the receiver, is heterodyned with the 149.8-mc oscillator signal; and the 200-kc IF signal results. If the receiver were not selective, it would pick up signals other than the desired 150-mc signal. For example, if a 149.6-mc signal were picked up, it would heterodyne with the 149.8-mc oscillator signal to produce a 200-kc IF signal. This undesired signal would be passed through the receiver.

However, if the oscillator is tuned to 140 mc and the first IF to 10 mc, the receiver will respond to a 150-mc signal and produce a 10-mc IF signal (150 − 140 = 10). A 130-mc signal, heterodyned against the 140-mc local-oscillator signal, would also yield a 10-mc IF signal. However, 130 mc is far enough removed from 150 mc for the RF and mixer tuning circuits, if tuned to 150 mc, to adequately reject it.

There are other, more complex combinations of signals, dictating the need for today's complicated circuits.

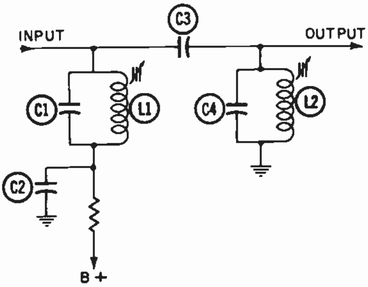


Fig. 3-7. Typical IF coupling circuit used in communications receivers.

You are probably familiar with the IF amplifiers as used in AM broadcast receivers. In these receivers, IF transformers provide inductive coupling between stages. In modern communications receivers, however, capacitive coupling is often used between stages, the plate and grid tuned circuits being isolated from each other to prevent inductive coupling. (See Fig. 3-7.)

A long time ago, Spartan radio receivers employed a variable bandpass filter. This filter could be tuned to any point in the AM broadcast band. As shown in Fig. 3-8, its output was fed to an untuned, broad-band RF amplifier. One of the ideas originated by Spartan engineers more than 30 years ago—using a bandpass filter at the input of an amplifier—is being revived today.

In order to obtain the required selectivity, particularly for split-channel operation (20-30 kc between channel center frequencies), manufacturers are employing special bandpass filters. Several filters now available, such as the Collins mechanical filter, are suitable for this purpose. However, they have not yet been used in commercial mobile receivers because of their high cost.

Motorola uses what is known as a *Permakay* filter, in which the components are in an enclosure. A receiver equipped with a *Permakay* filter for wide-band use (60-kc channel spacing) can be quickly modified for narrow-band, split-channel use by replacing the filter with one having a narrower bandpass. Kaar, GE, and others also employ LC filters which can be replaced to alter the selectivity characteristics of the receiver. Aerotron employs a crystal filter following the first mixer for achieving the required selectivity.

It is desirable to provide very great—but not needle-sharp—selectivity. The response curve should have a relatively flat top, as shown in Fig. 3-8, so that the entire FM signal (or AM signal and its sidebands) will be accepted. The flat top is considered equal to the two points, one on each side of the center frequency, where twice the signal voltage (6 db) is required to produce the same output as at the center frequency.

Fig. 3-9 is a schematic of one of the two 250-kc IF filters in the receiver section of the Comco 580 *Fleetcom*. There are two filters, one at the input and the other at the output of the second-IF amplifier stage.

In addition to sealed interstage filters, Bendix employs a 5.8-mc

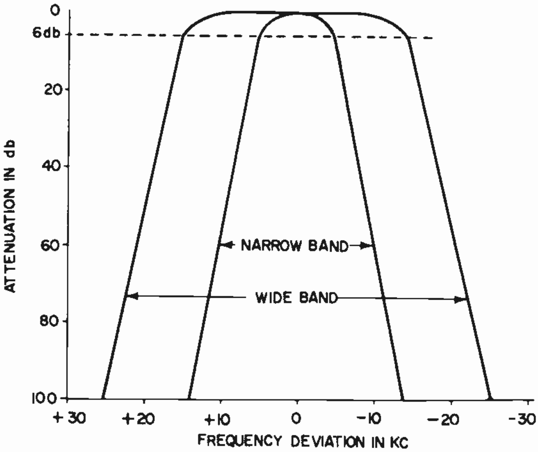


Fig. 3-8. Selectivity curves for narrow- and wide-band operation.

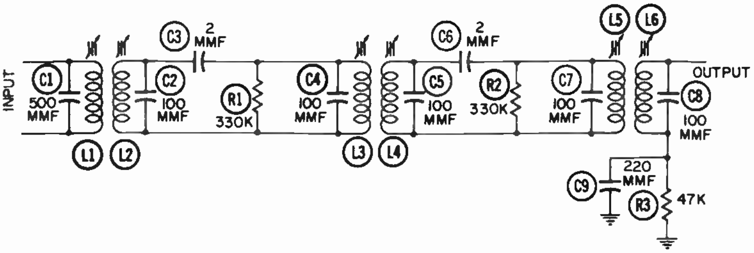


Fig. 3-9. One of two 250-kc IF filters in the Comco Model 580 receiver.

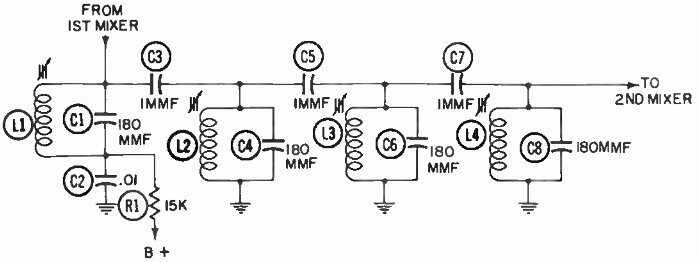


Fig. 3-10. 5.8-mc IF filter of Bendix Model 10RS receiver for the 25-54 mc band.

filter network (Fig. 3-10) between the first and second mixers. The 262.5-kc IF section employs eight triodes (four dual triodes) and one pentode, as shown in the block diagram in Fig. 3-11. Four interstage filters are used. The first one is between the second mixer and the first IF amplifier. The other three are fed from a cathode follower, and each one feeds a grounded-grid amplifier.

On the other hand, General Electric, in its Model 4ER26B2 receivers (450-470 mc), employs two pentode IF-amplifier stages between the third mixer and the first limiter. As can be seen from Fig. 3-12, multiple tuned circuits are used between the second and third mixers and between the third mixer and first IF amplifier. The circuits between the mixers are tuned to 3.2 mc. The ones between the third

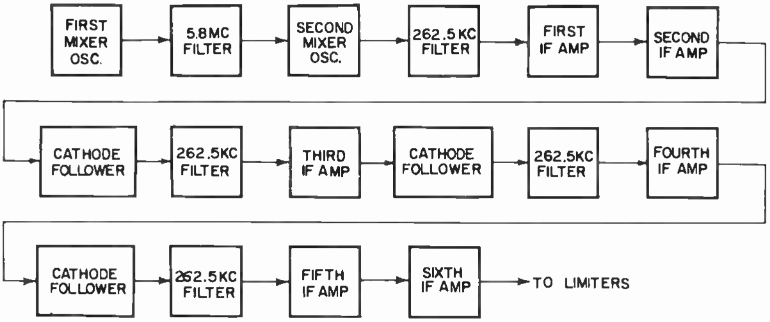


Fig. 3-11. Stages between the first mixer and limiter in the Bendix Model 10RS receiver.

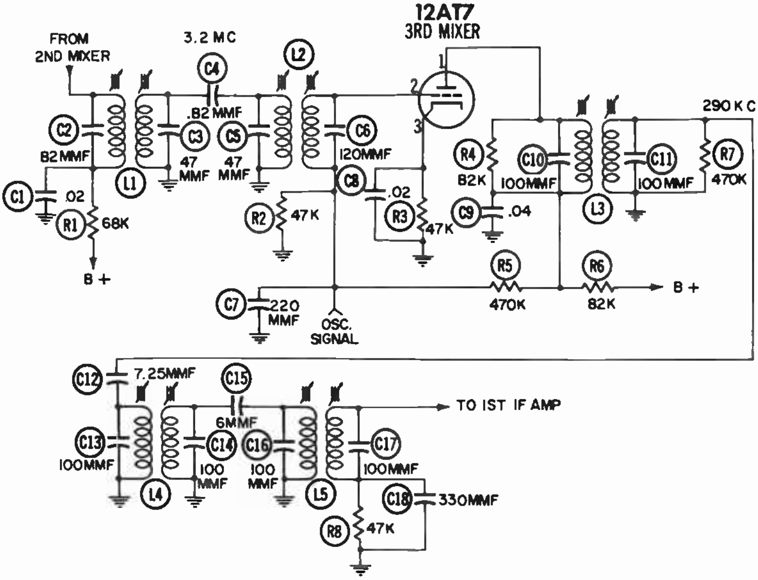


Fig. 3-12. Multiple-tuned circuits before and after the third mixer in the General Electric Model 4ER26B2 receiver.

mixer and IF amplifier are tuned to 290 kc.

Although various manufacturers employ different filters and tube combinations, they all must meet similar performance specifications in order to be competitive. The recent introduction of all-transistor receivers further widens the number of circuits the technician must become familiar with in order to competently service all makes of receivers. The big difference between tube circuits and transistor circuits is that the latter involve lower impedances. Fig. 3-13 is a schematic of the IF-amplifier section of an all-transistor VHF receiver. There are two low-IF stages. The stages are untuned; they obtain selectivity from a filter ahead of the amplifier.

IF-Amplifier Troubles

In an AM receiver, the IF amplifiers are operated Class A, and AVC (automatic volume control)

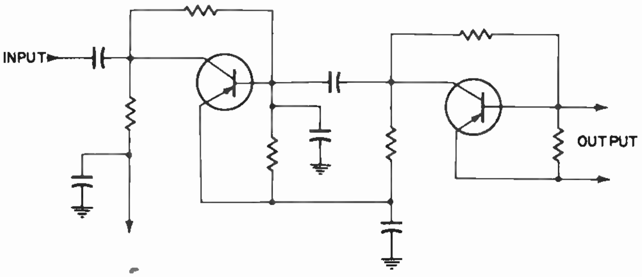


Fig. 3-13. IF section of an all-transistor VHF receiver.

automatically varies the gain to prevent overloading of the IF amplifiers. Hence, when distortion occurs, the AVC action and the bias voltages should be checked.

In an FM receiver, AGC (automatic gain control) is sometimes used. Possible overloading of IF amplifiers is not necessarily harmful, because any amplitude distortion will not affect the FM signal.

An IF amplifier can cease functioning because of a defective tube, lack of plate or screen voltage, or some defect which would cause a tuned circuit to be completely off-resonance. Self-oscillation can be caused by improper lead dress, an open bypass capacitor, or variations in the values of capacitors or resistors. Heat—and even time alone—can change the values of components. However, modern components, such as the feed-through ceramic capacitor in Fig. 3-14, are designed to withstand severe environmental conditions. Incidentally, this capacitor does not look like a conventional one. At first glance, the technician may even mistake it for a feed-through bushing.

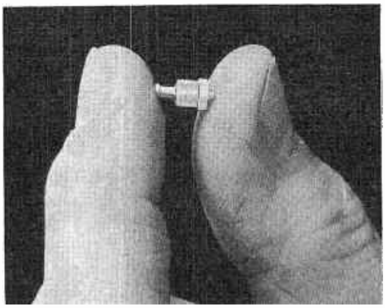


Fig. 3-14. A modern feedthrough ceramic capacitor. (Courtesy of Fluorocarbon Products, Inc.)

Erratic operation and some hard-to-find troubles are sometimes caused by tubes with grid emission. For this reason, a tube which checks "good" on a general-purpose tube tester may not function properly in certain circuits. Substituting a new tube or testing suspected tubes with a grid circuit tester is a good way to find out if grid emission is causing the trouble.

IF Alignment

Although alignment of IF stages is a well-known technique, the technician should read the appropriate instruction book before attempting it. Some of the circuits are intended for field tuning (see Fig. 3-15). Others, such as packaged filters, are pretuned at the factory and should not be touched. The tuned circuits in some receivers are quite complex in order that the required selectivity and bandpass characteristics can be achieved. Because of this complexity, special alignment procedures may be required.

Heat can cause IF-amplifier tuning circuits to drift. Ordinarily the circuits are designed, using compensating means where necessary, to minimize drift. If only one tuning adjustment has drifted, the components in that particular circuit should be checked. However, if all of the tuning adjustments have drifted, generally in the same direction, the receiver may have been running too hot. If so, more adequate ventilation should be provided.

LIMITERS

Most FM receivers employ one or more limiter stages (generally two) between the last IF amplifier and the discriminator. When a ratio detector is used, limiters are not required; nor are they used in AM receivers. A limiter is an amplifier stage which saturates (overloads)

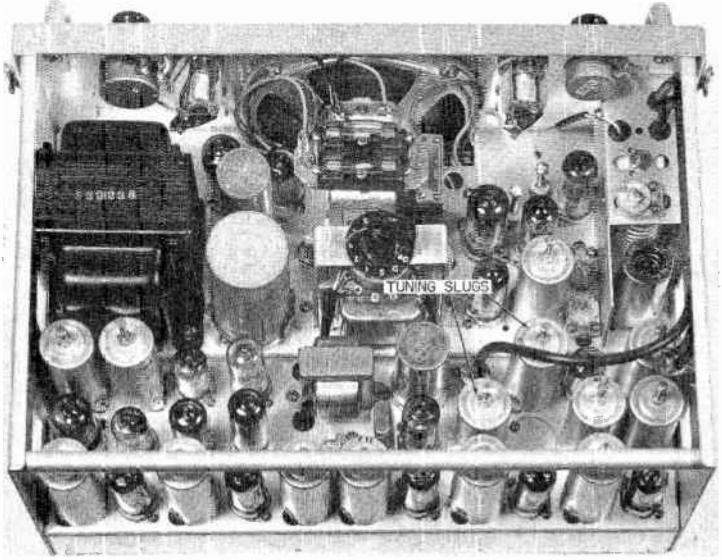


Fig. 3-15. A receiver, showing the IF adjustments used during servicing. (Some are located below the shielded cans.) (Courtesy of Communications Company, Inc.)

when a signal of sufficient amplitude is applied. When saturation occurs, a larger signal input will not increase the output. In an FM receiver, the limiters erase the AM components and, hence, eliminate AM noise impulses.

Either triodes or pentodes can be used as limiters; the limiters may be tuned or untuned. In the typical limiter circuit in Fig. 3-16, two 6BH6 pentodes, operated at reduced plate voltages, are used. In these tubes the inputs and outputs are untuned, except for the plate circuit of the second limiter, just ahead of the discriminator. Note that the cathodes are grounded. Hence, when there is no signal, there is no bias. Because of the high gain of the typical receiver, a signal actually is present at all times, even if it is only noise. Because of the diode action between grid and cathode, this signal causes the limiters to develop a bias voltage across their grid-return resistors.

When the signal is very weak, the limiters might operate as amplifiers and deliver a bigger signal at the output than was intercepted at the input. However, as the signal becomes stronger, the grid of the first limiter is swung further positive and negative. With each positive excursion, the control grid and cathode act as a diode rectifier. Capacitor C1 (Fig. 3-16) is charged, causing a negative DC voltage to be developed across R1 and R2 (total of 218,000 ohms in series). When the tube is biased beyond cutoff, a negative swing of the input signal will not affect the plate current, since the tube is already cut off.

Each positive swing of the grid of the first limiter becomes a negative swing at the plate because of the

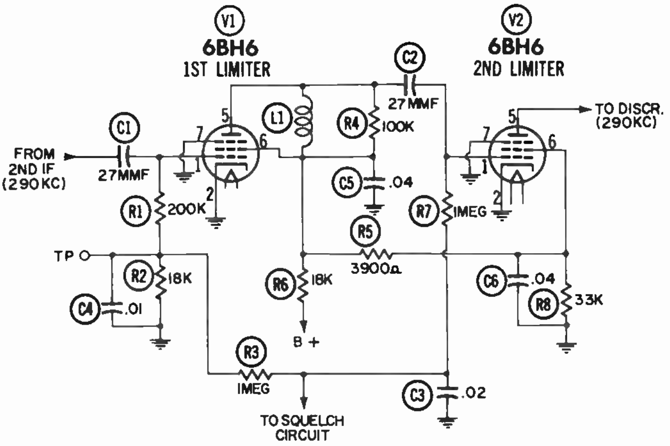


Fig. 3-16. Limiter circuit of the General Electric Model 4ER26B1 receiver for the 450-470 mc band.

180° inversion in the tube. This swing is limited in amplitude because of low plate voltage. The grid of the second limiter is also self-biased to cutoff for the same reasons as the first limiter. When applied to the grid of the second limiter, this negative swing is erased because the second limiter does not react to a further negative voltage on its grid. Hence, in a dual-limiter circuit, the first limiter does most of the work and the second limiter provides further refinement. The signal which the limiter feeds to the discriminator is of constant amplitude, regardless of the strength of the incoming signal, as long as it is strong enough to saturate the limiters.

A check of the negative DC voltage developed at the grid of the first limiter is a key test. The junction of R1 and R2 in Fig. 3-16 is the test point where the limiter voltage can be measured without upsetting the circuits. This is also a good test point for evaluating receiver performance. When there is

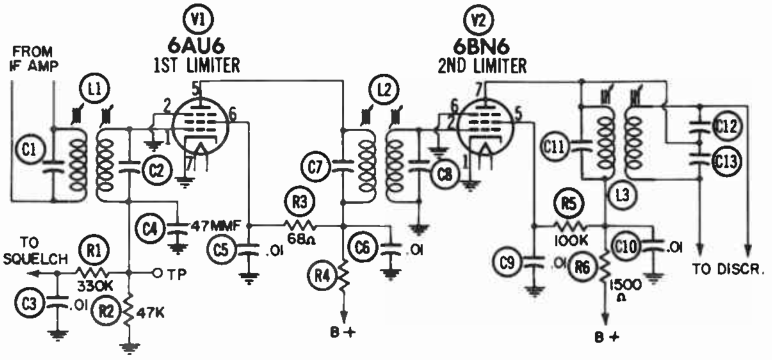


Fig. 3-17. First and second limiters in the Aerotron Model 600 receiver.

no voltage here, the receiver is obviously inoperative, since even noise will cause some voltage to be developed at this point.

In most FM receivers, limiter saturation occurs with only a very small signal. In fact, receiver sensitivity is often calibrated in terms of receiver quieting, which is directly related to limiter saturation. Ordinarily, AM noise is present in the receiver output (with the squelch open). When a signal is intercepted, the noise level drops because of limiter action. For instance, the noise may drop 20 db when a 0.5-microvolt signal is applied. Complete saturation of the limiter (noise wiped out) might occur in the same receiver with a 2-microvolt signal applied.

Fig. 3-17 shows another limiter circuit used in a commercial receiver. A gated-beam tube (V2) is used as the second limiter. The limiting action is inherent in the tube and thus requires no bias. Limiting in the first limiter starts with internal noise. Note that the limiter stages are tuned.

CHAPTER

4

Audio Squelch and AFC Circuits in Receivers

ALTHOUGH an AM detector can be used for demodulating an FM signal, it is not done in commercial receivers. However, this is an important point to bear in mind when one listens to an FM signal on an AM communications-type shortwave receiver made intelligible by slightly detuning the tuning dial. FM reception with an AM detector is made possible by detuning the detector, so that the center frequency of the FM signal is at a point on the tuning curve where an increase as well as a decrease in frequency will change the voltage at the detector output. For example, if a tuned circuit at the input of a detector is tuned to 500 kc and the center frequency of the incoming frequency is 490 kc, the voltage at the output will rise when the signal swings +10 kc to 500 kc, and will drop when it swings −10 kc to 480 kc.

FM DETECTORS

In actual practice, however, FM receivers employ a detector designed especially for responding to changes in frequency. The Foster-Seeley discriminator (Fig. 4-1) is the basic FM demodulator. Figs. 4-2 and 4-3 illustrate two versions of the Foster-Seeley discriminator for commercial equipment. Fig. 4-4 shows the unusual phase detector used by Kaar.

One of the best performing FM detectors (see the configuration in Fig. 4-5) is the Bradley detector

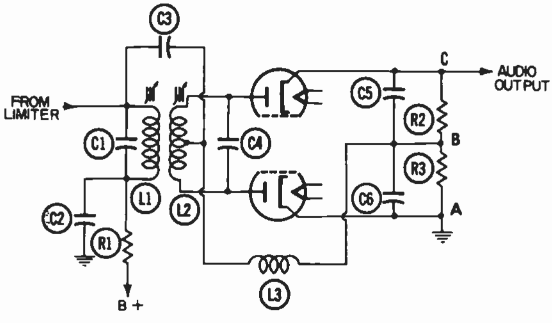


Fig. 4-1. Foster-Seeley discriminator.

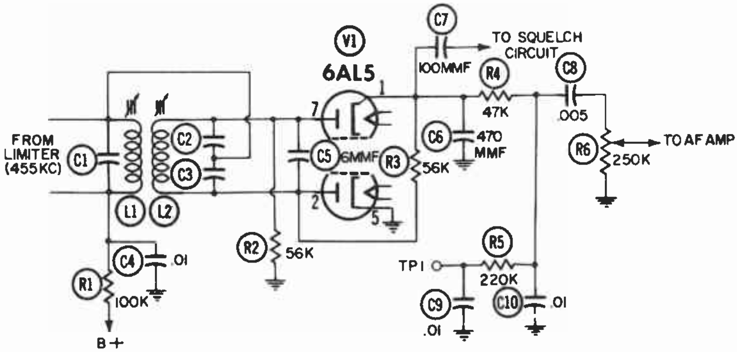


Fig. 4-2. Discriminator circuit of the RCA Model CMC-20A receiver for the 148-174 mc range.

used more than a decade ago in Philco mobile radio equipment. Field tests often demonstrated its advantages. However, some technicians resented these advantages because an oscilloscope and an FM signal generator were required for adjustments—as opposed to an ordinary VOM and almost any signal, which are adequate for makeshift discriminator adjustments in the field.

Another kind of FM detector used in commercial communications receivers is the gated-beam discriminator in Fig. 4-6.

The conventional discriminator has two basic adjustments. The primary of the discriminator transformer is tuned for maximum signal (as measured between points *A* and *B* in Fig. 4-1). The secondary is tuned to achieve balance. The output of each diode is 90° out of phase in opposite directions with point *B*, or 180° out of phase with each other, resulting in zero voltage at *A* and *C*. When metered at points *A* and *C*, the secondary is adjusted for zero indication. This adjustment can be made most readily with a DC VTVM set for zero reading at center scale, so that any positive or negative swings away from zero can be noted. These adjustments are made with an unmod-

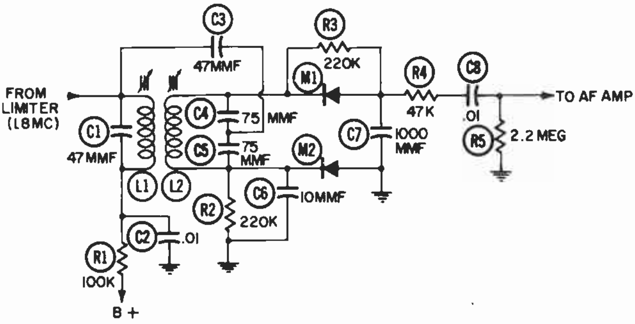


Fig. 4-3. Solid-state discriminator of the Pak-Fone receiver for the 25-54 mc range.

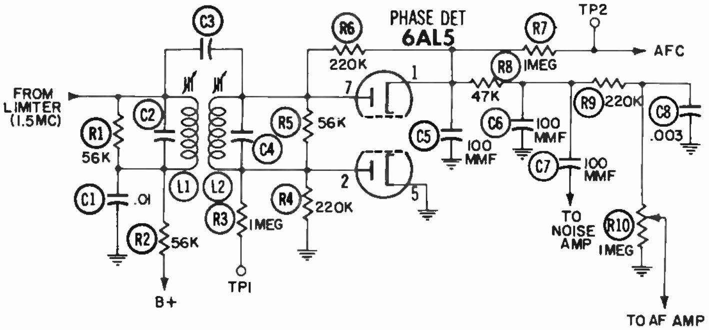


Fig. 4-4. Phase detector of the Kaar Model 8818 receiver for the 25-54 mc range.

ulated signal applied. When an FM signal is received, the voltages at *A* and *C* swing alternately positive and negative at the modulated rate. The amplitude of the resultant audio signal is determined by the amount of frequency deviation.

Discriminator Troubles

The maintenance of balance in discriminator circuits is important. Trouble may occur because of some defect in the tuned circuits or because of changes in resistor values. Therefore, both diodes, whether tubes or semiconductors, must be balanced with respect to each other.

SQUELCH

All commercial fixed-tuned superheterodyne receivers are equipped with a squelch. When squelched, the receiver is operative except for the audio amplifier, and the speaker is muted so that no background noise will be heard. When unsquelched (squelch open), the audio amplifier is operative.

Fig. 4-7 is a schematic of a simple squelch circuit. The circuit opens (allows audio to get through) when the limiter voltage rises (becomes more negative). Such a condition occurs when the incoming signal or noise (or both) rise above a specific level. The increased voltage reduces the current through V2. As a result, the bias is reduced on V1. The same circuit can be used with AM receivers that employ AVC voltage for control.

Limiter-operated squelch circuits were used in some early receivers. Most receivers now employ a

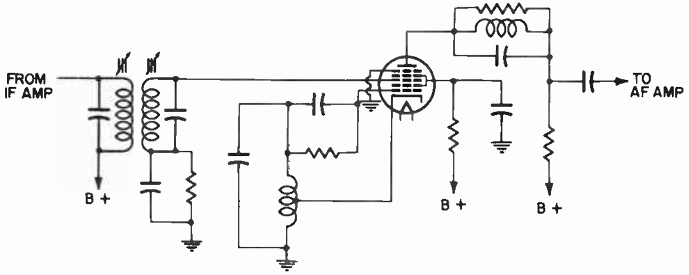


Fig. 4-5. Bradley detector of older Philco mobile receivers.

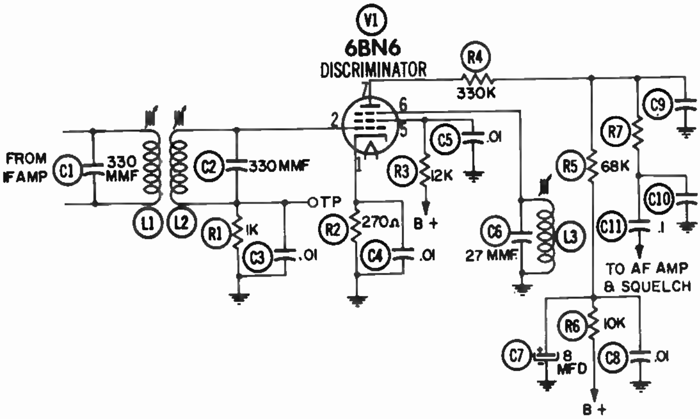


Fig. 4-6. Gated-beam discriminator of the Pye Model FM8102 receiver for the 132-174 mc range.

squelch circuit controlled by the noise level. When a signal is intercepted, the noise level drops, opening the squelch. In some receivers, the squelch is controlled by both the limiter voltage (DC) and the noise voltage (AC).

Typical squelch circuits are shown in Figs. 4-8, 4-9, and 4-10.

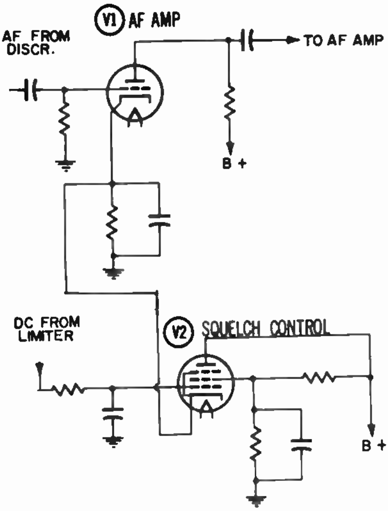


Fig. 4-7. Simplified limiter-controlled squelch circuit.

The circuit in Fig. 4-8 works as follows. When noise (but no signal) is present, V1A amplifies it. This amplification applies a positive DC voltage from the cathode of V1B to the grid of V2A. V2A conducts, making the grid of V2B negative. V2B is forced into cutoff by this negative voltage. When the noise disappears, the positive DC output of V1B drops, reducing the bias on V2B. At the same time, the limiter applies a negative DC voltage to V1B (further reducing its positive output), and to the grid of V2A (offsetting the positive voltage from the cathode of V1B). V2A stops conducting. This makes the grid of V2B more positive and thus allows it to conduct.

In the circuit in Fig. 4-9, noise, when present, is amplified by V4 and converted to a negative DC voltage. This voltage is applied through M2 to the grid of V2. V2 is then cut off. When the noise disappears (because a signal is present), the output of V5 drops, M2 stops conducting, and the extra bias on V2 is removed. This allows V2 to act as an amplifier. M1 compensates

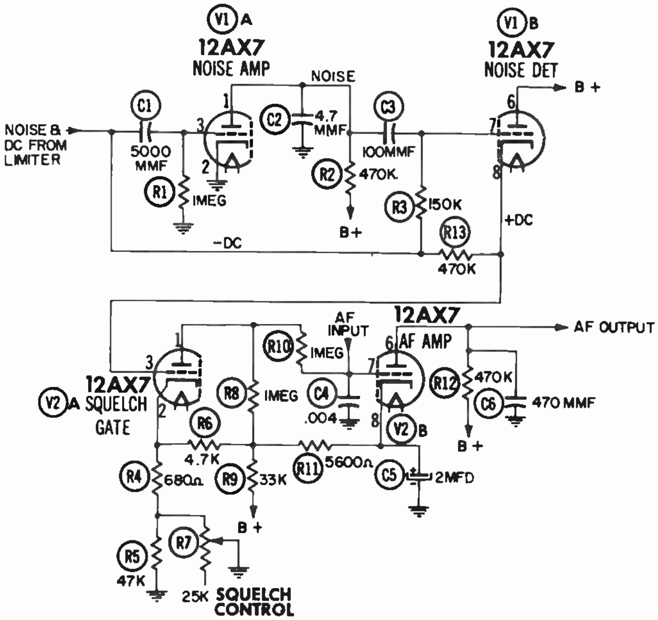


Fig. 4-8. Bendix squelch circuit.

against tightening of the squelch because of an increase in the supply voltage. Otherwise, the effective sensitivity would be reduced. When noise is present, M1 permits a negative DC voltage (proportional to the noise) to vary the gain of V4, in order to hold the output of V4 constant.

V2 in Fig. 4-10 is biased to cutoff when no signal is present. The biasing is provided by the negative DC voltage developed across noise rectifier M1 at the output of noise amplifier V1. The limiter voltage also controls the squelch action by varying the gain of noise amplifier V1.

Figs. 4-11 and 4-12 show squelch circuits employing relays. In the circuit in Fig. 4-11, the relay opens and closes the filament circuit of the AF amplifier, in response to noise from the second limiter. Note that the screens of limiter V1 and noise amplifier V2 are connected together, so that the conductivity of V1 affects the gain of V2. In the presence of noise, a negative DC voltage is applied to the grid of V3. This voltage reduces the plate current of V3 and de-energizes relay M1. As a result, the filament voltage is removed from the AF amplifier. When the noise disappears, V3 conducts, closing the relay. Filament voltage is then applied to the AF amplifier, allowing the tube to conduct.

Fig. 4-12 shows how a relay can be used in lieu of biasing the first AF stage to cutoff. Here the DC voltage from the noise rectifier (at point *X* in Fig. 4-9) is fed to the AF power amplifier. When a signal of sufficient amplitude is received, the bias drops, and the relay (in place of the cathode resistor) is energized. The relay contacts can be used to control a transmitter, a signal device, or a speaker.

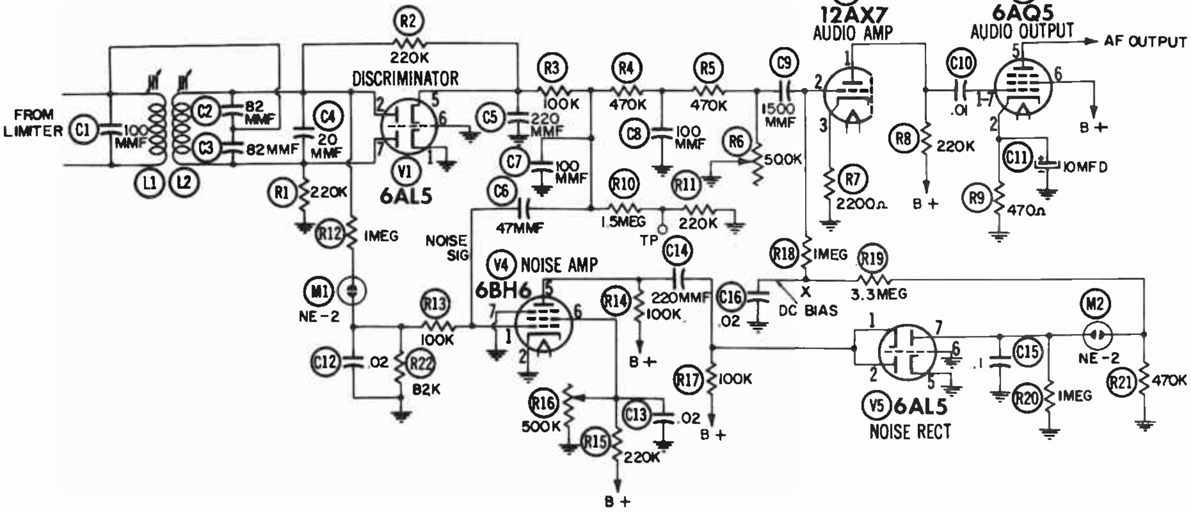


Fig. 4-9. Squelch circuit in Comco Model 580 Fleetcom receiver.

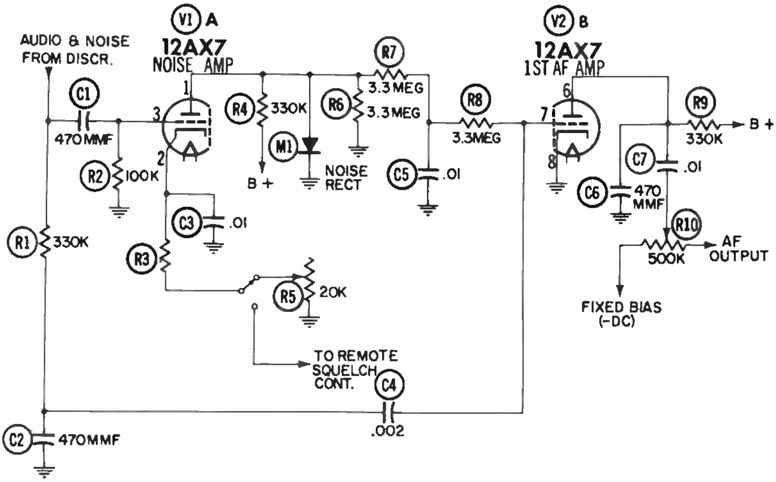


Fig. 4-10. Squelch circuit in the Aerotron 600 Series receiver.

The squelch control, with which the operator sets the signal-to-noise ratio at which reception is allowed to commence, is generally on the central head, remote from the receiver itself. In sets with built-in controls, of course, the squelch control is on the same chassis or is adjacent to the receiver chassis.

Squelch Troubles

Squelch circuits are critical and so may malfunction when any of the tubes fail to meet certain tolerances, or when they suffer from grid emission. Changes in resistor values can also affect performance. In the event of squelch trouble, the volt-

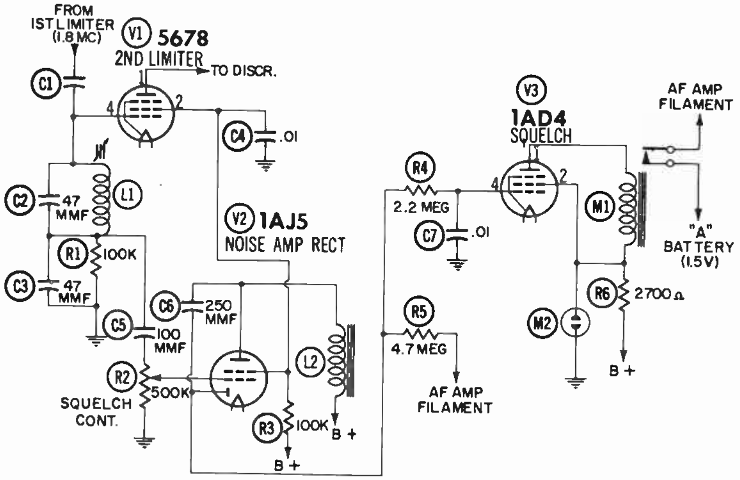


Fig. 4-11. Squelch circuit of the Pak-Fone Model PS40 industrial radio for the 25-54 mc range.

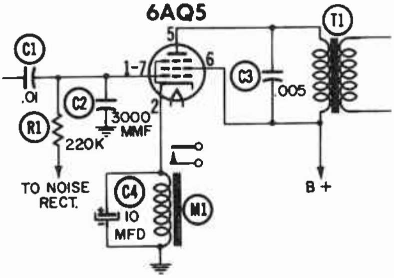


Fig. 4-12. Relay used in lieu of biasing the first AF stage to cutoff.

ages (as listed in the applicable instruction book) should be carefully checked with a VTVM.

AUDIO AMPLIFIERS

Conventional audio circuits are used, except for the section controlled by the squelch. Most receivers provide about one watt of audio output. Some receivers, particularly those used in railroad and other heavy-duty applications, may deliver from four to ten watts of audio output.

In mobile applications, audio is delivered at a low impedance for direct connection to a speaker. For base-station applications, the audio output may be available at a low impedance, at 600 ohms, or at both.

Figs. 4-13, 4-14, and 4-15 show the audio circuits of typical commercial receivers. In Fig. 4-13, two 6AQ5 tubes in parallel serve as the AF output amplifiers when the transceiver is receiving, and as the modulator of the AM transmitter when the transceiver is transmitting. Transformer T1 acts as an output transformer during reception, and as a modulation reactor during transmission.

The circuit in Fig. 4-14 is typical of those in most receivers. The one in Fig. 4-15 has a filter at the output. The filter attenuates all AF signals above 3,000 cps.

The method of controlling the volume varies among manufacturers.

Coupling capacitors are generally of lower value than the ones in broadcast receivers, to limit the low-frequency response and to favor the 300-3,000 cps speech band.

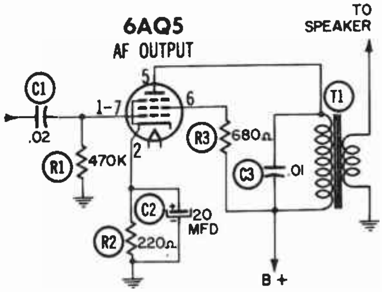


Fig. 4-14. AF power amplifier of the DuMont Model MCA-401C-C receiver.

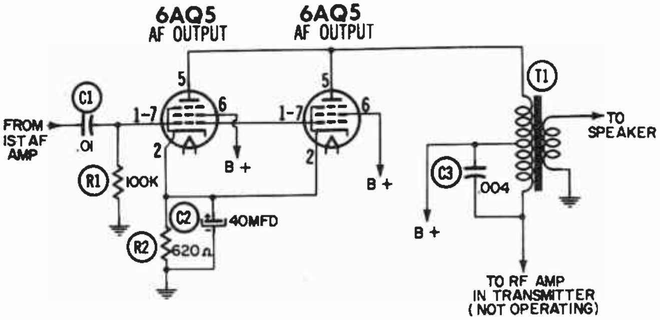


Fig. 4-13. Audio power amplifiers of the Aerotron 500 Series transceiver.

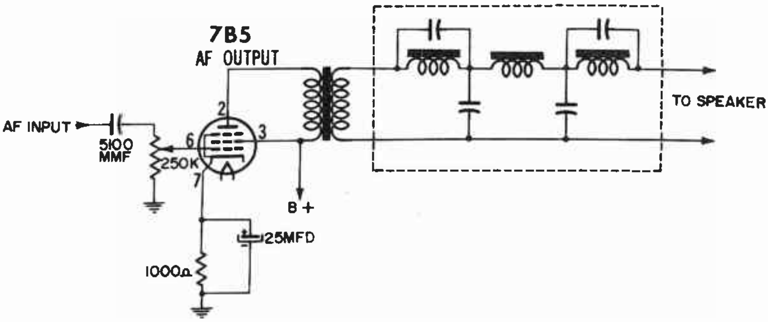


Fig. 4-15. AF amplifier of the Link 11-UF-Ed. 6 receiver.

Audio-Section Troubles

Because of its simplicity, very little attention is paid to the audio circuit, except to note that it is operative. Since only a few components are used, few troubles occur, and these are easily spotted.

The technician is interested primarily in knowing that the audio amplifier is operative. But he should also know whether it can deliver its rated output, and do so without excessive distortion.

The latter can easily be determined by feeding a tone from an audio oscillator to the grid of the first audio stage, and measuring the audio output with an AC voltmeter at the secondary of the output transformer. When the audio output is observed with an oscilloscope, any serious distortion can be noted on the sine-wave trace.

IMPULSE NOISE SILENCERS

Some AM receivers are equipped with noise-silencer circuits to reduce ignition and other impulse-type noises. Fig. 4-16 is a schematic of the AVC, noise clipper, detector, and noise-limiter circuits used in a radiotelephone unit. Diode V3, acting as a noise-pulse controlled switch, opens the audio circuit to prevent passage of impulse-type noises into the audio amplifier. Large noise pulses are clipped by neon lamp M1 before they reach the detector and noise limiter V3. The neon bulb ignites when excessively strong noise pulses are received at the plate of IF amplifier V1. This momentarily places a shunt across output-IF transformer T2.

Under normal conditions, the plate of V3 has the same audio and DC potentials as diode load R10, because of the relatively large values of R8 and C12. Because it is connected to a more negative point on the detector load, the cathode of V3 is at a higher negative voltage than the plate. Capacitor C10 and resistor R5 form another R-C network, in which C10 assumes a negative charge with a potential approaching that at the junction of R4 and C8.

Under normal conditions, diode V3 conducts, allowing audio signals from the detector to reach the audio amplifier. Thus, the audio signal developed across R8 also appears across volume control R9. A high-amplitude pulse of short duration will appear as a large negative swing at the plate of diode V3. This pulse will not appear at the cathode of V3 because of the large time con-

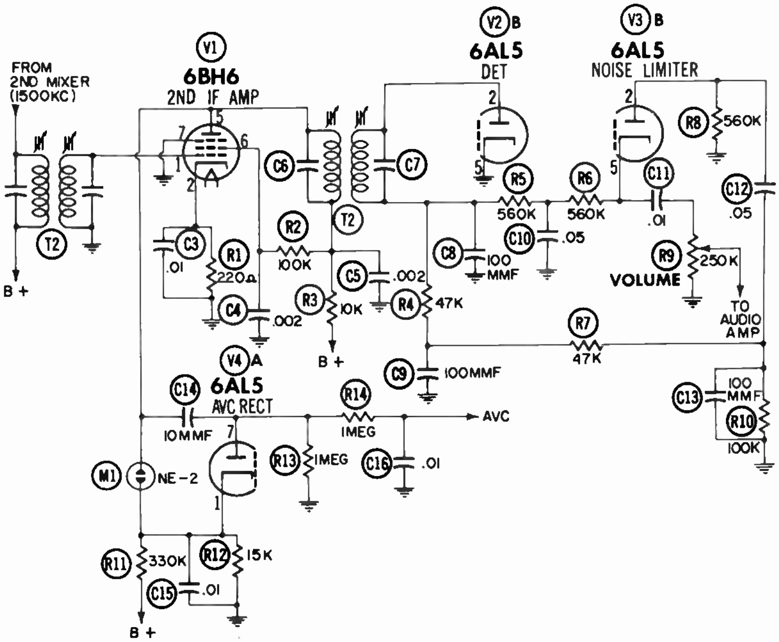


Fig. 4-16. AVC, noise clipper, detector, and noise-limiter circuits of the Kaar Model TR325 Class-D Citizens radiotelephone.

stant of C10 and R5, compared to the time constant of the diode load. The plate of diode V3 becomes negative with respect to the cathode for the duration of the pulse. Since the diode stops conducting under this condition, it appears as an open circuit. It thus prevents the pulse and any other audio signal from reaching the audio amplifier. Because this occurs for such small time durations, the desired audio signal is not significantly distorted.

Negative AVC voltage for the second mixer, first-IF amplifier, and the RF stage is produced by diode V4, which rectifies the 1500-kc IF signal fed through C14 and developed across diode load resistor R13. The AVC responds quickly because of the relatively short time-constant of C16 and R14. The cathode of the AVC diode is biased at +7 volts to prevent AVC action on weak signals. Thus, the useful sensitivity is increased.

AUTOMATIC FREQUENCY CONTROL

Some receivers are equipped with AFC (automatic frequency control). AFC automatically varies the frequency of the first heterodyne oscillator so as to maintain the desired IF signal frequency and thus compensate for variations in the frequency of the received signal, as well as for any frequency drift within the local oscillator.

For instance, if the received signal drifts +5 kc from its intended frequency, the resultant IF signal will also increase 5 kc. However, AFC action will shift the local oscillator frequency of the receiver +5 kc to restore the correct IF.

When the incoming signal or the oscillator drifts in frequency, a DC voltage is developed at the output of the detector. Its polarity depends upon the direction of the frequency shift, and its voltage depends upon the magnitude.

This DC voltage can be used to control the plate current of a reactance tube affecting its apparent reactance, which is shunted across the oscillator tuning circuit. When the DC voltage is negative, it adds to the normal bias on the reactance tube, reducing its plate current. When the control voltage is positive, the bias is reduced and the plate current is increased. The magnitude of the control voltage thus determines the amount of frequency correction, and its polarity determines whether the shunted reactance increases or decreases.

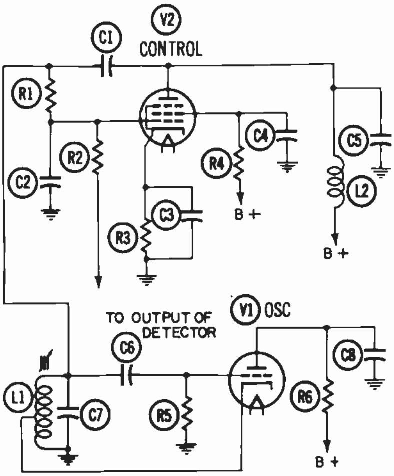


Fig. 4-17. AFC systems for FM broadcast receivers.

Fig. 4-17 is a basic AFC circuit for FM broadcast receivers employing a tunable heterodyne ocillator. It is similar to a phase modulator. The oscillator tuned circuit L1-C7 is shunted by control tube V2 and by a phase splitter consisting of R1 and C2.

The RF voltage developed across L1-C7 is applied across the phase splitter (R1-C2). R1-C2 applies an RF signal voltage to the grid of V2. This voltage lags the current in R1 by 90° because the resistance is much greater than the reactance of C2.

The plate current of reactance tube V2 is in phase with the voltage applied to its grid, but lags the voltage across the tuned circuit (L1-C7) by 90°. Since this lagging current through the tuned circuit decreases the inductive reactance of L1, the frequency of the oscillator is increased.

When the oscillator tuning and the frequency of the incoming signal are such that the correct IF signal is provided, the AFC-control voltage is zero. Under this condition, no frequency correction is required; but since the reactance tube and phase splitter are permanently shunted across the oscillator tuning circuit, allowance is made in the design for their effect.

AFC is also used in some crystal-controlled communications receivers. It provides automatic compensation when signals are intercepted from slightly off-frequency transmitters, as well as for instability of the receiver heterodyne oscillator. AFC also lessens the need for temperature control of the receiver crystal.

In Fig. 4-18, a reactance tube (V1) is shunted across the crystal, which is the tuned element of the receiver heterodyne oscillator. The AFC-control voltage varies the plate current of control tube V1. This affects the amount of reactance shunted across the crystal. (For the sake of simplicity, the complete oscillator circuit is not shown.) R1 isolates the discriminator from the control tube, while C1 bypasses any

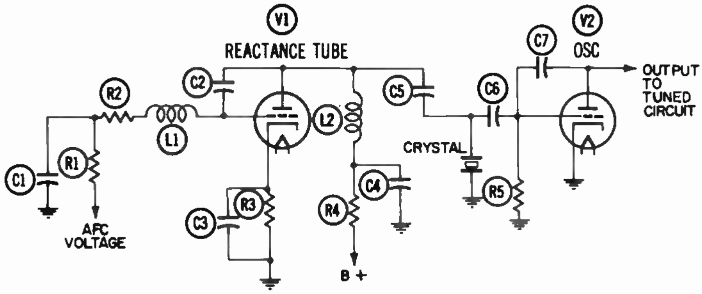


Fig. 4-18. AFC circuit for controlling a crystal oscillator.

audio component. The two jointly provide the desired AFC time constant (delay). Capacitor C2, a very small value (under 10 mmf), provides the desired phase shift.

AFC Troubles

One of the troubles about AFC circuits is "capturing" of strong unwanted signals. This occurred more often before the 460-470 mc Citizens band was divided into specific channels. Previously, licensees could operate on any frequency. This problem should be alleviated now that licensees must operate in specific channels and maintain tighter tolerances.

Internal troubles can occur because of changes in component values. This might cause the reactance tube to operate on an undesirable portion of its operating curve.

CHAPTER

5 Transmitters

ALL transmitters used in land mobile services, except those licensed as Class-B Citizens Radio stations, are required by the FCC to employ crystal control. Class-B stations may employ self-excited oscillators, but all others must stabilize transmitter frequencies with quartz crystals.

OSCILLATORS

Fig. 5-1 is a schematic of a tuned-plate, tuned-grid oscillator, a circuit commonly used by amateur radio stations in the pre-crystal control era. When L1-C1 and L2-C2 are tuned to approximately the same frequency, oscillations occur. Feedback through the interelectrode capacity C_{g-p}, between the grid and plate of the tube, sustains the oscillations.

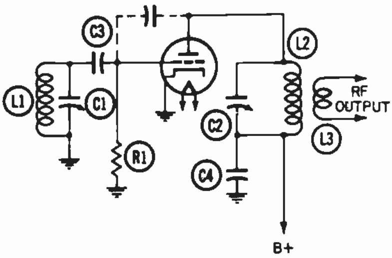


Fig. 5-1. Tuned-plate, tuned-grid oscillator.

When a crystal is substituted for L1-C1, the circuit will oscillate when L2-C2 is tuned to a frequency slightly higher than the one at which the crystal is resonant. The crystal appears as a tuned circuit at its resonant frequency. It remains constant at this frequency only, not varying except when temperature changes distort it physically.

A crystal provides adequate frequency stability for most applications. When greater stability is required, the crystal is enclosed in an oven, the temperature of which is maintained constant by a thermostat.

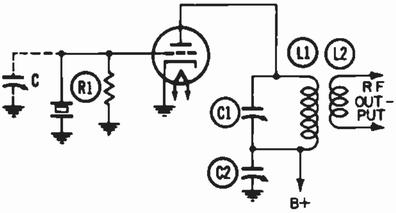


Fig. 5-2. Simple crystal-controlled oscillator.

The frequency of a crystal-controlled oscillator can be varied over a very narrow range by adding capacitor C (Fig. 5-2) across the crystal. Increasing the capacitance lowers the frequency; decreasing it raises the frequency.

Crystals are ordinarily ground to resonate at a lower frequency than the operating frequency of the transmitter. The frequency is increased by means of multiplier stages. For example, when a crystal is ground to resonate at 6.75 mc and the operating frequency is 27 mc, the crystal frequency must be quadrupled. This can be done by using two doubler stages after the crystal-oscillator stage. The first doubler changes the frequency to 13.5 mc, and the second, to 27 mc. A frequency-multiplier stage is an amplifier whose input is tuned to the incoming frequency and whose output is tuned to the desired output frequency, a multiple of the input frequency. The amplifier is operated Class C so that nonlinearity will result. The incoming frequency and its harmonics appear in the output.

In commercial transmitters, the crystal frequency must be multiplied many times before the desired output frequency can be obtained. The amount of multiplication can be reduced, however, by using the overtone operation of the crystal. When harmonic operation is employed, the crystal vibrates at its fundamental frequency. In overtone operation, the crystal oscillates at one of its overtones, rather than at the fundamental frequency to which it is cut. For instance, a 9-mc overtone crystal may oscillate at 27 mc, its second overtone or third harmonic.

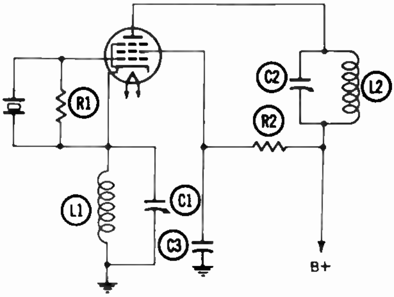


Fig. 5-3. Simple tri-tet oscillator.

Fig. 5-3 shows the circuit of a tri-tet oscillator. L1-C1 is tuned to a frequency higher than that of the crystal, and L2-C2 is tuned to a harmonic.

In Fig. 5-4, the crystal acts as a series-resonant circuit at its fundamental or at an overtone frequency, depending upon the crystal and the tuning of L1-C1. The tuned circuit, L1-C1, is tuned to the desired overtone of the crystal.

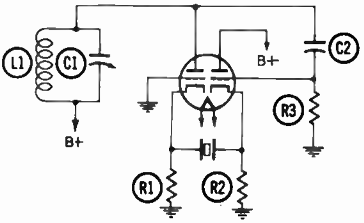


Fig. 5-4. Simple oscillator circuit for operation at the crystal overtone frequency.

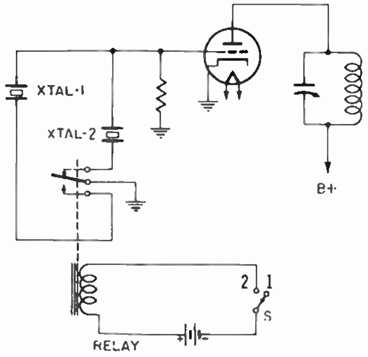


Fig. 5-5. Two-channel operation using crystal switching.

For operation on two frequencies, a second crystal can be added. It is connected in place of the first crystal by a switch-controlled relay, as shown in Fig. 5-5. The two frequencies must be fairly close to-

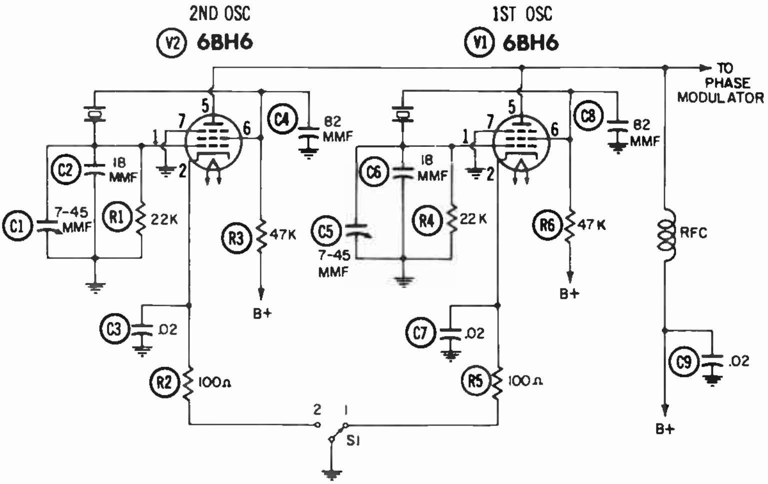


Fig. 5-6. Two oscillators, switch-operated, for two-channel operation.

gether, so that optimum tuning of the oscillator circuits, as well as those of the succeeding stages, can be obtained for both channels. Obviously, it is impractical to retune these circuits while switching from one channel to another.

Most transmitters, however, employ separate oscillators for each channel, with means for choosing any one of them. Fig. 5-6 shows an oscillator circuit used for dual-channel operation.

An electron-coupled oscillator circuit is used. When switch S1 is set to position 1, only V1 is activated. When S1 is set to position 2, V1 is disabled and V2 (operating on a different frequency) becomes operative. For 25-54 mc operation, the crystal frequency is multiplied twelve times in the succeeding stages of the transmitter.

For single-channel operation, the circuitry of V2 is omitted, and the cathode circuit of V1 is grounded instead of being routed through the switch (in the control unit).

Fig. 5-7 shows the oscillator circuit of a 450-470 mc transmitter. The crystal frequency, which is multiplied thirty-six times in the succeeding stages, can be varied slightly by adjustment of C1 (which is shunted across the crystal). C5 is pretuned at the factory, but may require field adjustment after a new oscillator tube is installed.

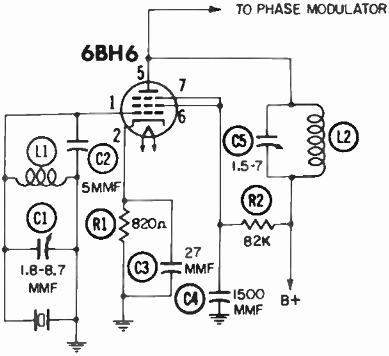


Fig. 5-7. Oscillator circuit of some General Electric 450-mc band transmitters.

For two-frequency operation, a second, identical oscillator is used. It is connected to the first oscillator and to the channel selector, as shown in Fig. 5-6.

In Fig. 5-8, the crystal-oscillator circuit contains a triode tube. Switch S1 (in the cathode circuit) permits operation on four different transmitting frequencies. The switch selects the desired channel by closing the cathode circuit of the appropriate oscillator.

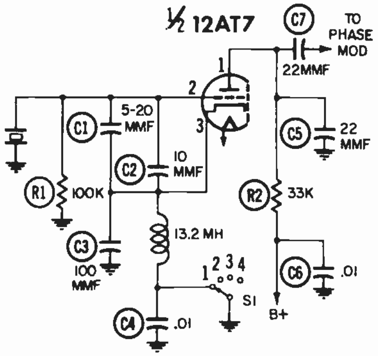


Fig. 5-8. Oscillator circuit of DuMont MC-401-C communications units.

FREQUENCY MULTIPLIERS

Except in very simple transmitters, the oscillator is followed by one or more frequency-multiplier stages. A frequency multiplier is an amplifier stage which is biased to distort as well as amplify the signal. The distortion is used to advantage. If no distortion were present, the output would be a clean replica of the input, both of the same frequency.

Because of the distortion, the output signal contains the input frequency as well as harmonics. By putting a tuned circuit in the output circuit, it is possible to derive the desired harmonic while suppressing the fundamental (input frequency) and the unwanted harmonics.

Fig. 5-9 shows a typical frequency-multiplier stage. The grid leak, R2, is of much higher value than required for normal operation of the stage as an amplifier. Since the tube is thus biased for cutoff, it conducts during the positive half of the input cycle only. This causes the output to be rich in harmonics, of which the desired one can be captured by appropriate tuning of C6-L2.

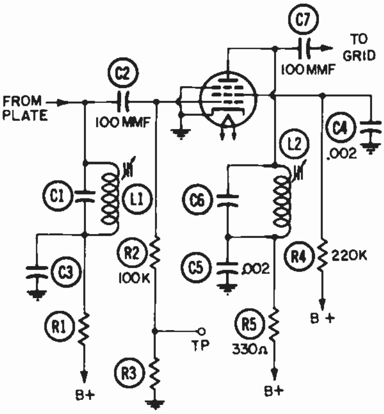


Fig. 5-9. Typical frequency-multiplier stage.

The test point (TP) at the junction of R2 and R3 may be available at a pin jack or metering socket. Grid current is measured between the test point and ground with a DC voltmeter or microammeter. L1 and C1, which tune the plate circuit of the preceding stage to the input frequency, are adjusted for maximum indication at the test point.

Various types of frequency-multiplier stages are in use. Push-pull stages are utilized where even harmonics are to be suppressed; single-ended stages can produce even and odd harmonics; and push-push stages are found where even harmonics are to be favored.

RF POWER AMPLIFIERS

In some transmitters the final RF power amplifier also acts as a fre-

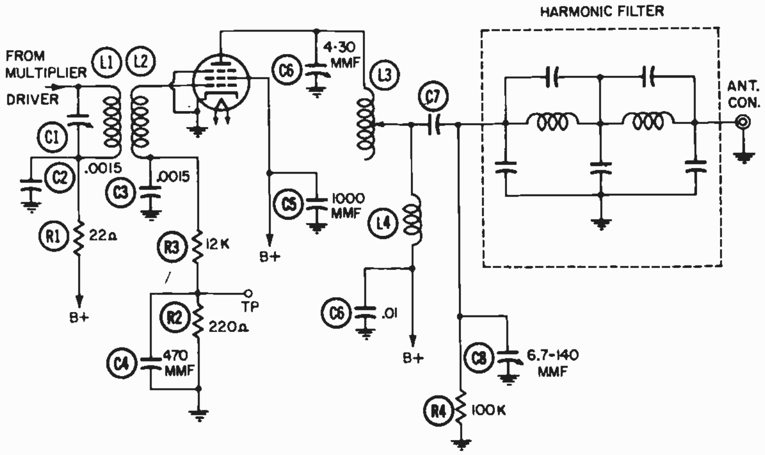


Fig. 5-10. Typical power amplifier in 25-50 mc band transmitter.

quency multiplier. However, this is often avoided to prevent spurious radiation of unwanted harmonics.

Fig. 5-10 shows the RF-amplifier circuit of a 25-50 mc band transmitter. L1-C1 and L3-C6 are tuned to the operating frequency. Although the output circuit looks more complex because of refinements, it is basically a pi-type circuit. C6 tunes L3 to resonance at the operating frequency, while C8 controls antenna loading.

At resonance, a high current flows through L3, C6, and C8. The voltage drop and the impedance depend upon the capacitance of C8. The lower the capacitance, the higher the voltage across C8 because of its higher impedance. By the same token, the higher the capacitance, the lower the voltage. L3 is tapped and adjustable so that the optimum value can be obtained for the operating frequency.

Two tubes are often paralleled in the RF power-amplifier stage of a 25-50 mc transmitter in order to increase the output. In Fig. 5-11, two 6146 tubes are paralleled. L3 is shunted by R8 in series with the plate of V1; L4 is shunted by R9 in series with the plate of V2; R5 is in series with the grid of V1; and R6 is in series with the grid of V2. Together they suppress parasitic oscillations, which might otherwise occur within this stage.

L1-C1, L2-C2, and L5-C5 are tuned to the operating frequency. Plate current for the driver stage is measured at TP1, and grid current for the power amplifier is measured at TP2. C7 is used to adjust antenna loading. A low-pass harmonic filter between the RF amplifier and the antenna suppresses the transmission of harmonics.

A single 6146 tube is employed in the RF-amplifier circuit of Fig. 5-12. The output power depends upon the applied plate voltage. This voltage can range from 350 to 400 volts. C2-L2, C3-L3, and C7-L4 (series-resonant circuits) are tuned to the operating frequency. Grid current, monitored at TP1, is measured to determine optimum tuning of C2-L2 and C3-L3. The RF-amplifier plate current is determined by measuring the drop between TP2 and TP3, and the B+

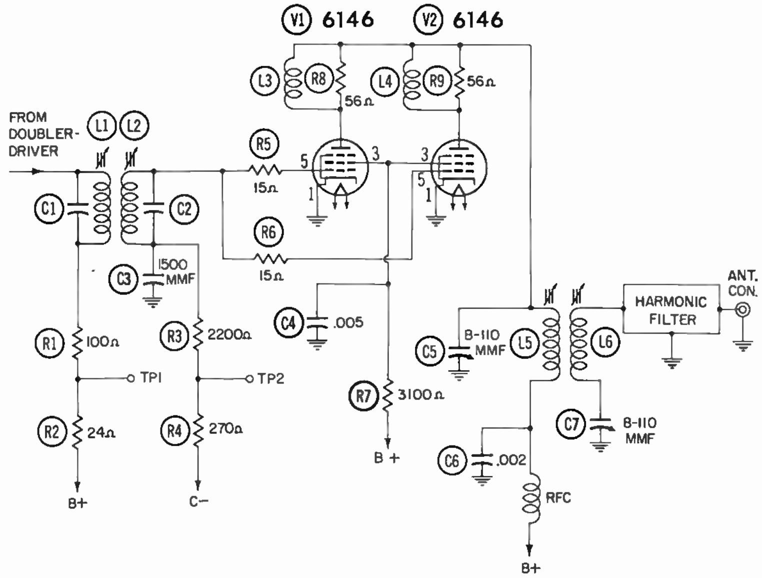


Fig. 5-11. Two 6146 tubes are paralleled to provide a higher RF output.

voltage is measured between TP3 and ground. C9 tunes the antenna circuit for optimum loading.

Fig. 5-13 shows the circuit of a push-pull RF amplifier for the 450-470 mc band. Note that the tuned circuits consist of lines, the resonant points of which are adjusted by capacitors. The input, fed inductively from the preceding stage, is tuned by C1; the output is tuned by C2; antenna loading is adjusted by C3; and the antenna circuit is tuned by C4.

Grid-leak bias is developed across R1 and R2 for each half of the dual tube. In addition, the amount of bias—and hence, the grid drive—can be adjusted with R3. Grid current can be metered between TP1 and ground. Plate current for the power amplifier is measured across

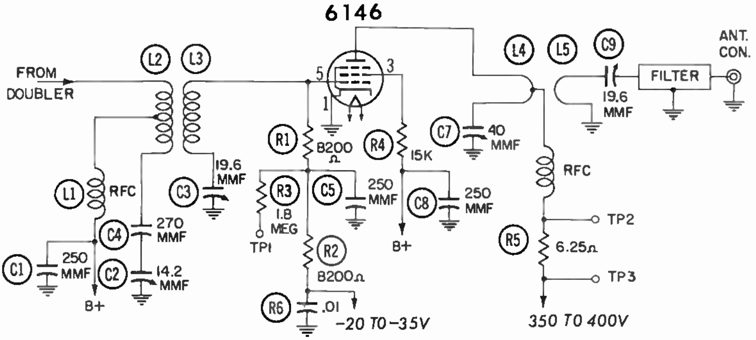


Fig. 5-12. Single-ended power amplifier for the 152-174 mc band.

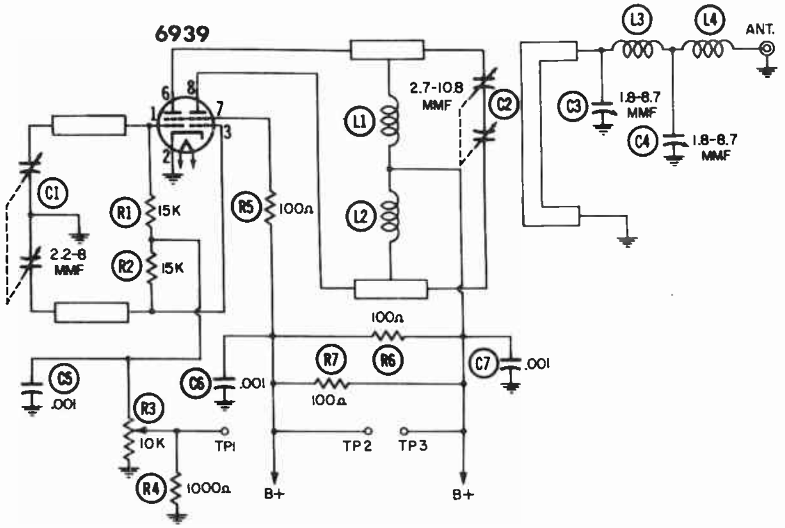


Fig. 5-13. Push-pull RF amplifier in the Kaar TR500 for the 450-470 mc band.

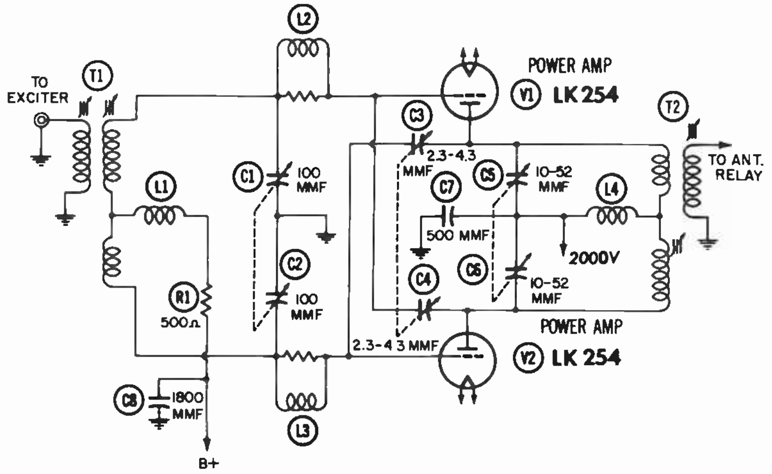


Fig. 5-14. A 250-watt booster amplifier in the Bendix 14TS-1 and 14TS-2 transmitters.

TP2 and TP3, and B+ voltage is measured between TP2 and ground.

BOOSTER AMPLIFIERS

All mobile transmitters, and most base transmitters with low and medium power, have a self-contained RF power amplifier. A booster power amplifier may be added at base stations when higher power is required. Fig. 5-14 is a schematic of a 250-watt amplifier which may be driven by a lower-powered transmitter.

RF input is applied through a coaxial cable which drives the pair of LK254 tubes connected in push-pull. Since 2,000 volts DC are re-

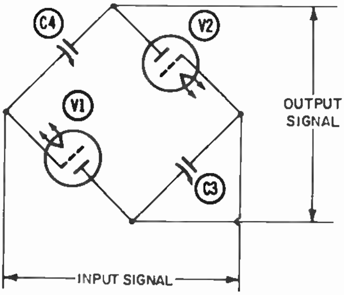


Fig. 5-15. Neutralizing capacitors and tubes of Fig. 5-14 form a bridge network.

quired as the plate voltage, a separate power supply is employed.

In lower-powered RF amplifiers, tetrode or pentode tubes (which usually require no neutralization) are used. The triodes in Fig. 5-14 require neutralization. Capacitors C3 and C4 are part of a bridge circuit, as shown in simplified form in Fig. 5-15. When the capacitors are correctly adjusted, the bridge is balanced, and the input signal gets through only because of amplifier action. Plate-to-grid capacitance, if not neutralized, would permit the stage to burst into self-oscillation.

AM TRANSMITTERS

Most transmitters for the 27-mc Citizens band are very simple devices that must employ AM only. Fig. 5-16 shows part of a *Radio-Phone* unit for the 27-mc Citizens band. The RF portion of the transmitter has only one tube (V1). This 6AQ5 tube is the crystal oscillator. It is modulated by another 6AQ5 (V2), which also serves as the AF power amplifier when receiving. There is a third overtone crystal.

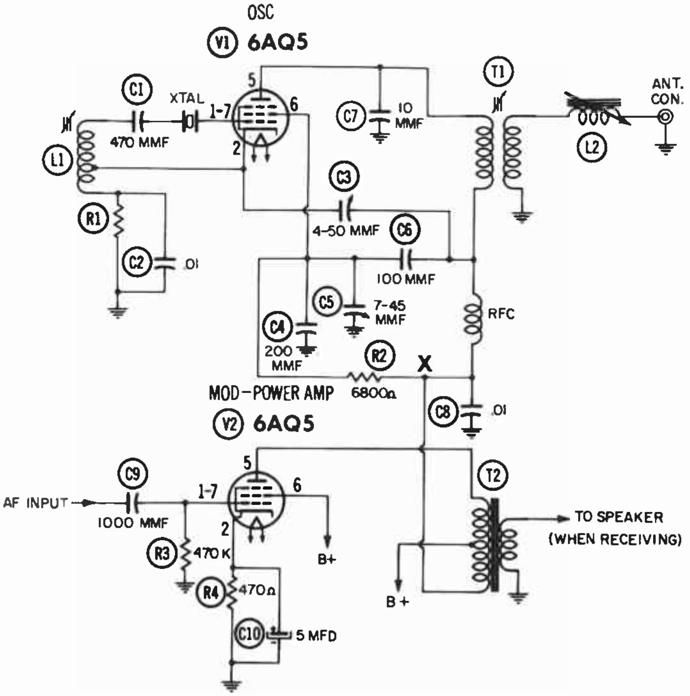


Fig. 5-16. A portion of the RCA CRM-P2A-5 transmitter for the 27-mc band.

Thus, for operation at 27 mc, a 9-mc crystal would be ground to resonate on its second overtone (third harmonic), which is 27 mc.

The receiver output transformer also plays a role in the transmitter. First, let's look at the basic modulator. Fig. 5-17 shows the basic circuit—devised by Raymond A. Heising—which can modulate an oscillator or RF amplifier. Both the modulator and the modulated stage receive plate voltage through coil L1. This voltage tends to maintain the current constant.

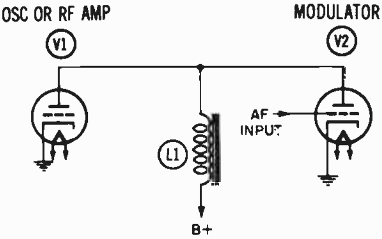


Fig. 5-17. Basic Heising modulator.

When the AF signal drives the grid of modulator V2 less negative, this tube draws more current. When its grid is swung more negative, V2 draws less current. This current flows through the reactor. The varying current causes the reactor to build up across it a voltage in series with the DC plate voltage.

Without modulation, the plate current of V1 remains constant. When modulated, it varies because its plate voltage is being modulated (the voltage developed across the reactor alternately adds to and subtracts from the DC plate voltage).

Fig. 5-18 is a simplification of a commercial modulator system. Here the primary of transformer T1 acts as an autotransformer. When the plate current of V2 varies with modulation, an AC voltage is developed between points *X* and *Y*. The same AC voltage is developed between points *Y* and *Z* because of transformer action. The AC voltage between points *Y* and *Z* is added to and subtracted from the DC plate and screen voltages of V1, thus varying RF output.

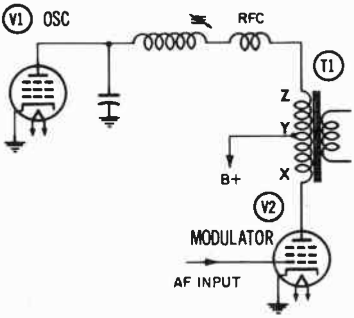


Fig. 5-18. Simplified circuit of RCA Radio-Phone modulator.

MORE COMPLEX AM TRANSMITTERS

Fig. 5-19 shows a more complex transmitter. It can be used as a Class-D Citizens Radio, or in any other land mobile service in the 25-50 mc band. The AM transmitter has three stages (V1, V2, and V3). V1 is the crystal oscillator, V2 is a frequency doubler, and V3 is an RF power amplifier-doubler. The crystal frequency is doubled. Hence, for 27 mc the crystal would be ground for 13.5 mc.

The values of all capacitors except C5, C12, and C14 are shown in Fig. 5-19. The values of the latter depend upon the exact operating frequency. Test points TP1, TP2, TP3, and TP4 actually run to a socket into which a special test meter is connected when the transmitter is being tuned. TP1 provides an indication of oscillator tuning, which is controlled by adjusting the slug of L1. At TP2, the adjustment of L1 indicates the amount of drive

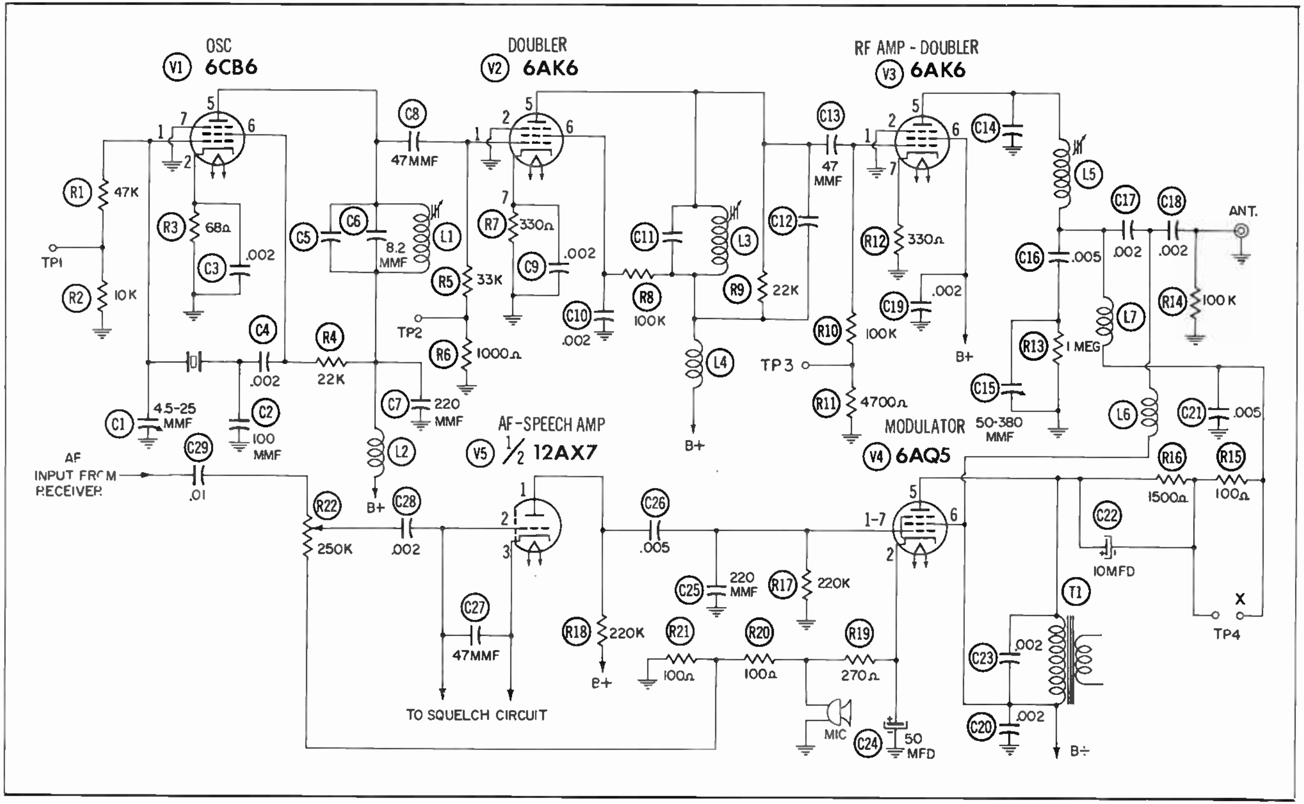


Fig. 5-19. The Kaar TR425 AM transmitter for 25-50 mc band.

Fig. 5-20. Three VHF AM transmitters for ground-to-air communications. Adaptable for airport ground communications.

to V2. At TP3, the amount of grid drive to V3 is measured when L3 is adjusted. At TP4, a microammeter is connected for measuring the plate current to V3 when L5 is tuned for minimum current and C15 for antenna loading.

The final RF amplifier, V3, is amplitude-modulated by V4. The primary of receiver output transformer T1 acts as the reactor in a Heising modulator circuit. R16 lowers the plate voltage to V3, so that the audio voltage at V4 will be greater than the DC plate voltage on V3, in order to allow a higher percentage of modulation.

V5, one triode section of a 12AX7 tube, serves as the speech amplifier when transmitting, as well as the AF voltage amplifier when receiving. When the unit is set for receiving, this tube is controlled by the squelch circuit (not shown in detail here to avoid confusion). In Fig. 5-19, note the clever way of hooking in the carbon microphone. Its excitation voltage is obtained from the junction of R19 and R20, through which the cathode current of V4 flows. The speech amplifier receives its input signal from the common point of R20 and R21, where the current flow is varied by the microphone current.

HIGH-POWERED AM TRANSMITTERS

AM transmitters to be used as Class-B or -D Citizens Radio stations are limited by FCC regulation to five watts input to the final RF amplifier (or if a single stage, to the oscillator). Higher-power AM transmitters (like the one in Fig. 5-20) are used primarily in radio paging systems and at airports, for ground as well as ground-to-air communications.

The simple basic Heising circuit in Fig. 5-17 is not used in a modern high-powered AM transmitter. Instead, the circuit is similar to the one in Fig. 5-21. V1 and V2 are the modulator tubes (shown here in a

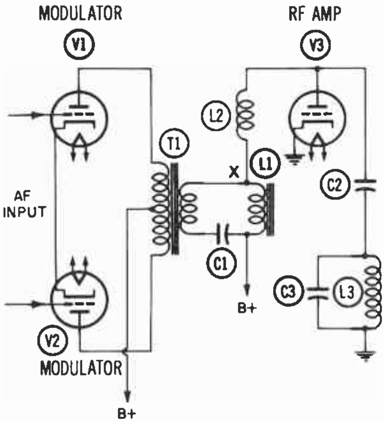


Fig. 5-21. Simplified circuit of a modern high-level modulator.

push-pull circuit). Plate current to RF amplifier V3 flows through modulation coil L1.

When unmodulated, the plate current flowing through L1 is steady. When modulated, the audio voltage adds to or subtracts from the DC voltage applied to V3. When modulation is 100%, the AC voltage at point *X* is equal to the normal DC plate voltage applied to V3. At the peak of the other half of the modulating audio cycle, the voltage at *X* is zero. At that point, the audio voltage from the secondary of T1 is equal, but opposite in polarity, to the DC voltage applied to V3. During the other half of the cycle, the audio voltage is of the same polarity as the applied DC voltage to which it is added. This raises the plate voltage and current of V3.

Coil L1 looks like a high impedance to the audio voltage. It therefore allows the plate voltage of V3 to vary with the modulating signal. Capacitor C1 prevents DC from flowing through the secondary of T1. C1 is critical in value because it is part of the AC circuit. Hence, it must be chosen with care, since it affects the efficiency as well as the frequency response of the modulator system. RF choke L2 and capacitors C2 and C3 are also part of the audio as well as the RF circuit. Hence, their values affect the frequency response.

Fig. 5-22 shows a modulation transformer and reactor for a high-powered AM transmitter. For optimum performance, the two should be matched.

CHECKING MODULATION

Overmodulation is easily checked in an AM transmitter. When it occurs, the audio voltage swings so far that it causes a negative voltage

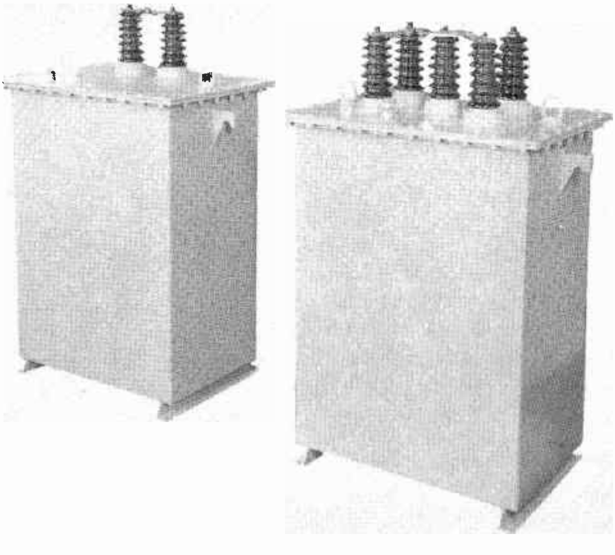
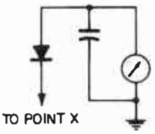
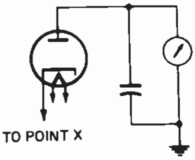


Fig. 5-22. Modulation reactor (left) and transformer (right) must be matched for optimum performance. (Courtesy of Electro Engineering Works.)

(with respect to ground) to appear at the plate of the modulated RF amplifier or oscillator during the negative audio half cycle. When this occurs, both the negative and positive peaks are excessive. Limiting thus starts in the modulated stage and squares off the wave. The sidebands are widened, resulting in ICW (interrupted continuous-wave) transmission. Consequently, the signal is distorted, and can cause severe interference because of its expanded bandwidth.



(A) Using a semiconductor diode.



(B) Using a vacuum-tube diode.

Fig. 5-23. Simple overmodulation indicators.

Fig. 5-23 shows simple overmodulation indicators for AM transmitters. In Fig. 5-23A, a semiconductor diode is used; in Fig. 5-23B, a vacuum-tube diode. Ordinarily the meter indicates zero, since the voltage at point *X* in Figs. 5-16, 5-19, or 5-21 is normally always positive with respect to ground. However, when overmodulation occurs, so that point *X* becomes negative with respect to ground, current flows through the diode and the meter.

Fig. 5-24 shows another simple modulation indicator, which can be calibrated in percentage of modulation. The meter needle "kicks" on overmodulation peaks.

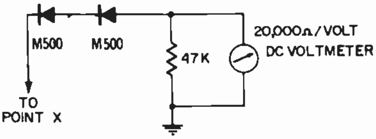


Fig. 5-24. A 20,000-ohm-per-volt VOM used as an overmodulation indicator.

FM TRANSMITTERS

Fig. 5-25 is the schematic of a simple, self-excited Hartley oscillator. When stable, it generates a CW (continuous-wave) signal. If its plate current, grid bias, or output-circuit current is varied, its output will vary accordingly, resulting in amplitude modulation.

If the capacitance of its tuning capacitor (C1) or the inductance of its tank coil (L1) is varied, the frequency of its output signal will also vary. If the tuning capacitor could be used as a microphone, so that the distance between its plates would change with the sound waves striking them, a simple FM transmitter would result.

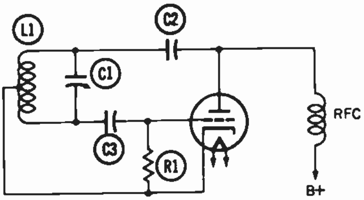


Fig. 5-25. Self-excited Hartley oscillator.

Since transmitters must be crystal controlled, such a simple scheme is not used because the crystal locks the oscillator to the resonant frequency or overtone of the crystal. Physical changes in the crystal, due to temperature changes, will shift the frequency slightly. The operating frequency of a crystal-controlled oscillator can also be shifted over a narrow range by varying the capacitance in the crystal circuit.

FM can be produced by varying the oscillator frequency. Since this is a difficult feat with a crystal oscillator, most so-called FM transmitters employ phase modulation (PM). This results in an output signal, the frequency of which is varied at the modulating signal rate.

Fig. 5-26 shows the modulator circuit of an early transmitter. The RF output of the crystal oscillator (V1) is fed to the grids of the two modulator tubes (V2 and V3) through a phase-shifting network (C2-R2 and C4-R6). The signal to one grid is leading 45°, and the one to the other is lagging 45°. Thus, the signals at the two grids are 90° out of phase with each other. The modulating audio signal is fed through the frequency-response limiting filter networks (C9-R13 and C10-R12) to another grid (pin 6) of each modulator tube. The audio signal causes the plate current of one of the modulator tubes to rise while the current in the other falls, and vice versa. This causes phase shift in the resultant current [in the tuned circuit (L1-C12) at the output of the modulator tubes] fed to the frequency multiplier and RF-amplifier stages.

The frequency of an RF signal, the phase of which is shifting, is actually changed. Although this modulator also changes the amplitude of the signal somewhat, the following transmitter stages (operated as Class-C amplifiers) clip off the AM, leaving only an FM signal.

Figs. 5-27 and 5-28 show typical phase-modulator circuits used in commercial equipment. In Fig. 5-27,

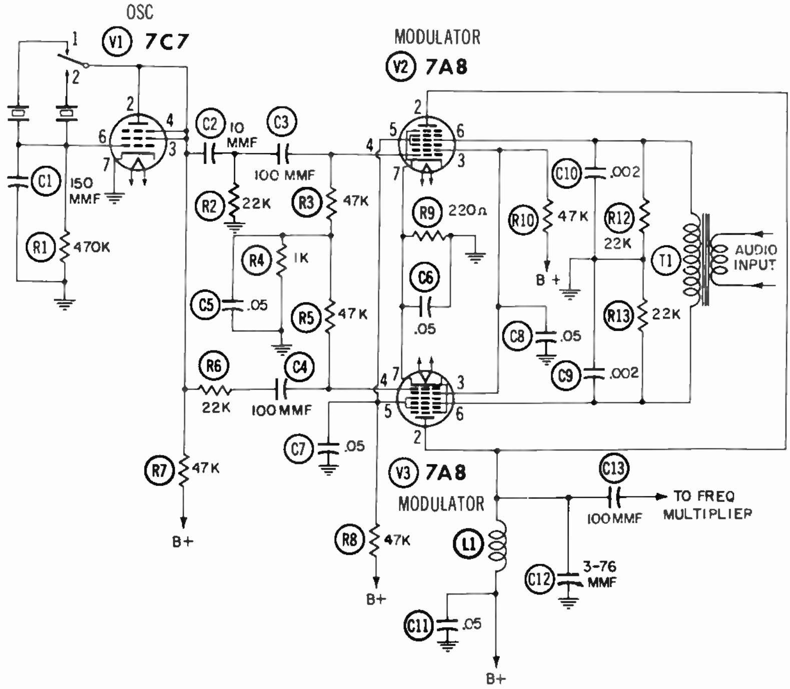


Fig. 5-26. Phase modulator of the Link Model 35-UFM-Ed. 2 transmitter.

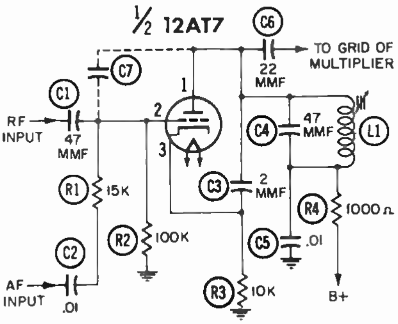


Fig. 5-27. Phase modulator of the Pye Model FM8102 transmitter.

the signal at the grid is inverted and is thus 180° out of phase at the plate. This signal is combined with the one that gets through because of plate-to-grid interelectrode capacitance. The latter signal is 90° out of phase (C7 symbolizes interelectrode capacitance). The first signal is varied in amplitude by the audio signal. It causes the currents in L1 and C4 to combine in order to produce FM by phase modulation. In Fig. 5-28, the oscillator signal is fed, through C1, directly to the plate and—via phase-shift network C2-R2—to the modulator input.

MODULATION LIMITING

FCC regulations require that both AM and also FM transmitters be equipped with a method for preventing overmodulation. In an FM transmitter, this means that the amount the signal deviates from its assigned frequency must be confined within specified limits.

The easiest way is to limit the amplitude of the modulating audio signal applied to the modulator. There are many circuits which will prevent an audio amplifier from delivering a signal having an amplitude beyond a prescribed limit. In these circuits, the speech-amplifier gain is automatically reduced when the amplitude of the input signal rises beyond a certain level. A further rise in the input signal will not increase the output.

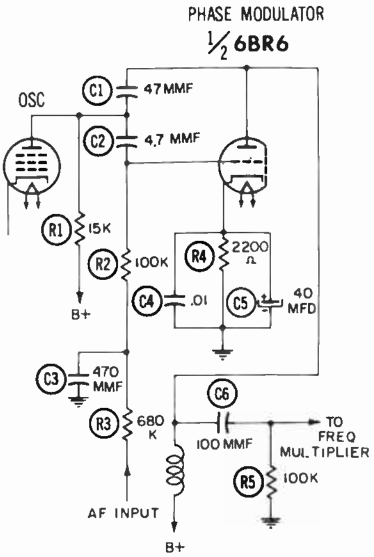


Fig. 5-28. Phase modulator of the Aerotron 600 Series transmitter.

The resultant action is similar to that of an AVC (automatic volume control) circuit in AM broadcast receivers which yield the same sound level from powerful stations nearby and weaker stations farther away. The limiter stages in FM receivers perform a similar function.

In an audio amplifier, AVC can be used or the circuit can be designed to provide limiting. Figs. 5-29 and 5-30 show two modulation-limiting circuits used in commercial equipment.

A single 6BN8 tube is used in Fig. 5-29. V1A is an AF amplifier. V1B and V1C form a limiter circuit. V1C conducts all the time, since its plate is positive. On the positive audio half cycle at the cathode of V1B, the current decreases through

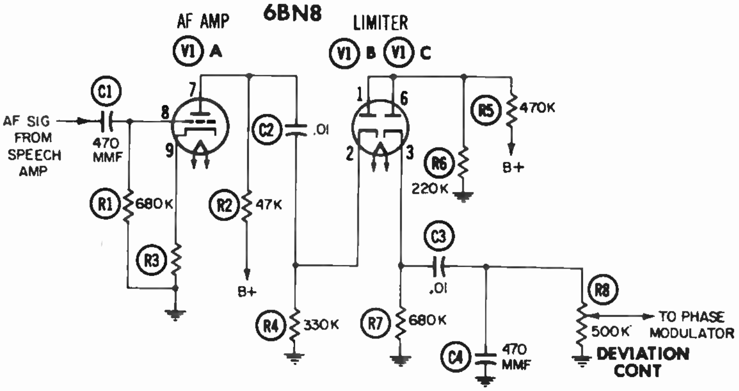


Fig. 5-29. Deviation limiter in the Aerotron 600 Series transmitter.

V1B and increases through V1C. If the signal is too strong, the cathode of V1B becomes more positive than the plate. As a result, the plate is cut off, opening the audio circuit. On the negative half cycle, the current of V1B increases and that of V1C decreases. When the negative peak swings past a critical point, the current through V1B reaches its maximum. The maximum current reduces the voltage across R7, and thus prevents the output signal from increasing any further.

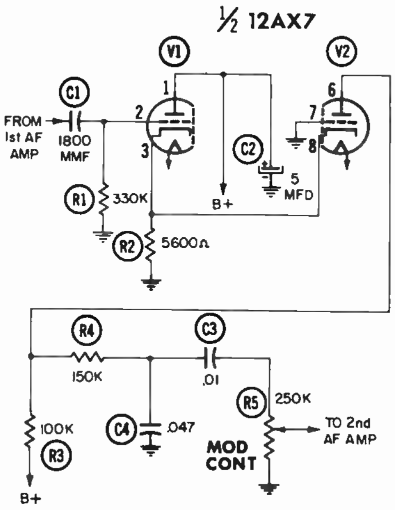


Fig. 5-30. Two-stage triode limiter used by RCA.

When the signal at the grid of V1 (Fig. 5-30) swings too positive, the bias on V2 (developed across R2) cuts off V2. On an excessively large negative swing, V1 is cut off because of the combined effect of the signal and cathode bias.

Most transmitters have a deviation control with which the allowable amount of frequency deviation can be set. This control is connected between the speech-amplifier output (which is limited) and the modulator output. This makes it easy to set the deviation at ±5 kc for narrow-band operation or ±15 kc for wide-band operation.

FREQUENCY LIMITING

Since intelligibility of voice transmission is not enhanced significantly by modulating the transmitter at frequencies above 3,000 cps, filters are being used in speech amplifiers or modulators to attenuate the response above this level. Where not used, such filters should be added to improve the quality of speech transmission and reduce the likelihood of unnecessary interference.

At the low end, the frequency response can be cut off at 200-500 cps to reduce rumble and hum. However, low-frequency response is required when tone-operated squelch or some types of selective calling are employed. Fig. 5-31 illustrates a typical RC low-pass audio filter used in commercial equipment. The filter, between the limiter and modulator, provides 6-db-per-octave deemphasis between 300 and 3,000 cps; the attenuation rises sharply at 3,000 cps. Frequency response is also controlled by selection of interstage components.

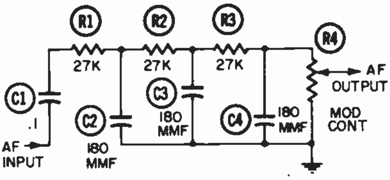


Fig. 5-31. General Electric low-pass audio filter. Used between deviation limiter and modulator.

TRANSMITTER TROUBLES

As in receivers, changes in the electrical characteristics of components in transmitters can upset tuning or voltage conditions. Most transmitters are designed for intermittent use. For this reason, they cannot be operated over a long period. In normal operation, the transmitter is active for only the short intervals when speech is transmitted. Excessively long transmissions can overheat components, which are then crammed into a small space, as is evident from Fig. 5-32. Such overheating will tax the power supply and shorten tube life.

Locating the source of trouble is relatively easy, since the transmitter is basically a simple device. If the oscillator stage is functioning, its

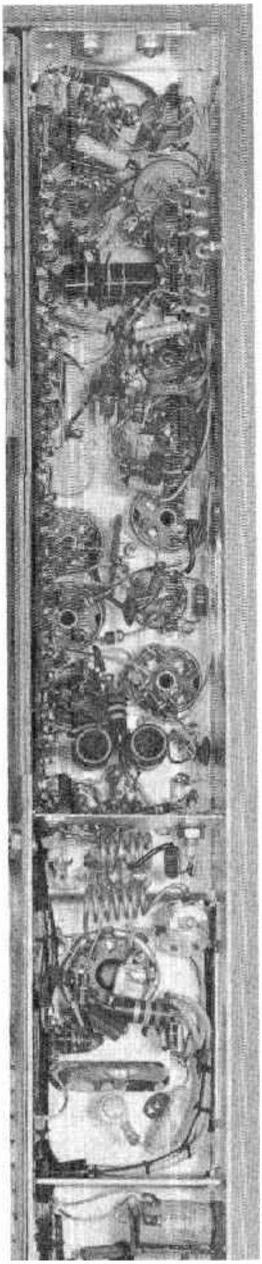


Fig. 5-32. In most mobile transmitters, a lot of parts are crammed into a small space.

signal causes grid current to flow in the succeeding stage. This is true of all stages. However, if the oscillator is not functioning, neither will the succeeding stages.

Oscillator failure may be due to a defective crystal, tube, or component. Replacement of first the oscillator tube and then the crystal is a quick way to determine whether either is at fault, or to dismiss them both as the culprit.

Most transmitters are provided with pin jacks, where the grid current of each stage beyond the oscillator can be measured with a VTVM, DC voltmeter, or microammeter (check the instruction book); or else they have a metering socket (Fig. 5-33) into which a test meter can be connected. The transmitter metering socket in Fig. 5-33 is near the front of the unit. Here it can be easily reached by pulling the chassis partway out of its housing.

Fig. 5-34 shows a rugged railroad radiotelephone. It has a metering jack and a switch on the chassis, for selecting the circuits to be measured. Field adjustments can be made with a DC milliammeter.

Transmitter tuning also is easy. Each stage is tuned for maximum grid drive to the stage ahead. First the power-amplifier plate circuit is tuned for minimum plate current (dip). Then the antenna circuit is tuned to provide optimum loading, which increases the power-amplifier plate current. The tuning procedures for each transmitter should be performed explicitly, as outlined in the instruction manual.

With the exception of power-amplifier tubes, all other transmitter tubes (which are usually receiving types) can be tested with a conventional tube tester. The power-amplifier tubes are most readily tested by substitution. An RF wattmeter is used to note any change in output power after a new tube is tried.

WARNING: FCC regulations require that adjustments or repairs which can affect the ability of the transmitter to meet

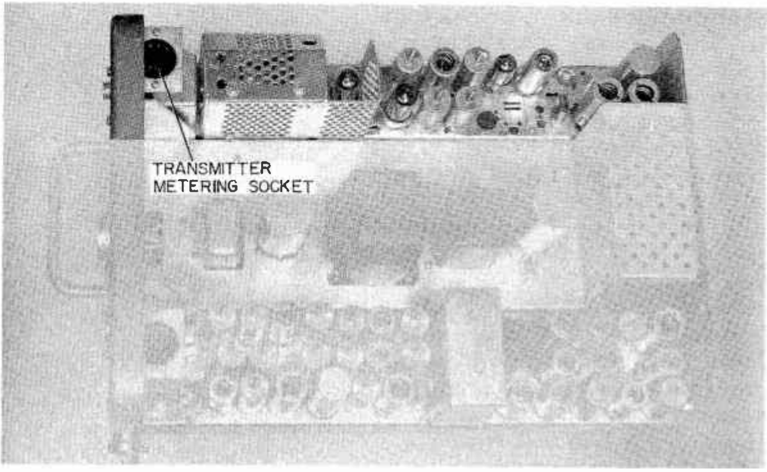


Fig. 5-33 Metering sockets (near front of unit). Pulling the chassis partway makes them accessible.

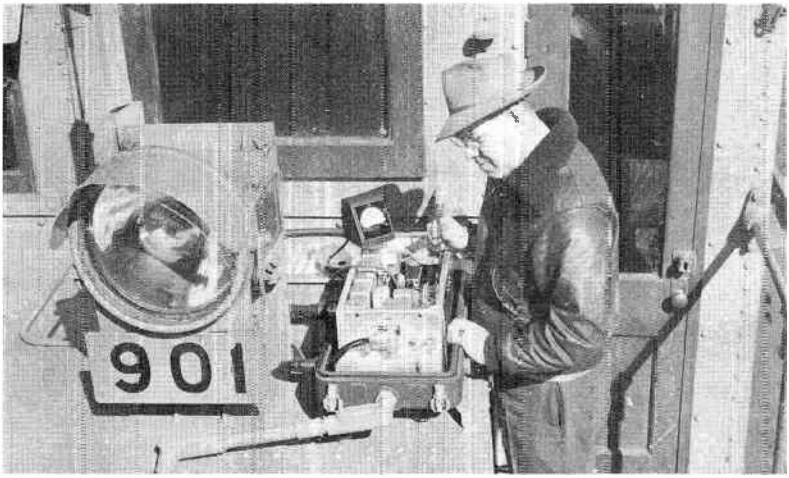


Fig. 5-34. Metering jack and switch on chassis of this railroad radiotelephone allows selection of circuits to be measured. (Courtesy of Chicago, South Shore & South Bend Railroad.)

FCC requirements, must be performed only by persons holding a first- or second-class radiotelephone operator's license. However, an unlicensed person *can* perform these functions under the supervision of a suitable licensed person. The licensed operator assumes responsibility, as does the licensee of the radio station, for the proper operation of the transmitter.

All transmitters except those meeting the requirements of FCC Rules and Regulations, Part 15—which concerns certain low-powered devices—must be licensed. The license certificate is posted at the base station or master control point of a mobile radio system. A tag, affixed to each mobile and portable transmitter, lists the applicable license information. These tags are available from the FCC.

CHAPTER

6 Control Systems

A MOBILE unit or a base-station assembly may have its controls built in. This is true in the case of underdash mobile units and consolette-type base-station assemblies. A trunk-mounted mobile unit is usually remote-controlled. A control head (see Fig. 6-1), external speaker, and microphone are installed in the driver compartment. The microphone, speaker, and control leads are extended to the control head through a multiconductor cable. (The control head in Fig. 6-1 has a four-position channel-selector switch that permits remote selection of any of four Class-A channels.) Power from the battery is usually run directly to the set through a separate cable.

The on-off switch on the control head does not open and close the power circuit directly. Instead, it controls a relay or solenoid, the contacts of which are in series with the main power conductors. Thus, the switch does not have to handle the full current required by the equipment. The resultant losses in the control cables can therefore be avoided.

A mobile unit equipped with an appropriate power supply is sometimes used as a base or fixed station. The unit may be controlled through a multiconductor cable, in the same manner as in a vehicular installation.

A mobile unit mounted in the trunk (see Fig. 6-2) and controlled

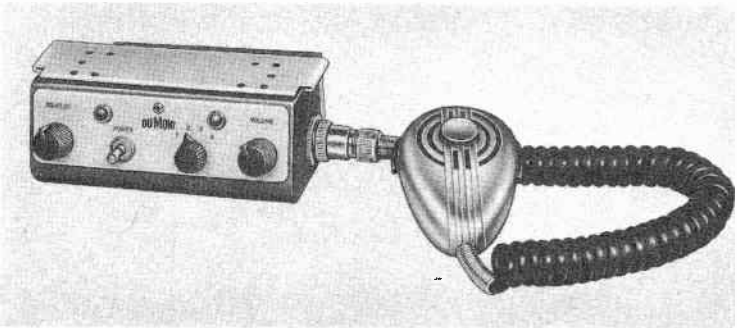


Fig. 6-1. Control head for mounting in the driver compartment. (Courtesy of Allen B. DuMont Laboratories, Inc.)

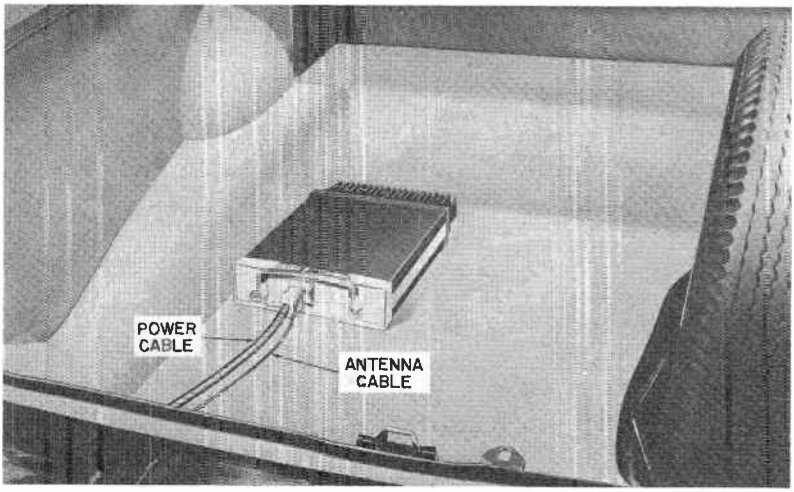


Fig. 6-2. A mobile unit mounted in a trunk. (Courtesy of Motorola Communications and Electronics, Inc.)

from a control head in the same vehicle is legally considered a locally controlled station. A base or fixed station is also considered locally controlled when the transmitter and the control point are in the same room, or at least within sight of each other. It is considered to be remote-controlled when they are in different rooms, or when the operator at the control point cannot see the transmitter.

The operator must have indicators which show when the power is on or off, as well as when the transmitter control circuits have been set to "transmit." Pilot lamps are customary for this purpose.

The remote-control point may be in the same building as the transmitter, or it may be many miles away. Although a station may have more than one control point, only one is called the *remote-control point*. The others are called *dispatch* points. The person at the remote-control point is in charge of the station. He must have means for cutting off the transmitter at any time, to prevent improper use of the station by persons at dispatch points. As shown in Fig. 6-3, a cutoff switch is provided to disable the dispatch units.

Some mobile units are sometimes equipped with more than one control point. On boats, and particularly on railroad locomotives, two or more control points may be provided. On some switching locomotives, the engineer and fireman have access to the radio equipment, as does the engine foreman afoot, who has an external-control unit at one

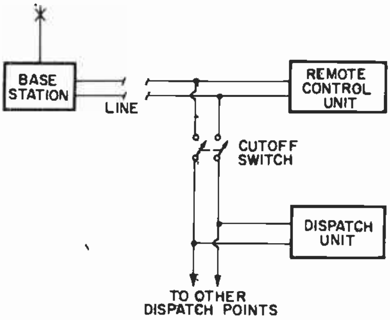
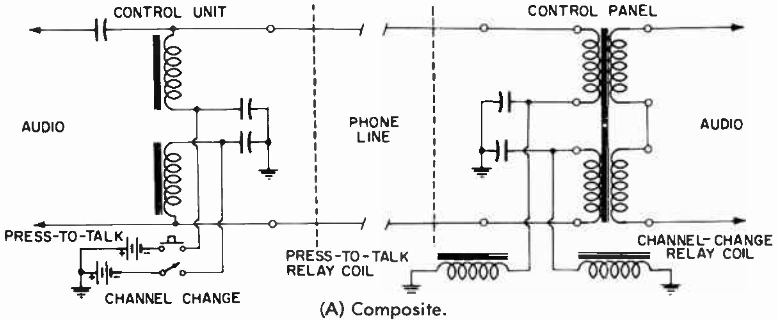
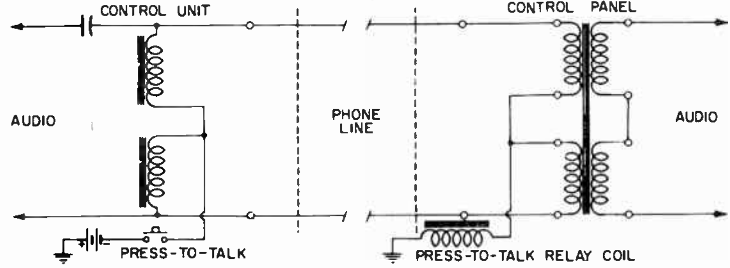


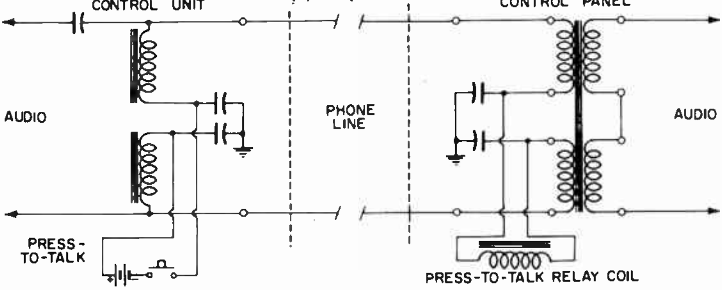
Fig. 6-3. Cutoff switch can be used to disable dispatch units.



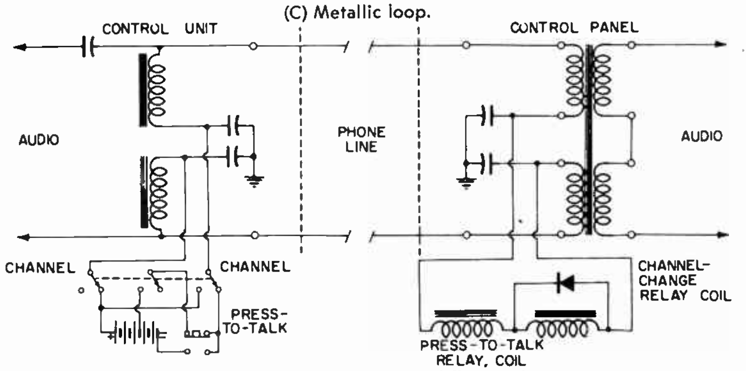
(A) Composite.



(B) Simplex.



(C) Metallic loop.



(D) Metallic-loop current differential.

Fig. 6-4. Base-station control circuitry.

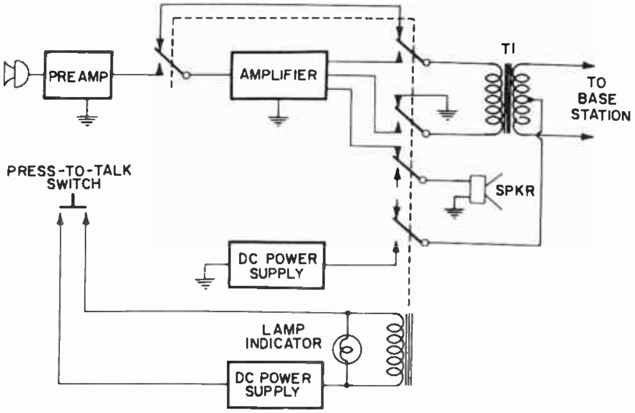


Fig. 6-5. Single-amplifier control unit.

or both ends of the locomotive. Intercommunication between control points, without putting the transmitter on the air, is often provided.

A base or fixed station is most often connected to its control points' through a two-wire telephone circuit. Audio is fed—via the line—to the transmitter from a remote-control unit, at around 0 dbm (0 dbm equals 1 milliwatt into 600 ohms). Audio from the remote receiver is also fed, via the line, to the control units, at around 0 dbm.

Fig. 6-4 shows various methods for transmitting audio in both directions sequentially but not simultaneously, as well as a DC control

Fig. 6-6. A push button on front panel transmits a tone to alert mobile units before voice transmission. (Courtesy of Allen B. DuMont Laboratories, Inc.)

voltage, over a two-wire line. Most often, the line is simplexed to ground. The audio signal travels over both wires, while the DC travels over the wires and ground.

The control unit may consist of two audio amplifiers. One raises the output signal of the microphone to 0 dbm. The other increases the 0-dbm audio signal from the receiver to a level high enough to actuate a speaker.

In practice, however, a single amplifier serves both purposes. Fig. 6-5 shows a single-amplifier control unit. When the press-to-talk switch is closed, the relay connects the microphone to the amplifier input, connects the amplifier output to line transformer T1, and applies a DC voltage to the center tap of the line side of T1. When the switch is released, the speaker is activated, and the line is fed through T1 to the amplifier input.

The typical control unit (see Figs. 6-6 and 6-7) is a relatively simple device with a self-contained AC power supply. It is designed to conform with telephone standards, so that it can be connected to a leased telephone pair.

Sometimes it is necessary to lease two lines, or at least pay for the use of two circuits. Although only two wires are required, a telephone company may consider the voice circuit as one facility and the DC control circuit as another. Sometimes a repeat coil (line transformer) is inserted in a line, so that DC cannot be transmitted over the line (see Fig. 6-8), yet transmission of audio frequencies is not opposed.

Where private wire facilities are available for radio-station control

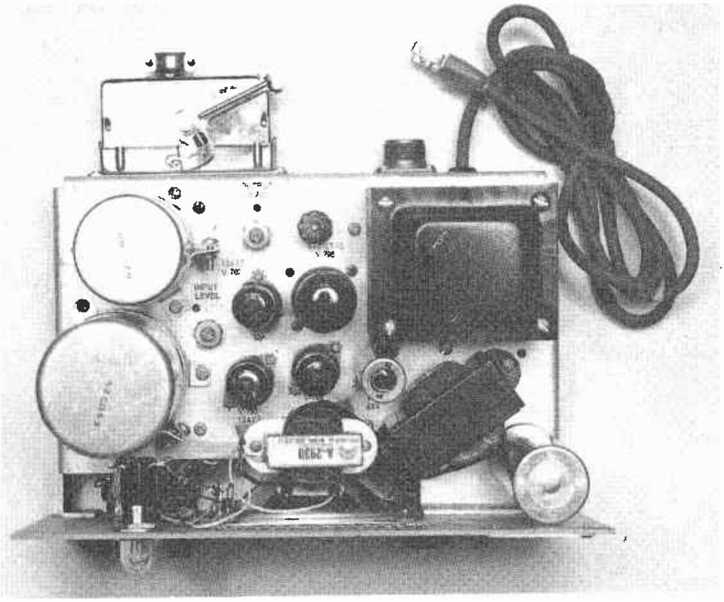


Fig. 6-7. External connections to this base-station remote-control unit are made through plug-in connectors behind chassis. (Courtesy of Sperry Products, Inc.)

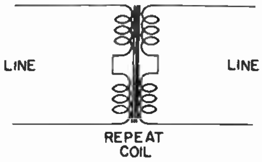


Fig. 6-8. Repeat coil inserted in line passes AC but blocks DC.

and such lines are already employed for other purposes, telephone carrier equipment can be used for superimposing another two-way voice channel on the line. At the control point, the microphone output, after preamplification, is fed to a carrier *mod* unit. (See Fig. 6-9.) This unit transmits a carrier signal over the wire line to the transmitter. There, a *demod* unit intercepts the audio signal, converts it back to normal audio, and then feeds it to the modulator input of the transmitter.

In the reverse direction, the audio output of the receiver is fed to a *mod* unit which feeds a carrier signal to the control unit. Here a *demod* unit converts the signal back to audio. The audio signal is amplified and fed to a speaker.

The "ringing" circuit of the carrier equipment is used for keying the transmitter. When the press-to-talk switch is closed, a tone is transmitted over the line. The tone actuates a relay in the tone receiver at the distant station.

There are several types of carrier equipment. Most popular is the single sideband-suppressed carrier type. The audio signal modulates a small AM radio transmitter (*mod* unit) operating at a frequency above audibility. The carrier is removed, and only one of the sidebands is transmitted. At the receiving end, the

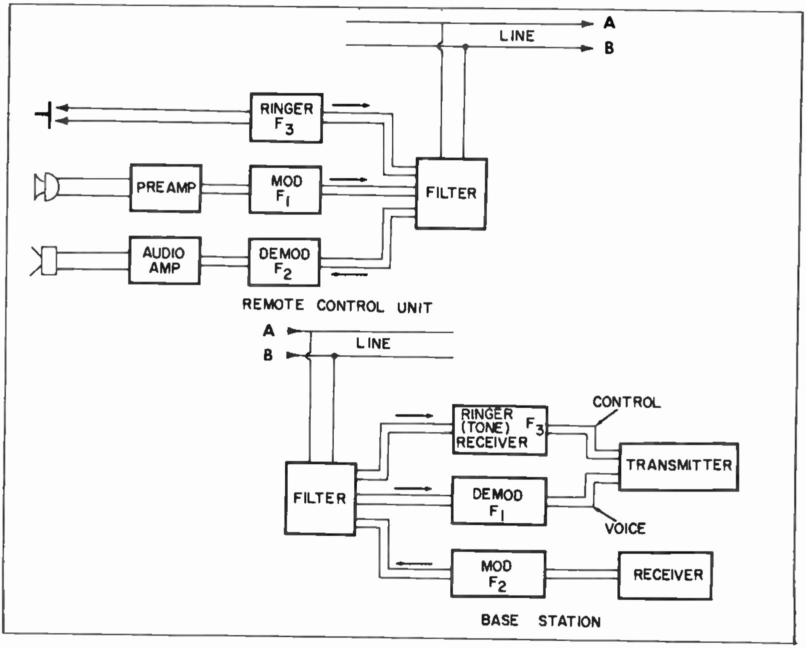


Fig. 6-9. Telephone carrier equipment for controlling a remote base station over a regular telephone line.

carrier is generated locally, and the radio signal is demodulated (*demod* unit).

Ringing may be provided in various ways. This facility, in the carrier equipment of telephone systems, enables ringing or dialing of distant telephones. The ringing sender is merely an oscillator, the signal of which is demodulated at the far end and converted to DC for operation of a relay.

Where wire lines are not available, a distant radio station can be controlled by radio. A radio link conveys voice in two directions sequentially, as well as a control signal.

The control point and the base station are each equipped with a transmitter and receiver. As shown in Fig. 6-10, a transmission from the control point is picked up by the link receiver. The output of the link receiver is fed to the base-station transmitter, which is keyed on by a carrier-operated relay. This relay is actuated by the squelch circuit of the link receiver. The signal from the control point is then transmitted by the base-station transmitter. To prevent inadvertent use by other stations, a coded or noncoded tone signal may be transmitted from the control point to actuate the base-station transmitter.

When the base-station receiver intercepts a signal, the link transmitter is turned on by a carrier-operated relay (controlled by the squelch circuit). This transmitter retransmits the intercepted intelligence to the control point.

Radio links for remote control of radio stations are generally operated in the 450-470 or 952-960 mc bands. Although operation in the 2,000-, 6,000-, or 10,000-mc microwave bands might be more desirable under some circumstances, the cost could be prohibitive.

RIGHT-OF-WAY SYSTEMS

Railroads in particular operate extensive right-of-way radio communications systems, which consist of numerous base stations along the right of way. These radio stations are sometimes controlled by telegraph operators at wayside towers. Often, however, they are controlled from the dispatcher's office, which may be a hundred or more miles away.

When controlled from a central point, these radio stations are gen-

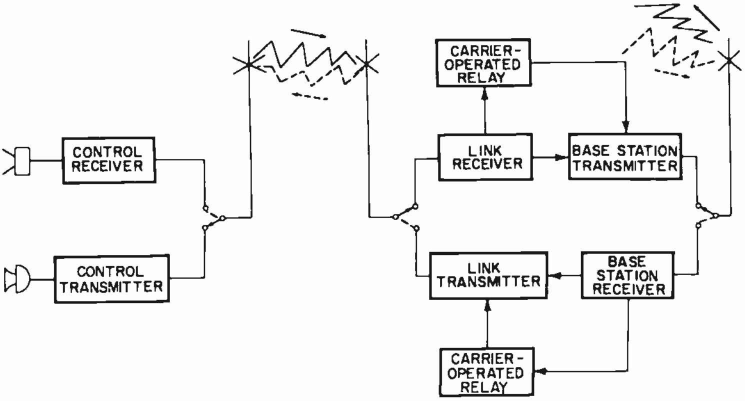


Fig. 6-10. Simplex radio link can be used to control a remote base station.

erally connected to a party-line telephone circuit. All stations in the same division are bridged across the same wire line. The dispatcher can usually select any base station individually. A different tone or combination of tones can be used for actuating frequency-selective decoders at each station. Coded tones may also be transmitted which actuate Secode selectors, or Western Electric or Federal 3.5-cycle type selectors. The selector at each station is responsive to its own code only.

Because of varying line losses, special audio amplifiers are usually installed at all stations. These amplifiers automatically compensate for changes in the level of the audio signal received over the line from the dispatcher's office. Transmitter keying is accomplished by transmitting a tone burst or continuous audio tone, which is filtered out at each station.

Pipelines and other users of microwave communications systems often control mobile-system base stations via one or more voice channels of the microwave system. The technique is similar to that for telephone carrier equipment employed on wire lines, as described earlier.

MULTIFUNCTION CONTROL

In addition to keying of a remote transmitter, it is sometimes necessary to provide control points with means for controlling other functions. These functions include changing of frequencies, control of tower lights, switching over to stand-by equipment, etc.

This can be done—over a two-wire line—on a DC basis to a limited extent, and on a tone (AC) basis to a very broad extent. Fig. 6-4 shows how, on a DC basis, the transmitter can be keyed and the frequency changed. Further functions can be performed by providing a dial at the control point and a selector at the distant station, as shown in Figs. 6-11 and 6-12. In Fig. 6-11, a single pair, simplexed to ground, can be used for remote control of several functions at a base station, as well as control of the transmit-receive function and transmission of audio information. In Fig. 6-12, the opera-

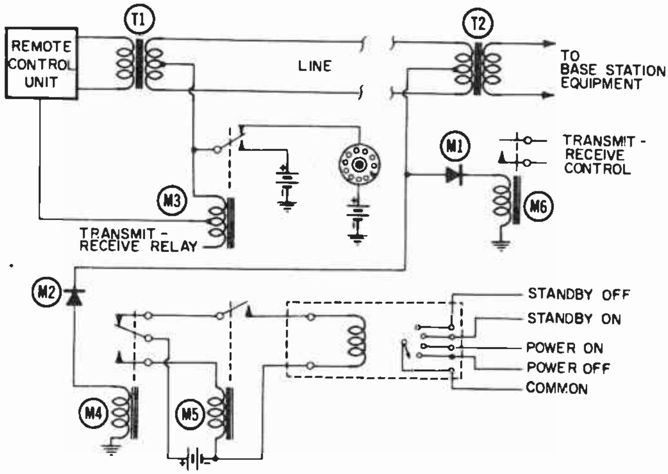


Fig. 6-11. Single pair, simplexed to ground, for controlling several functions.

tor can select any of four antennas at the base-station site by dialing the proper number. The same single pair is used for audio transmission, transmit-receive control, and conveyance of dialing pulses.

On an AC basis, multiple functions can be controlled over a wire line, carrier channel, or radio link. Each function requires a different audio tone. A single tone can be coded to permit its use for a very large number of functions. Figs. 6-13 and 6-14 illustrate both techniques.

TROUBLESHOOTING

Extended Local Control

When a multiconductor cable is used for controlling a station over a relatively short distance, the troubleshooting techniques are simple. Only DC control circuits (keying and squelch) and a low-level (microphone) and a high-level audio circuit are involved.

The transmitter control circuit may fail because of a poor connection or a defective press-to-talk switch, relay connector, or cable. A small DC voltage should be found across the press-to-talk switch contacts when the switch is open. If the relay at the radio equipment closes but the transmitter does not turn on, the trouble, of course, is not in the control system.

If no sound is heard at the remote speaker, the audio output at the receiver should be checked with a

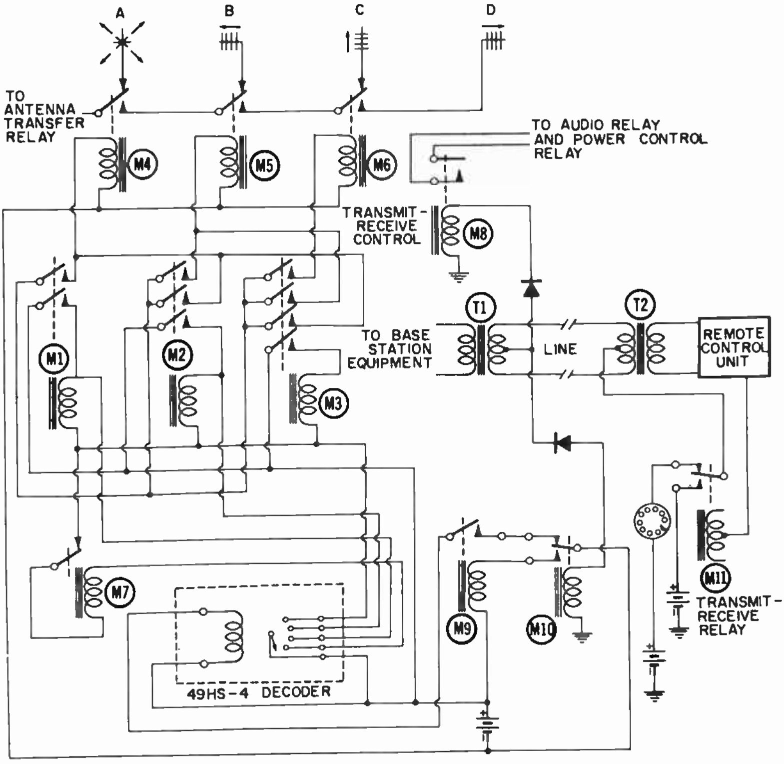


Fig. 6-12. Base-station operator selects antenna by dialing proper number.

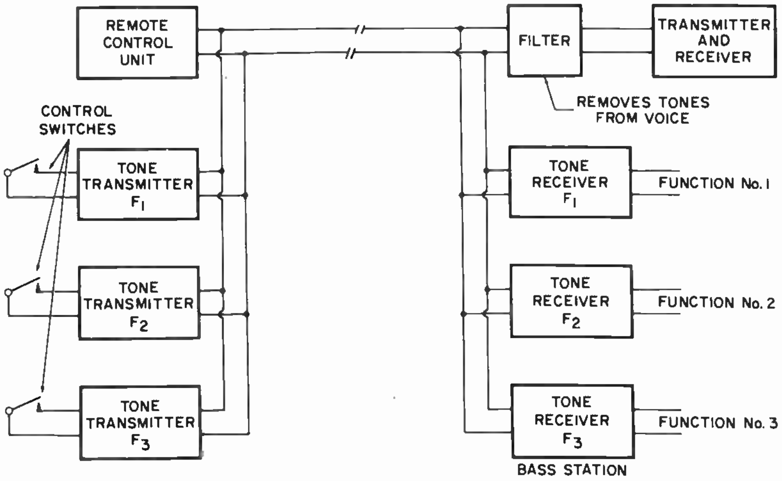


Fig. 6-13. Different tones can be used to control various functions.

speaker. If there is audio at the receiver output, either the circuit to the control point is shorted or open, the remote volume control is defective, or the speaker itself has an open voice coil.

Hum in the carrier when transmitting can be caused by inadequate shielding of the microphone line. The shield should be grounded at the radio-unit end of the cable only, never at the microphone location. If the shield is grounded at both ends, hum is most likely to result.

Two-Wire Remote Control

When one is speaking into the microphone of a remote-control unit and the press-to-talk switch is closed, an audio signal should be present at the line terminals of the control unit. A reading of around 0.775 volts should be obtained (0 dbm into 600 ohms) when the unit is

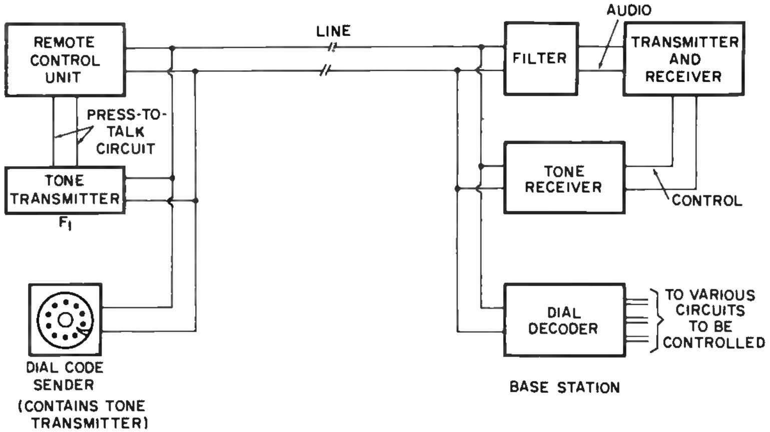


Fig. 6-14. One tone controls the transmit-receive. The other, pulsed by a dial, controls one or more additional functions.

connected to the line or its output is loaded with a 600-ohm resistor.

No audio at this point could be due to a defective microphone or amplifier, a poor connection, or dirty relay contacts. If it turns out to be relay trouble, burnish the contacts with a proper burnishing tool. Never sandpaper relay contacts!

If audio is present but the transmitter does not go on when the press-to-talk switch is closed, the fault could be in the remote-control unit, the line, or the line relay at the station.

With the press-to-talk relay closed, the DC control voltage should be available between one of the line terminals and the ground terminal if a simplexed-to-ground system is used (see Fig. 6-15). If one of the composite circuits is used, check the schematic to determine where DC should be present when the control unit is set to transmit.

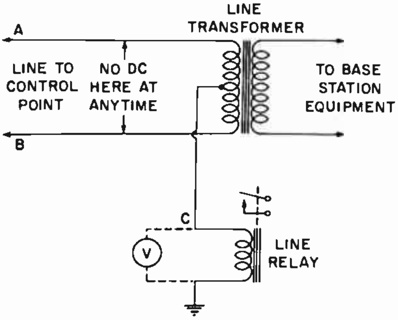


Fig. 6-15. DC should be present across line relay and between either side of line and ground when remote control is set to transmit.

The voltage across the coil of the line relay, at the station end of the circuit, can be checked. When the remote-control unit is set to transmit, a DC voltage should appear across the coil. If this voltage is too low to pull in the relay and the one at the control unit is normal, the trouble could be a poor ground at either or both ends of the line or ground currents. Although the voltage at the control unit is adequate and the line is all right, ground currents of opposing polarity can reduce the voltage across the relay coil, and thus make the relay inoperative.

A good ground is absolutely necessary at each end of the system when a simplexed-to-ground circuit is employed. A ground connection can be easily checked. Merely connect one terminal of a 115-volt lamp to the ground connection and the other terminal to one side of the AC line, at a convenient outlet (see Fig. 6-16). If the lamp does not light, try the other side of the line. If it will not light either way, the ground is ineffective. The lamp should light brightly when connected to one side of the AC line (ungrounded side) and ground, but not when connected to the other side of the line (grounded).

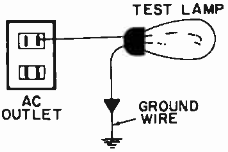


Fig. 6-16. Checking a ground connection by using a test lamp.

If the line is leased from a telephone company and is suspected as being defective, do not make any tests or repairs. Instead, call the telephone company. The continuity of a private line can easily be checked by shorting one end and measuring the resistance at the open end. The normal resistance can be learned by consulting a wire table. Remember that a one-mile line has two miles of wire.

Troubleshooting telephone carrier equipment is a whole field by itself and is not within the scope of this book. Any experienced technician should be able to diagnose and correct carrier equipment troubles by following the procedures outlined in the appropriate instruction manuals.

MONITORING

A radio station which transmits and receives on the same frequency is provided with means for automatically monitoring on its operating frequency. Many two-frequency radio stations which transmit on one channel and receive on another are not—but should be—equipped for monitoring the transmitter channel, to avoid interfering with other systems operating on the same frequency.

A monitor receiver at the main remote-control point enables the operator to hear his own signal and thus determine its quality. A meter can be connected to the receiver to indicate the relative field strength, so that the operator can note when the power output falls off.

All base and fixed mobile stations are required to monitor CONELRAD. An ordinary AM broadcast receiver or TV set will do. Before the transmitter is turned on, it must be determined that a CONELRAD alert does not exist. Several automatic CONELRAD monitors are available. They actuate a signal in case of an alert, warning the operator not to go on the air. The automatic monitor obviously is preferable because the operator is not required to maintain a continuous vigil.

SELECTIVE CALLING

Ordinarily, mobile radio units and base stations are arranged so that all transmissions within range on the same frequency will be heard. When the base station calls one mobile unit of a system, all other mobiles will also hear the transmission. When two or more systems share the same channel in the same vicinity, they will hear each other's transmissions. The channel is like a party line, with everybody listening in.

As the number of systems that must share a common channel becomes greater, the mutual interference and lack of privacy will become less tolerable. Many systems have already been equipped with tone squelch, and the number of systems equipped with selective calling is increasing rapidly.

In a conventional mobile unit, the speaker is muted except when a signal of sufficient strength is intercepted. The squelch is not selective in regard to the station to which it will respond. When tone squelch is added, the speaker will be activated only when the incoming radio carrier is accompanied by a tone of a specific frequency. If all mobile units and base stations are equipped with one squelch, the speakers at these stations will be activated only by transmissions from stations within the same system, not by stations of other systems operating on the same frequency.

A tone-squelch device may be an add-on accessory or a built-in feature. It consists of an audio oscillator (tone generator) and a frequency-selective tone receiver. The tone is transmitted automatically when the press-to-talk switch of the associated transmitter is closed. Both tone and voice are thus transmitted at the same time. The frequency-selective tone receivers at all stations in the system respond to the tone, which is rectified and used to control the speaker. Thus, whenever a station goes on the air, the transmission is heard by all other stations in the same system. However, signals from other systems are locked out.

The tone may be at any frequency between about 50 to 3,300 cps. Since it is transmitted at the same time as the voice, it must be filtered out at the receivers in order not to interfere with voice reception. The tone will not be heard by stations within the system because of the filter, but will be heard by all stations not equipped with tone squelch if they are on the same frequency and within range. Fig. 6-17 is a block diagram of a tone-squelch system.

In some tone-squelch systems, the tone is present whenever the transmitter is turned on. In others, a short tone burst is transmitted at the start of a transmission. The tone burst opens the squelch; the radio carrier holds it open, closing it at the end of the transmission. A second tone burst can also be used to disable the squelch.

By using tones of differing frequencies, two or more systems can operate in the same vicinity and on the same radio channel without mutual interference. The stations of system *A*, for example, will hear transmissions from other system-*A* stations only, and so on.

Tone squelch is a step forward in the right direction. In addition to locking out transmissions from other nearby systems operating on the same frequency, it also locks out long-distance skip interference. The

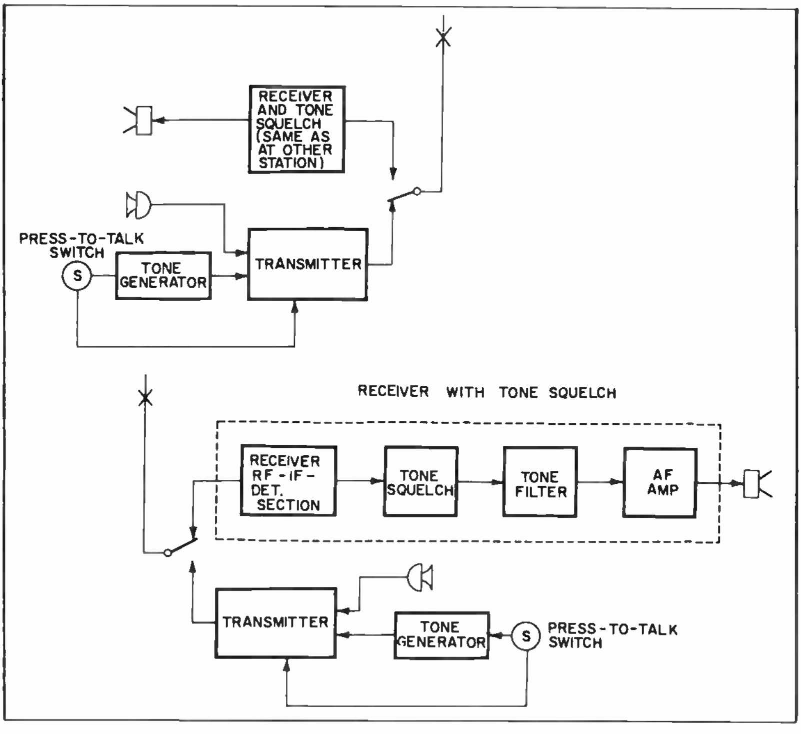


Fig. 6-17. Tone-squelch system.

same basic idea has been extended to provide selective calling. In a tone-type selective-calling system, the base station is equipped to transmit a different tone to signal each mobile unit. All mobile receivers are equipped with a tone receiver, each responsive to a different tone. The base-station operator merely pushes a different button for each mobile to be signaled. The speakers at all mobile units remain silent except when a tone which matches the one from the tone receiver is intercepted. The tone signal may be a burst, a continuous tone, or a combination of tones. Fig. 6-18 shows a typical tone-selective signaling system.

Tone signaling is fast in response but limited in capacity. However, it is adequate for systems consisting of a small number of stations. For larger systems, dial-type selective calling offers much greater capacity and almost unlimited expandability.

DIAL SYSTEMS

In a selective-calling dial system, a single tone is pulsed by an ordinary telephone dial. The pulses are transmitted by radio, and are intercepted by all receivers within range that are tuned to the same frequency. Each receiver in a system is equipped with a dial pulse decoder. The decoders are set so that each one responds to a different number. The base-station operator dials one number to signal mobile unit *A*, another to signal mobile unit *B*, and so on.

The decoder contains a frequency-selective audio amplifier (see Fig. 6-19) and an electronic control circuit. The latter actuates an electromechanical selector which steps with each pulse. The selector contacts close only when a matching train of pulses is intercepted. Although all of the decoders in a system are actuated by the incoming tone pulses, only the one whose selector setting matches the incoming pulse train closes its contacts. Closure of the contacts momentarily sounds a buzzer and turns on a lamp, which remains lit until turned off by an indicator release switch located on the call head. The lamp serves as a "leave word" indicator. Should a call be intercepted at an unattended mobile station, the lighted lamp warns the driver, upon returning to his vehicle, to check in by radio.

Stepping relays or a Secode 59HS selector are used in decoder units for responding to dial-coded sig-

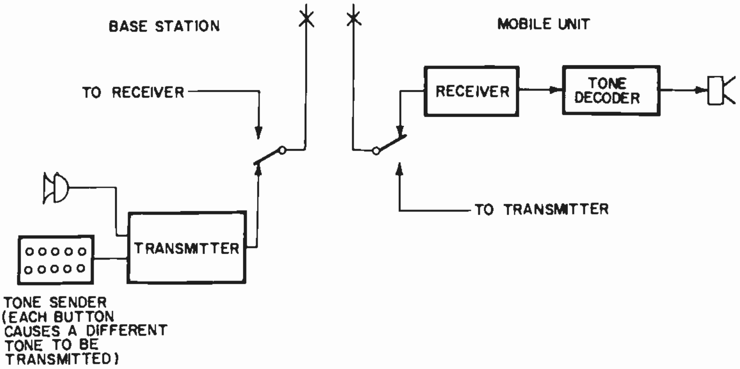


Fig. 6-18. Tone-type selective-calling system.

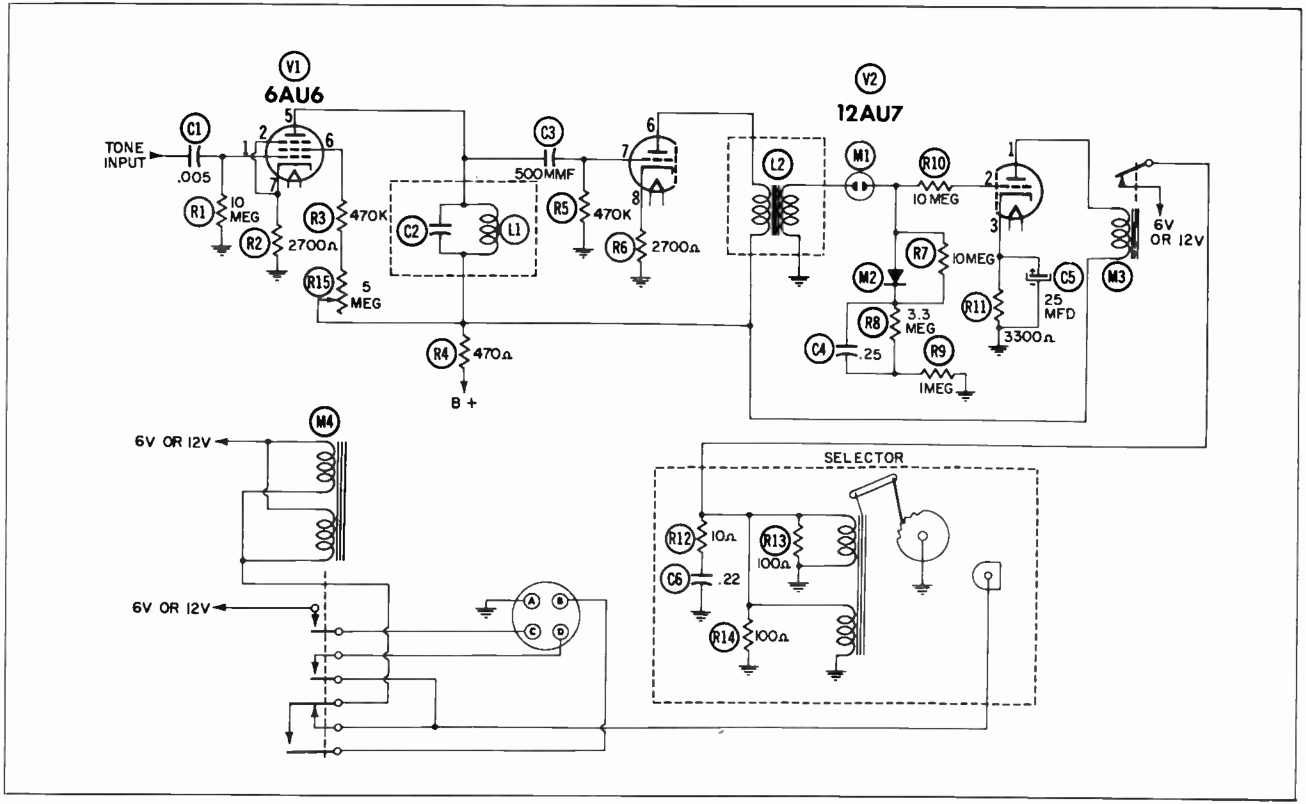


Fig. 6-19. Dial-pulse decoder circuit in the Secode unit.

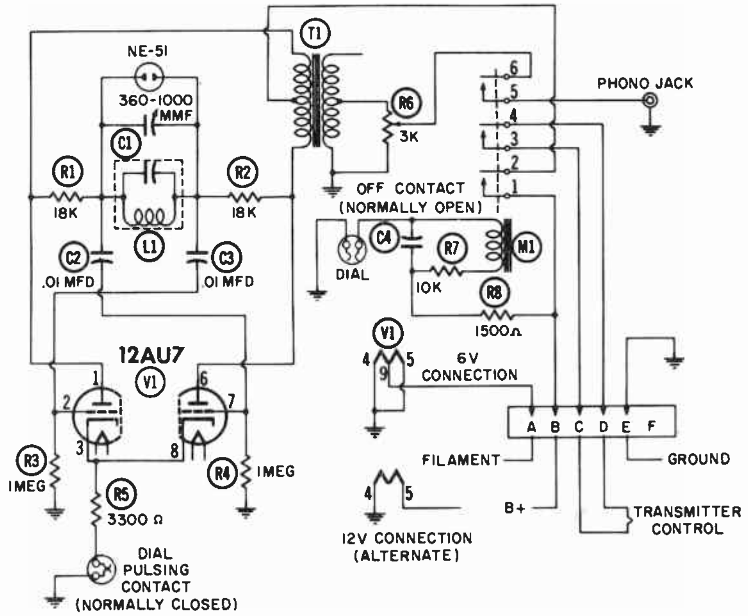


Fig. 6-20. Dial-code sender circuit in the Secode unit.

nals. The Secode selector does the work of several stepping relays. By merely inserting small wire pins into small holes in its code wheel, it is possible to set the device to respond to any of 20,000,000 different numbers.

The pulses are generated by a dial code sender, which is connected to the audio input of the base-station transmitter. When the dial is spun at the start of a call, its off-normal contacts (see Figs. 6-20 and 6-21) close a relay circuit. The relay applies plate voltage to an audio oscillator, connects the oscillator output to the transmitter, and turns on the transmitter. The oscillator now generates a tone. As the dial returns to its normal position, its pulsing springs break the tone ten times when "O" is dialed, nine times when "9" is dialed, and so on. The continuous tone makes the decoder receptive to the pulses. Each time the tone is interrupted by a "break" pulse, the selector steps once.

The main advantage of selective-calling dial systems employing the Secode selector is that the code to which a decoder will respond can be changed without tools in less than one minute. Sometimes the selector is equipped with more than one contact pair. When equipped with five contacts, the same selector can be set to respond to any of five different code combinations. This is advantageous when one number, common to all mobiles, is used for signaling all mobiles at once, another number is used for alerting a group of vehicles, another for alerting an individual mobile, another for momentarily turning on the vehicle horn to call the driver back to an unattended vehicle, etc.

In addition to base-to-mobile signaling, selective calling is being

Fig. 6-21. Under-the-dash mobile dial code sender. (Courtesy of Secode Corporation.)

used for mobile-to-mobile signaling, as well as for mobile-to-base signaling when a system has more than one base station or several remote and dispatch control points, each to be signaled individually.

SERVICING

The makers of selective-calling equipment normally furnish an instruction manual which outlines specific procedures for testing and repairing their equipment. Preventive-maintenance procedures—such as periodic cleaning of the equipment, tube testing, and adjustment checkups—can generally be applied to all types. Since even dial systems employ tones, it is necessary to maintain the transmitted tone (or tones) at the desired frequency. This frequency can be affected by the line voltage and by temperature changes. Where the line voltage is subject to greater than normal variations, a line-voltage regulator is recommended.

Relay contacts can be a source of trouble. Relays, which are not hermetically sealed, require periodic cleaning. The contacts must never be sandpapered. Cleaning must be done only with a proper burnishing tool. Selectors should not be adjusted or repaired by anyone who does not have the proper experience. It is better to return it to the manufacturer for overhaul, than to attempt field adjustments and repairs beyond the procedures specified in the instruction manual.

Solid-state decoders employing transistors and diodes have also been developed. These units are faster, and are expected to be more reliable, than electromechanical decoders. At the present time, however, their cost is fairly high. For this reason, their wide acceptance in private mobile-radio applications must await cost reductions.

CHAPTER

7 Antenna Systems

A MOBILE unit or a base or fixed station is no more effective than its antenna system. A low-powered transmitter equipped with an effective antenna system will often cover a larger area than a high-powered transmitter with a poor antenna system.

Transmitting range is determined by transmitter power, receiver sensitivity, electrical efficiency of the antenna system, effective antenna elevation, and noise level.

Effective antenna elevation is not the same as *antenna height*. Fig. 7-1 illustrates the difference between these often-confused terms. An antenna 200 feet tall in a valley 100 feet deep would have an effective elevation of only 100 feet. On the other hand, a 20-foot antenna on top of 980-foot Twin Peaks in San Francisco would have an effective elevation of 1,000 feet.

A center-fed half-wave dipole antenna is the standard against which

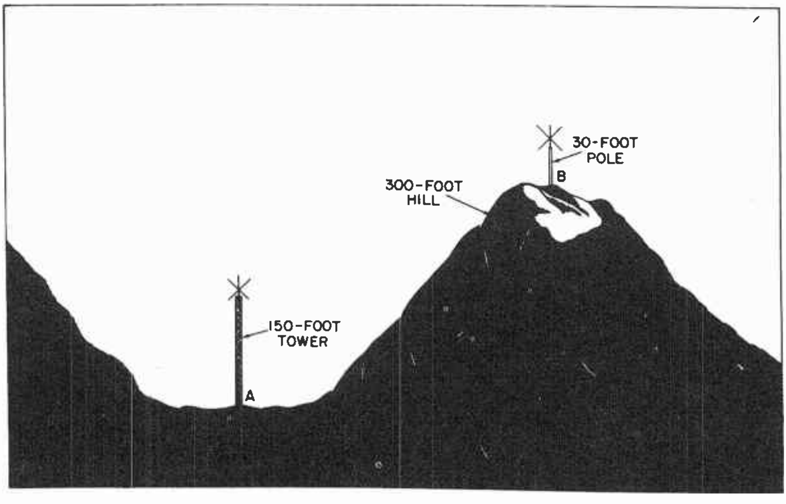


Fig. 7-1. The effective elevation of antenna "A" is less than that of antenna "B", even though "A" is taller than "B". The effective elevation of "B" is 330 feet.

antennas are compared for electrical efficiency. It is said to have *unity gain*. An antenna with 10-db gain is one which radiates a signal ten times more powerful than that of a dipole.

The antenna is fed through a transmission line, in which RF power is lost. If an antenna that has a 3-db gain is used with a transmission line that has a 2-db loss, the antenna system will be 1 db more effective than if the transmitter were fed directly to a dipole through a zero-loss cable.

A 3-db gain in the antenna system doubles the effective radiated power (watts). A 6-db gain is required in order to double the effective receiver sensitivity (microvolts).

BASE- AND FIXED-STATION ANTENNAS

There are many types of antennas for use at base stations. (See Figs. 7-2 to 7-8.) Vertically-polarized types are customarily used because horizontal polarization is impractical for mobile units. A horizontally-polarized antenna transmits best ahead and behind its broadside. A vertically-polarized antenna transmits equally well in all directions. For point-to-point communication, horizontal polarization is better. For transmitting and receiving equally well in all horizontal directions, omnidirectional antennas are preferred. The ground plane, *Unipole,* coaxial, and various other special types are popular. Some have unity gain. Others, of the gain type, increase their effective radiated power by compressing the signal along the earth's surface. (See Fig. 7-9.)

A directional antenna can be used to minimize interference to other stations operating on the same frequency, or to reduce interference from other transmitters. When communication over a broad area is desired but signal strength can be sacrificed in some directions, a cardioid-type antenna is often used. This type of antenna provides a power gain of 3-3.2 db in the favored directions. For bidirectional communication (figure-8 pattern), a pair of ground plane or coaxial antennas can be placed side by side. This combination provides gain in two directions while suppressing radiation in the other directions. A Yagi array, corner reflector, or parabolic antenna is used for transmitting and receiving in one direction only. Fig. 7-10A shows a corner reflector used for unidirectional transmission. In Fig. 7-10B, two corner reflectors are connected back-to-back for bidirectional transmission.

Directional antennas for the 25-50 mc band are quite large, compared to those for the 152-174 and 450-470 mc bands. Therefore, highly directional arrays of high gain are easier to make and install as the frequency becomes higher.

MOBILE ANTENNAS

For the 25-50 mc band, the bumper- or cowl-mounted vertical whip antenna is most widely used. The body of the vehicle is a part of the antenna system, servicing as the ground plane of a quarter-wave Marconi antenna. Fig. 7-11 shows mounting details of this antenna.

As an alternative, a base-loaded whip can be used. Since the whip of a loaded antenna is shorter than a full quarter wave, it is less conspicuous. For this reason, it can be installed on the cowl, fender, or roof of the vehicle. Fig. 7-12 shows the difference between a loaded antenna (left) and a full quarter-wave whip (right).

Among the base-loaded antennas is the Tele-Beam *Magic Wand* (see

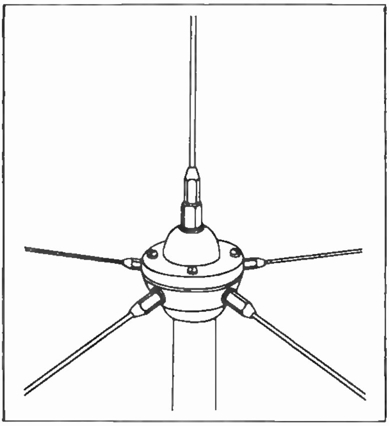


Fig. 7-2. Adjustable ground-plane antenna with telescoping vertical element and ground radials. (Courtesy of Radio Corporation of America.)

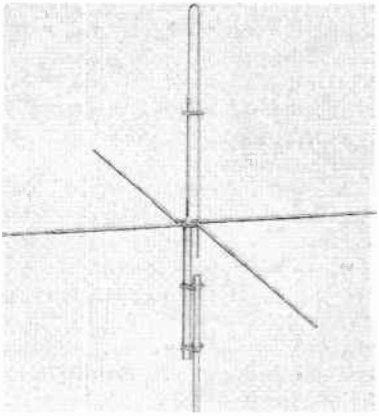


Fig. 7-3. Unipole antenna (a version of the ground-plane antenna). Notice the folded vertical element. (Courtesy of Andrew Corporation.)

Fig. 7-4. An indoor antenna will suffice for short ranges. The loaded ground-plane antenna on this 25-50 mc band radiotelephone is a fraction of the size of a conventional low-band antenna. (Courtesy of Kaar Engineering Corp.)

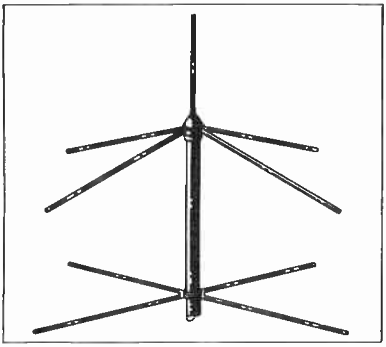
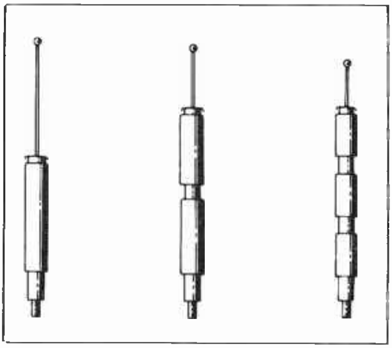


Fig. 7-5. Isoplane antenna for 152-174 mc band. (Courtesy of Motorola Communications and Electronics, Inc.)



(A) Standard. (B) Dual skirt. (C) Triple skirt.

Fig. 7-6. Coaxial antennas. (Courtesy of Motorola Communications and Electronics, Inc.)

Fig. 7-13). It employs a hermetically-sealed shunt-fed loading coil at the base. The whip, of the telescoping type, can be adjusted to the length giving the optimum performance. It is then locked in place with an Allen set screw.

A vertical quarter-wave (approximately 18 inches long) whip mounted in the center of the roof is the most popular antenna for 152-174 mc band mobile installations. (See Fig. 7-14.) Sometimes it is mounted on the cowl, but reception and transmission are definitely inferior because of the distortion caused by the propagation pattern.

A coaxial antenna mounted on a piece of pipe or tubing and supported by a bumper is sometimes

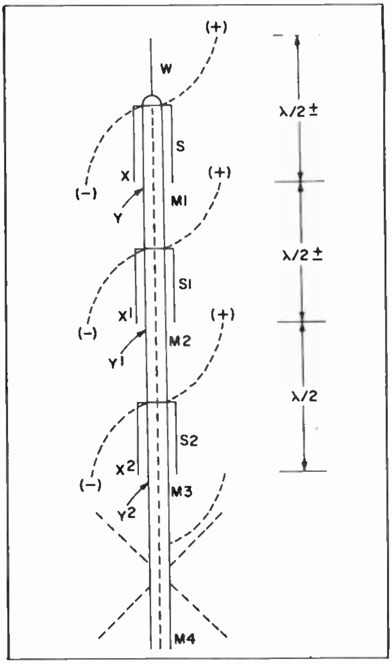


Fig. 7-7. Multi-skirt collinear coaxial antenna. Standing waves and polarities are indicated. Estimated gain over that of a dipole is 2-3 db. (Courtesy of Motorola Communications and Electronics, Inc.)

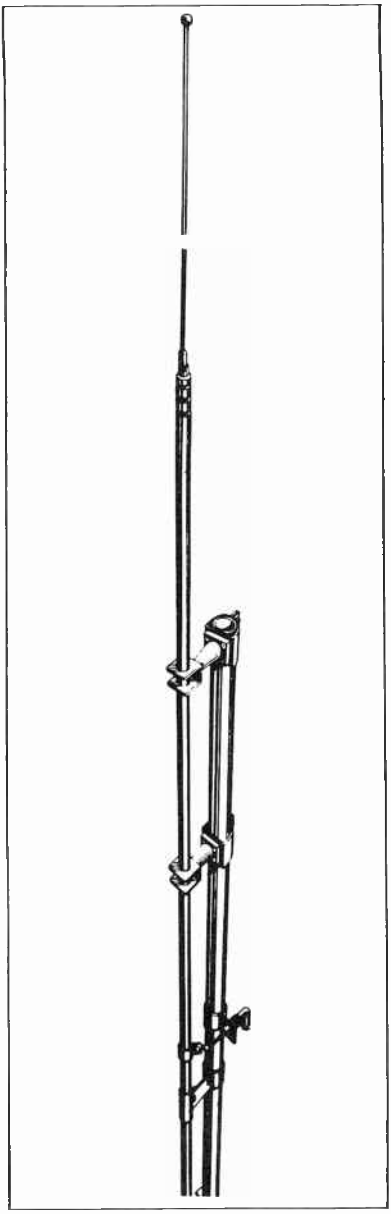


Fig. 7-8. Acro-Match antenna for 25-50 mc band. Consists of a half-wave vertical radiating voltage fed at lower end by a quarter-wave "J" stub. (Courtesy of Communications Company, Inc.)

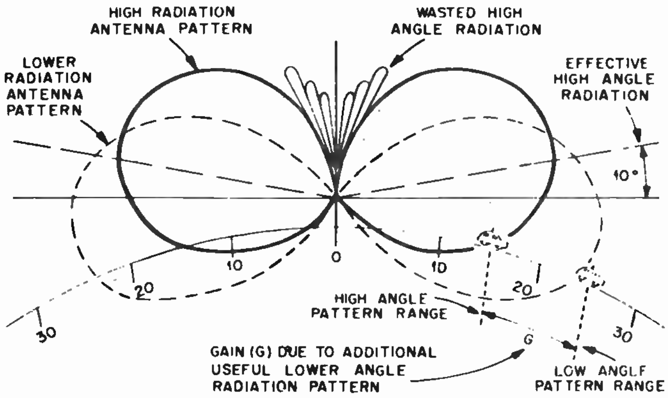
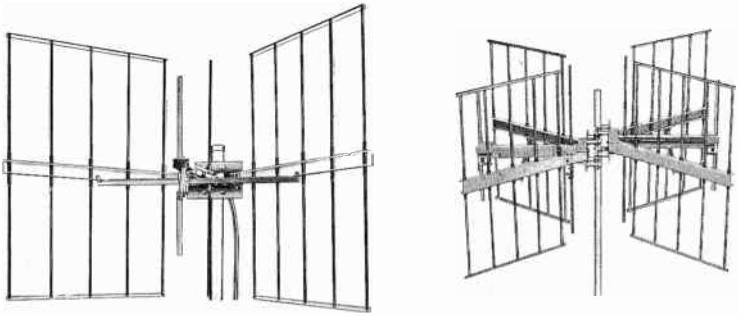


Fig. 7-9. Comparison between patterns of dipole and multi-skirt coaxial (dotted lines) antennas. (Courtesy of Motorola Communications and Electronics, Inc.)



(A) For unidirectional transmission.

(B) For bidirectional transmission.

Fig. 7-10. Corner-reflector antennas.

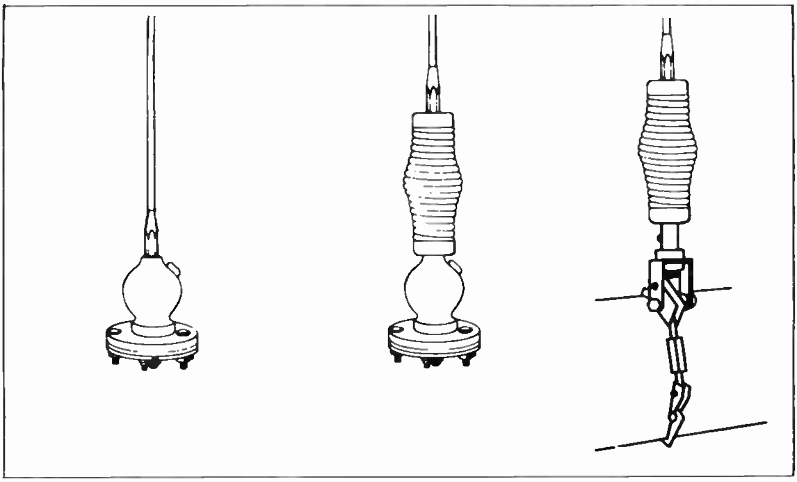
used when the owner does not want a hole drilled in the roof of his car. Since an auto body mechanic can easily fill in the small hole, there is little excuse for using a coaxial antenna here, except on convertibles.

Only a six-inch whip is required as the vertical radiator of a 450-470 mc band antenna. It should be installed in the center of the metal top. Sometimes a pole-mounted ground-plane antenna is used. However, the roof-mount antenna is less unsightly and, hence, the most satisfactory.

There are gain-type mobile antennas, for the 450-470 mc band, which are about the same length (around 18 inches) as a 152-174 mc band quarter-wave whip. Among these are *Wonderod* and Andrew antennas.

TRANSMISSION LINES

Most commercial antennas are designed to match a 50-ohm transmission line, although some match a 72-ohm line. Solid dielectric coaxial cable is widely used for short runs, as well as for longer runs at lower frequencies. Hollow transmission line is often popular for long runs to minimize losses. Hollow line and many of the so-called spiral lines



(A) Swivel ball without spring. (B) Swivel ball with spring. (C) Bumper mount.

Fig. 7-11. Some 25-50 mc band mobile whip-antenna mounts. (Courtesy of Radio Corporation of America.)

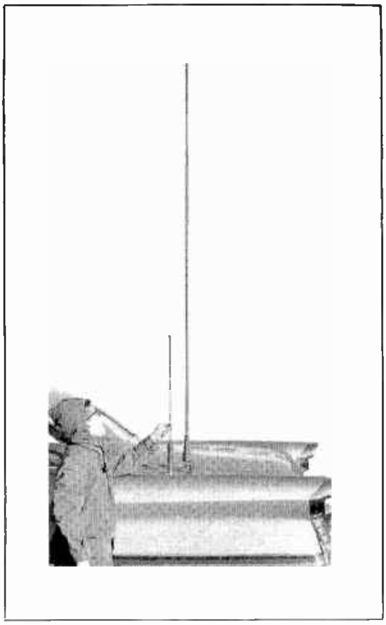


Fig. 7-12. (Left) Base-loaded antenna with a whip considerably shorter than a quarter wave. (Right) Full-length whip antenna for 25-50 mc band. (Courtesy of Tele-Beam Industries, Incorporated.)

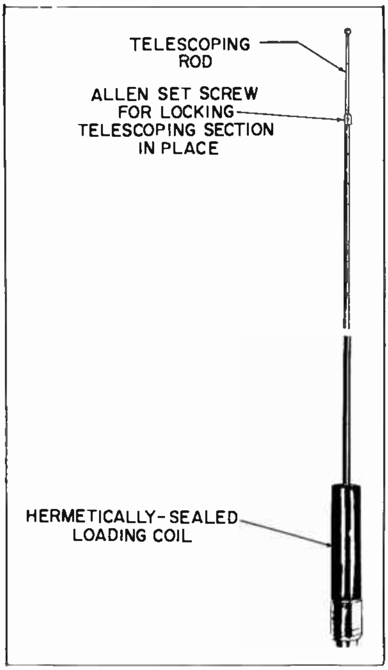


Fig. 7-13. Magic Wand tunable 27-mc antenna. (Courtesy of Tele-Beam Industries, Incorporated.)

Fig. 7-14. Vertical 18-inch whip antenna is most commonly used for the 152-174 mc band.

(see Fig. 7-15) are filled with a gas or dry air, which is kept within the line under pressure to prevent moisture from entering.

The center conductor of these transmission lines is connected to the radiating element of the antenna and to the antenna terminal of the radio unit. The shield is connected to the ground radials, ground plane, car body, or ground sheath of the antenna (depending upon the type), and to the radio ground terminal.

Fig. 7-16 is a chart listing the important characteristics of various antenna transmission lines at mobile-system frequencies.

FIXED-ANTENNA SUPPORTS

A wooden telephone or power pole is a convenient base- or fixed-

Fig. 7-15. Spir-O-Line, a semiflexible aluminum sheath transmission line. Pressurized air is the dielectric. (Courtesy of Prodelin, Incorporated.)

Cable Type	*Attenuation in Db Per 100 Feet*			*Approximate Cost Per Foot*
	30 Mc	*160 Mc*	*460 Mc*	
RG-58/U	2.6	6.5	13.0	$ .10
RG-8/U	1.0	2.6	5.0	.17
RG-17/U	0.4	1.0	2.0	.70
⅜″ hollow-line	0.6	1.4	2.5	.75
⅞″ hollow-line	0.22	0.54	1.0	1.75

Fig. 7-16. Transmission-line chart.

station antenna support. Arrangements for installing the pole can usually be made with a local telephone or power company or with Western Union. Since guy wires are seldom needed, a minimum of ground area is required. Steps should be provided so that the antenna can be easily serviced.

Metal towers are also widely used as antenna supports (see Fig. 7-17). Available in great heights, they are excellent where high antennas are required, because they can withstand high winds and heavy ice loading. (The antenna should be no higher than necessary to provide the required range. Otherwise, it will cause—as well as suffer from—interference from other stations.)

A water tank or roof of a building is often used as an antenna support. Installation is no more complex than for a TV antenna, except that the support must be strong enough to withstand high winds and ice loading.

LIGHTNING PROTECTION

The ground plane of the antenna is grounded through the coaxial cable if the radio unit is grounded. For maximum lightning protection, however, a separate ground should be provided. A heavy wire, No. 10 or larger, should be run from the base of the antenna to a ground rod. The ground wire should have no kinks or sharp bends, which offer a high impedance to the sharp leading edge of a static discharge.

FIXED-ANTENNA INSTALLATION

Although it is generally true that the higher the antenna, the greater the range, it has sometimes been found that maximum range is obtained by installing the antenna at a critical height. Notice in Fig. 7-18 the increase in useful range obtained with a 300-foot antenna compared with a 125-foot antenna. For example, when a 125-foot antenna is used, a 10-microvolt signal at 50 mc can be received at a distance of 23 miles. With a 300-foot antenna, the same signal can be received 32 miles from the base station.

For obvious reasons, the antenna should be kept away from sources of electrical interference. Noise is a problem in the 25-50 mc band, but is of much less significance in the 450-470 mc band.

Although the transmission line is sometimes connected directly to the antenna, a coaxial connector is usually employed. A connector is always used at the radio end. Only connectors should be used which were specifically designed for the particular transmission line. If not, losses can be introduced because of impedance mismatches.

Whenever possible, the antenna transmission line should be one continuous length: splices should never be used. When necessary to join two pieces of cable, suitable connectors should be utilized. If hollow transmission line or RG-17/U coaxial cable is used, small-diameter coaxial cable may be needed at one or both ends to provide flexibility. Suitable adaptors and connectors must be used when two different kinds of transmission lines are joined. (See Fig. 7-19.)

The transmission line must be suspended and not allowed to hang. Care must be exercised, when the cable is fastened, to avoid damaging the line. Changes in the shape of the line can cause impedance variations, which will result in undesirable losses.

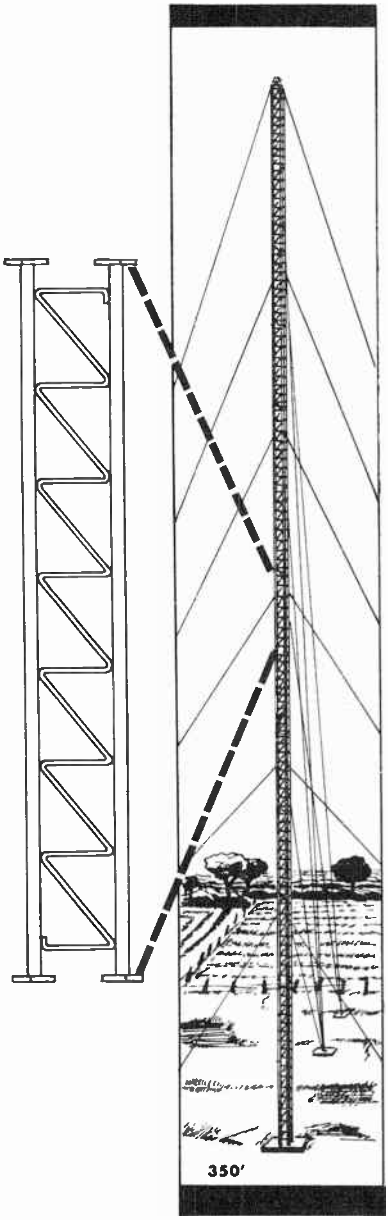


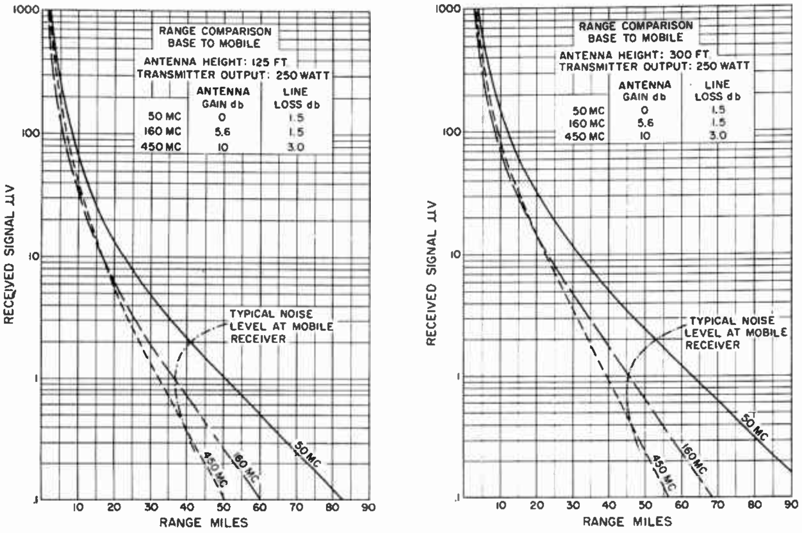
Fig. 7-17. Metal tower used as an antenna support. (Courtesy of Rohn Mfg. Co.)

MOBILE-ANTENNA INSTALLATIONS

Mobile antennas are customarily provided with a length of coaxial cable which, unless specified otherwise, may be cut to length. When a roof-mount or cowl-mount antenna is used, the shield of the coaxial cable must make positive contact with the metal roof.

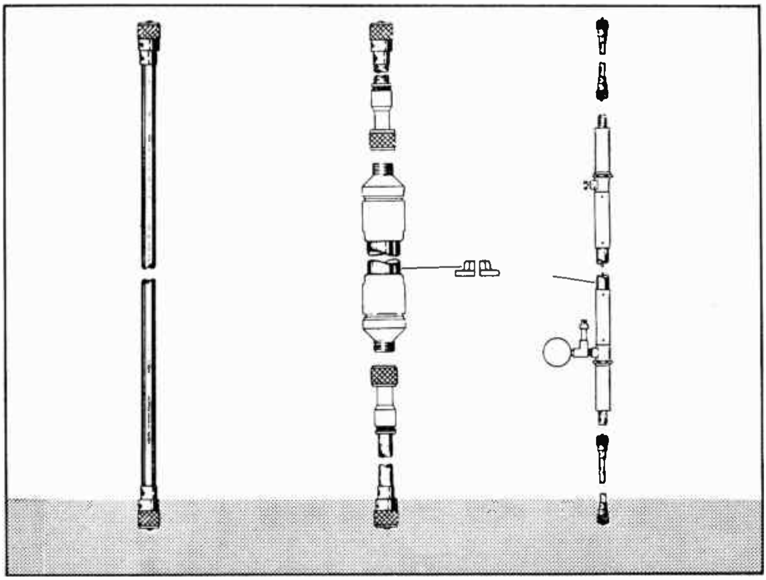
A ground plane must be provided when the conveyance does not have a metal roof. It may be a round sheet of metal or screening with a radius equal to at least one-quarter wavelength at the operating frequency.

When a bumper-mount antenna is used, the coaxial-cable shield must be properly grounded as close to the base of the antenna as possible. The whip cannot be of an approximate length: it should be cut to the exact length required for the operating frequency. DuMont



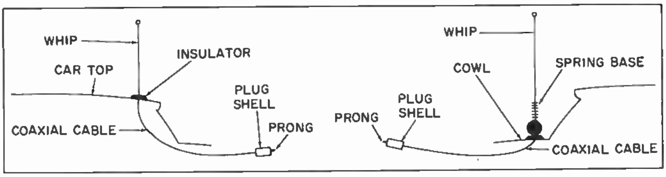
(A) Antenna height equals 125 feet. (B) Antenna height equals 300 feet.

Fig. 7-18. Range-comparison charts for base-to-mobile. (Courtesy of General Electric Co.)



(A) RG-8/U—for short runs. (B) RG-17/U—for long runs. (C) ⅞-inch copper air line—for long runs.

Fig. 7-19. Base/fixed station antenna transmission lines, connectors, and adaptors. (Courtesy of Motorola Communications and Electronics, Inc.)



Ohmmeter Connections	*Indication*	*Condition*
Prong and shell of coaxial connector.	Open circuit.	OK.
	Low resistance.	Short circuit in cable or plug, or at antenna insulator.
	High resistance.	Leaky cable insulation; dirty plug or antenna insulator.
Shell of coaxial connector and vehicle body.	Short circuit.	OK.
	Open circuit.	Defective ground connection at antenna base, or broken connection to cable shield at antenna base or plug.
Prong at coaxial connector and vehicle body, but with antenna whip temporarily grounded through a test lead to vehicle body.	Short circuit.	OK.
	Open circuit.	Open cable or broken connection.

Fig. 7-20. Trouble chart for mobile quarter-wave antennas. (Does not apply to antennas with shunt-fed loading coils or shorted matching stubs.)

offers a telescoping test antenna which can be adjusted to the critical length. Its length is then measured and the permanent antenna cut to the required length.

Troubles in a mobile-antenna system can be in the antenna itself, the transmission line, or the connectors, or can be due to faulty installation. The chart in Fig. 7-20 lists the various faults and how they can be found.

The best way to check out the antenna system is by measuring the signal strength at a distant receiver, and comparing it with the signal from another mobile unit at the same location. The comparative signal strengths can be measured by metering the limiter voltage in an

FM receiver or the AVC voltage in an AM receiver. This check requires three people, one at each mobile unit and the third at the distant receiver.

A one-man check can be made with a fluorescent lamp, as shown in Fig. 7-21. One end of the lamp is touched to the antenna while the transmitter is on. If power is reaching the antenna, the lamp should glow. Another one-man check is with a bidirectional RF power meter. One coaxial connector is connected to the transmitter through a short coaxial jumper cable. The coaxial connector of the antenna is connected to the other receptacle on the instrument. The instrument is set to read incidental power first, and then reflected power. The difference between the two is the amount of power absorbed by the antenna. For example, if the first reading is 30 watts and the second is 5 watts, it can be assumed that 25 watts are being absorbed by the antenna, and that 5 watts are being wasted in the transmission line. The loss can be due to attenuation in the cable, and to standing waves caused by impedance mismatches.

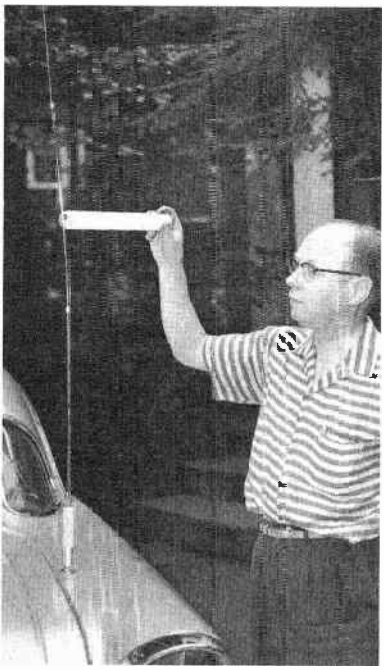


Fig. 7-21. Fluorescent-lamp antenna checker. (Courtesy of Tele-Beam Industries, Inc.)

In the absence of an RF power meter, a field-strength meter can be used. The relative field strength is measured in the vicinity of the antenna, and the readings compared with those made previously.

An antenna that is exposed to the elements may need periodic replacement. The base insulator may become caked with dirt. This dirt will cause leakage. Because of skin effect, rust and accumulated film on the whip can become a path through which the RF current flows, in preference to the actual whip.

Poor connections and accumulated dirt and moisture at the antenna cables are a frequent source of trouble. Contact by the cable shield with the car body should be checked in particular.

FIXED-ANTENNA TROUBLESHOOTING

If both the talk-out and talk-in ranges are shorter than normal, the antenna system should be suspected. A quick check is to substitute another antenna system. A piece of wire connected to the antenna terminal (a 9- to 10-foot piece for the 25-50 mc band, an 18-inch piece for the 152-174 mc band, or a 6-inch wire for the 450-470 mc band) can be used temporarily. If an improvement is noted, the antenna system is obviously at fault.

A bidirectional RF power meter, connected in series with the antenna transmission line at the radio-unit end, can be used to measure incidental and reflected power. The difference between readings is the amount of power consumed by the antenna. This difference will normally be higher in the 152-174 or 450-470 mc band, with a long cable run, than in the 25-50 mc band.

An excessive difference between incidental and reflected power indicates trouble in the transmission line, antenna, or connectors. If feasible, the power at the antenna end of the cable (with the antenna disconnected) should be measured with a termination-type RF wattmeter. If the power is less than anticipated—considering the cable length, attenuation per 100 feet for the type of cable, and the operating frequency—the trouble apparently is in the cable.

The trouble may be due to improper transmitter tuning. The antenna tuning controls are there to balance out the reactance in the line, so that the line (terminated in the antenna) looks like a pure resistance (50 or 72 ohms). If the transmitter is correctly tuned, the transmission line may be faulty.

A solid dielectric cable that has been damaged or whose insulation has absorbed excessive moisture can be an inefficient transmission medium. When this occurs, the cable should be replaced.

Another common fault is a short circuit or a high-resistance contact, resulting from improper installation of connectors.

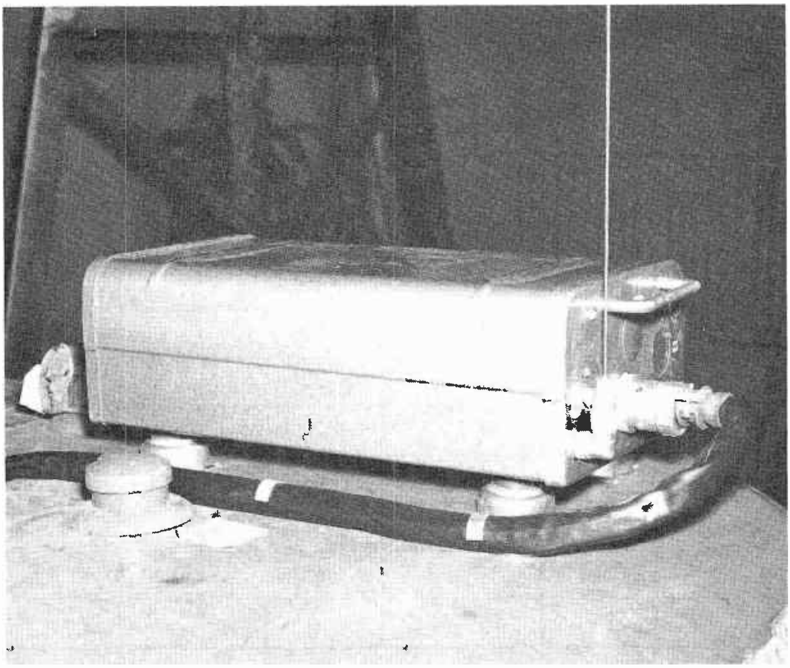


Fig. 7-22. A stiff wire attached to the connector makes a good intra-plant antenna. (Courtesy of Radio Corporation of America.)

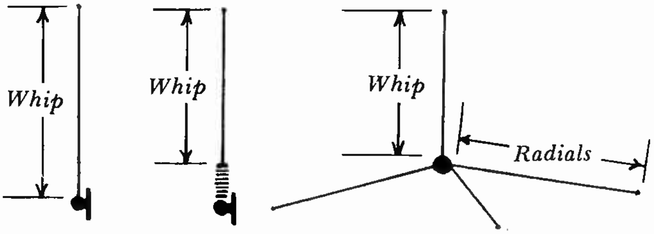
MOBILE

Whip With Base Only

Whip With Base & Spring

FIXED STATION

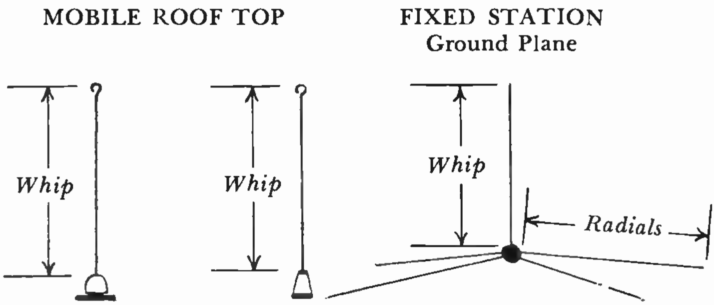
Ground Plane Antenna and Radial Lengths



Freq. in Mc	*Whip*	*Whip*	*Whip*	*Radials*
27.0-27.7	108″		108″	108″
27.7-28.4	104″		104″	108″
28.4-29.0	102″		102″	108″
29.0-29.5	98″	96″	100″	108″
29.5-30.5	96″	96″	98″	108″
30.5-31.5	96″	84½″	96″	96″
31.5-34.0	84½″	84½″	90″	96″
34.0-36.5	84½″	79″	84½″	84½″
36.5-37.0	79″	79″	79″	84½″
37.0-39.0	79″	72″	79″	84½″
39.0-40.0	72″	72″	72″	84½″
40.0-42.0	72″	68″	72″	84½″
42.0-44.0	68″	62″	68″	84½″
44.0-45.0	62″	62″	62″	84½″
45.0-48.0	62″	57″	62″	84½″
48.0-50.0	57″	57″	57″	84½″

(A) For 27-50 mc antennas.

Fig. 7-23. Element lengths of quarter-wave whip and ground-plane



Freq. in Mc	*Whip*	*Whip*	*Whip*	*Radials*
120-128	23¼″	23″		
128-138	21½″	21″		
138-143	19½″	18¾″		
144-147	19½″	18¾″	19⅜″	18″
149	18″	18¾″	19⅜″	18″
150	18″	17½″	19⅜″	18″
151-152	18″	17½″	19⅜″	17″
153-155	18″	17½″	17⅞″	17″
156-158	18″	17½″	17⅞″	16″
159-160	18″	17½″	17⅞″	16″
161-162	18″	16½″	17⅞″	16″
163	16¾″	16½″	17⅞″	16″
164	16¾″	16½″	17⅞″	15″
165-168	16¾″	16½″	16⅞″	15″
169-171	16¾″	15⅛″	16⅞″	15″
172-176	16¾″	15⅛″	16⅞″	14″
450-470	6″	6″	6″	6″

(B) For 120-176 and 450-470 mc antennas.

antennas. (Courtesy of Antenna Specialists Company.)

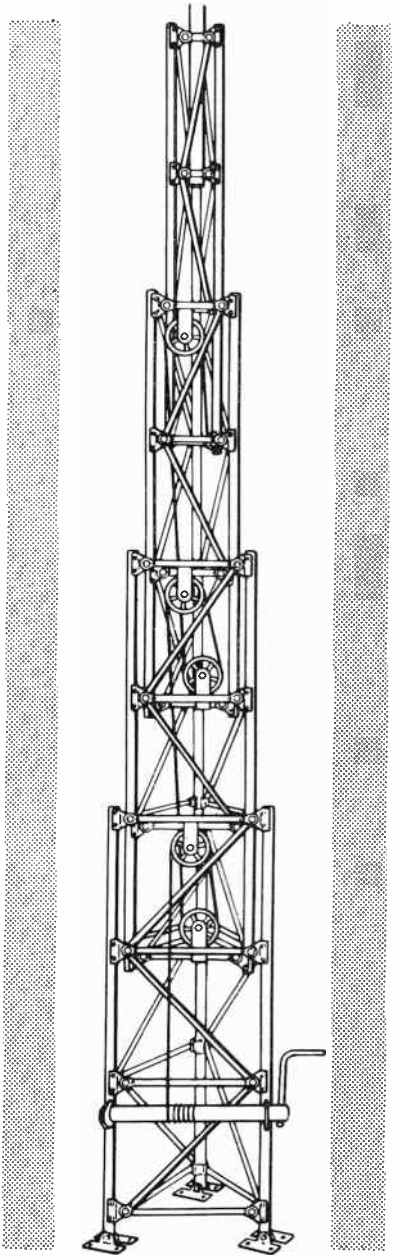


Fig. 7-24. Crank-up towers are handy during field surveys. (Courtesy of Alpar Manufacturing Corporation.)

When temperatures are extremely low, troubles may be caused by contraction of the inner conductor of the cable. This happened in Duluth, Minnesota. The inner conductor of the cable contracted so much that the center pin of the connector, at the antenna end of the cable, was pulled out of its mating receptacle, causing an open circuit.

When an antenna system is checked with an ohmmeter at the radio end of the cable, an open circuit is generally indicated between the inner conductor and the shield of the cable. However, some antennas are provided with a matching stub, or are otherwise so designed that a short circuit will be indicated. This is a DC short circuit; but to the signal, the circuit looks like 50 ohms at the operating frequency.

The best test of the performance of an antenna system is an actual field test. By driving around in a mobile unit to determine the range, one can find out for sure how effective the antenna actually is. An external antenna is usually required. In some short-range applications, however, a stiff wire of the proper length, attached directly to the radio unit, will suffice (see Fig. 7-22).

The lengths of the antenna radiating elements, reflectors, directors, and ground radials are critical. Fig. 7-23 lists the element lengths of quarter-wave whip and ground-plane antennas for various frequencies. The minimum required antenna height (the critical height) for a given range can be determined during a field survey by using an antenna support, like the one in Fig. 7-24, the height of which can be adjusted.

CHAPTER

8 Power

WALKIE-TALKIES, *Handi-Talkies,* and packsets, as well as some of the recently developed all-transistor receivers, can operate from self-contained dry batteries because of their low-power requirements. At the present time, transmitters still require considerable power. High-voltage DC is required for tube plates and screens, and either AC or DC at fairly heavy current values for heating the tube filaments.

BATTERY CONSERVATION

Power consumption of mobile units can be reduced by employing transistors instead of tubes in receivers and in those transmitter circuits where they are feasible. The mobile unit in Fig. 8-1 employs only transistors in the receiver, and

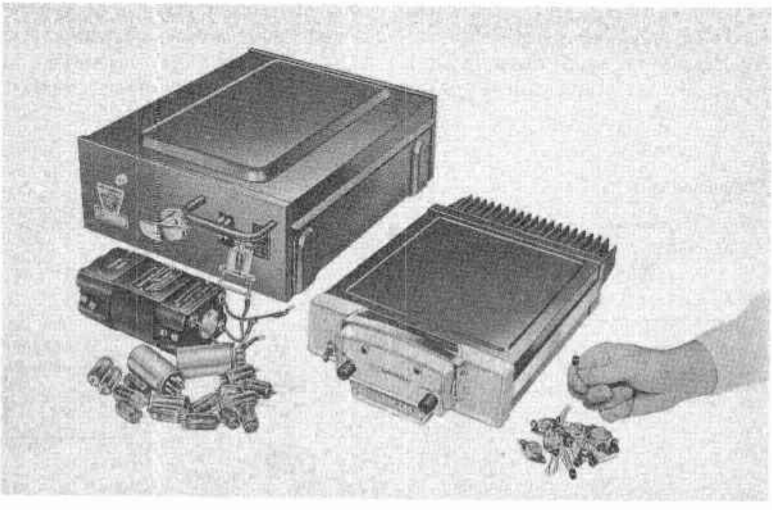


Fig. 8-1. (Left) Tube-type unit using two vibrators and a dynamotor.
(Right) The new Motrac employs only transistors in the power supply and receiver.
(Courtesy of Motorola Communications and Electronics, Inc.)

both tubes and transistors in the transmitter. Fred M. Link, noted mobile radio pioneer, has come up with a worthy suggestion in regard to battery conservation. He points out that keeping the filaments of transmitter tubes turned on at all times while the receiver is turned on is unnecessary in most instances.

If the tube filaments are kept heated, the transmitter is ready for use almost instantly when the push-to-talk button is operated. However, in many applications a one- or two-minute delay is tolerable. The transmitter can be kept off until needed. A switch is often provided which is actuated by removal of the microphone or handset from its hanger. This switch turns on the transmitter filaments, and turns them off when the microphone or handset is replaced on its hanger. The user must wait until the tubes warm up before attempting to transmit.

Where selective calling is used, automatic shutoff of the mobile receiver, after an unattended vehicle has been signaled, can be easily provided. In selective calling, the receiver is left on when the vehicle is unoccupied, so that a calling station can leave word that an attempt has been made to reach the vehicle.

When the calling station dials or pushes a button to signal a certain mobile unit, a call-indicator lamp is lighted at the mobile unit. This lamp remains lit until shut off by the occupant of the vehicle.

Once the lamp has been lit by an intercepted code call, there is no point in allowing the receiver to continue draining the battery. Fig. 8-2 shows the battery-saver circuit for mobile units equipped with selective calling. Switch S1 is the master on-off switch. It energizes relay M1 (or a solenoid) when closed, feeding DC from the battery. When the vehicle is occupied, S2 is set to the In position. This grounds one end of the winding of relay M1, allowing S1 to exercise full control.

When the vehicle is unattended, S1 is left on, and S2 is set to the Out position. The ground return of the coil of M1 is now routed through the contacts of relay M2. The radio remains on as long as S1 is closed and M2 is not energized. When a coded signal is received which closes the contacts of M3 *momentarily*, M2 is energized. Its contacts open the

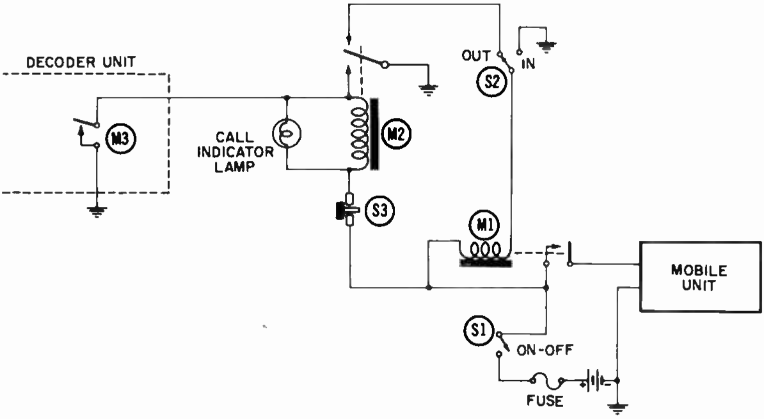


Fig. 8-2. Battery-saver circuit.

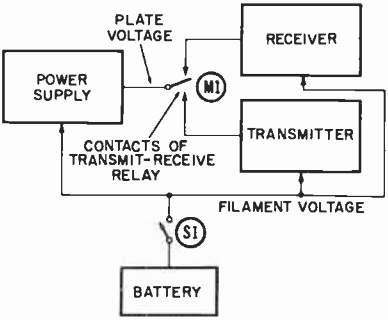


Fig. 8-3. A single power supply may furnish plate voltage for both the transmitter and receiver.

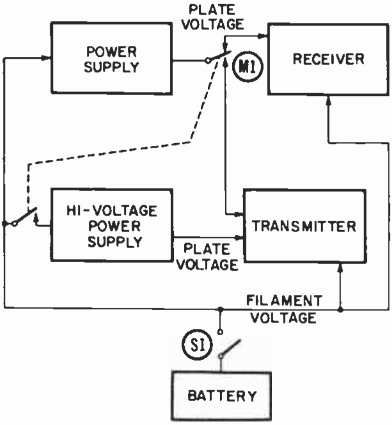


Fig. 8-4. In some units, two power supplies furnish plate voltages to the transmitter.

circuit to M1, turning off the radio. The contacts also lock up relay M2 so that it will remain pulled in after M3 opens. When the call-indicator release push button S3 (normally closed contacts) is operated, M2 drops out and M1 is energized, turning the radio back on.

MOBILE POWER SYSTEM

In equipment using low-powered transmitters, a single high-voltage power supply may be used—sequentially, but not simultaneously—for both the transmitter and the receiver. M1 in Fig. 8-3 shows the contacts of the microphone switch-actuated (push-to-talk) relay. These contacts complete the plate-voltage circuit to either the transmitter or the receiver. When S1 is closed, low voltage from the battery is fed to the tube filaments of both the transmitter and the receiver, as well as to the high-voltage power supply.

In higher-powered transmitters, separate power supplies may be

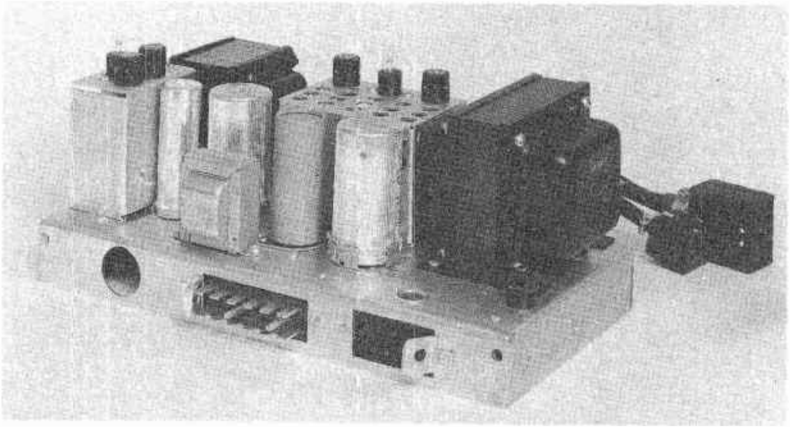


Fig. 8-5. Two power supplies assembled as one unit. (Courtesy of Allen B. DuMont Laboratories, Inc.)

used for the transmitter and receiver. Or, as shown in Fig. 8-4, the receiver power supply may furnish plate voltage to some of the transmitter tubes, while another power supply energizes the remaining stages. The two power supplies may be assembled as a single unit, as shown in Fig. 8-5.

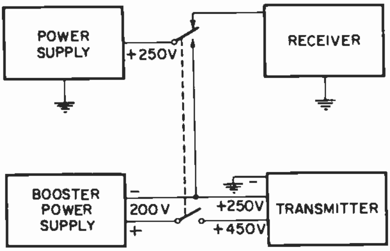


Fig. 8-6. Series-connected power supplies, to provide higher voltage for transmitter power amplifier.

In Sperry railroad equipment, for instance, there are two power supplies mounted on the same chassis. One supply functions only when transmitting. The other operates continuously, providing plate voltage to the receiver when receiving and to the oscillator and multiplier stages when transmitting. When transmitting, both power supplies function. Their DC outputs are connected in series, as illustrated in Fig. 8-6, to provide the higher voltage required by the transmitter power amplifier.

MOBILE POWER SUPPLIES

Plate voltage is derived from the vehicle battery by first converting the DC to AC, boosting the voltage, and then rectifying it back to DC. The power supplies in Figs. 8-7 and 8-8 convert low-voltage DC to high-voltage DC. A dynamotor may also be used for boosting the DC voltage without converting it to AC.

DYNAMOTORS

A dynamotor is a simple motor generator using a common field for

Fig. 8-7. Vibrator-type power supply for converting from low- to high-voltage DC. (Courtesy of Cornell-Dubilier Electric Corp.)

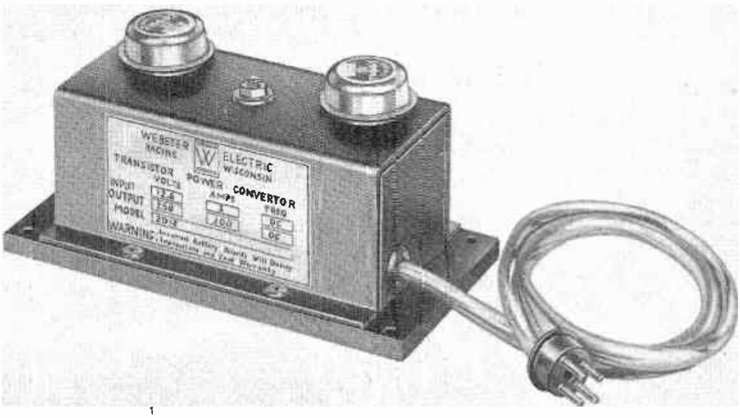


Fig. 8-8. Transistor power converter for converting from low- to high-voltage DC. (Courtesy of Webster Electric Co.)

an armature equipped with two commutators. One commutator is connected to the low-voltage windings and the other to the high-voltage windings. When DC is applied across the low-voltage armature and field coil, the machine operates as a motor. High DC voltage (the level of which depends upon the turns ratio of the low- and high-voltage windings, the speed the armature rotates, the field current, and the load connected to the high-voltage output) is obtained across the brushes, which touch the high-voltage commutator.

The high-voltage commutator is a mechanical rectifier which prevents the armature output voltage from reversing in polarity. The output is pulsating DC, something like that obtained at the output of an unfiltered rectifier. The ripple frequency is rather high; hence, only a small filter is required to provide smooth DC.

Dynamotors are seldom employed as receiver power supplies, but are widely used for powering transmitters because of their high-power capabilities. Given proper care, a dynamotor is a very reliable device.

The contacts in the microphone switch are never used for directly turning on a dynamotor. Instead, the push-to-talk switch or a microphone hanger switch closes a circuit to the coil of a relay or solenoid, which opens and closes the DC input circuit to the dynamotor (Fig. 8-9). The inrushing current drawn by a stalled dynamotor is several times greater than its running cur-

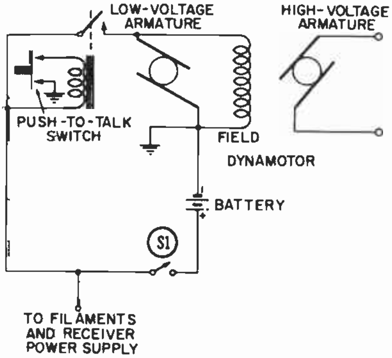


Fig. 8-9. A relay or solenoid turns a dynamotor on and off.

rent. The fuses must be capable of handling this short-term high current.

6- TO 12-VOLT CONVERSION

When a 6-volt mobile unit is converted for 12-volt operation, the same dynamotor can be used if a resistor is added in series with the low-voltage commutator, as shown in Fig. 8-10. For example, if the running current of the dynamotor is 30 amperes when operated at 6 volts, a 0.2-ohm resistor should be connected in series with the DC input for 12-volt operation. The desired voltage drop across R is 6 volts. From Ohm's law:

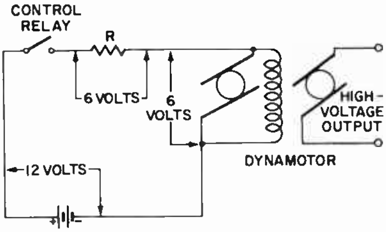


Fig. 8-10. Series resistor permits a 6-volt dynamotor to be operated from a 12-volt source.

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

$$= \frac{6}{30}$$

$$= 0.2 \text{ ohms.}$$

This practice should be resorted to only as an emergency measure, when the cost of replacing the dynamotor is prohibitive. With a series resistor in the circuit, the output-voltage regulation will be poor because of the "rubber band" effect of the resistor. When the dynamotor is operated directly from a battery of the proper voltage, the input voltage will remain fairly constant

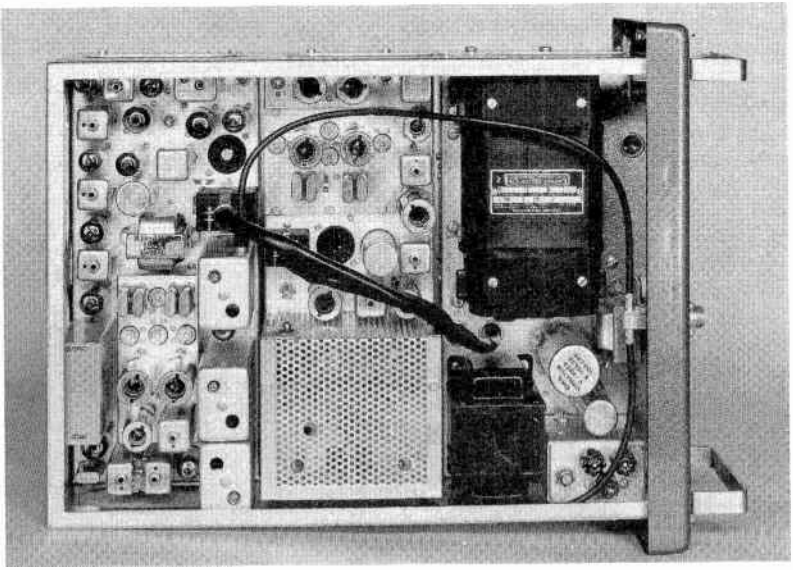


Fig. 8-11. Power-supply chassis (right) employs a vibrator to power the receiver, and a dynamotor to power the transmitter. (Courtesy of Allen B. DuMont Laboratories, Inc.)

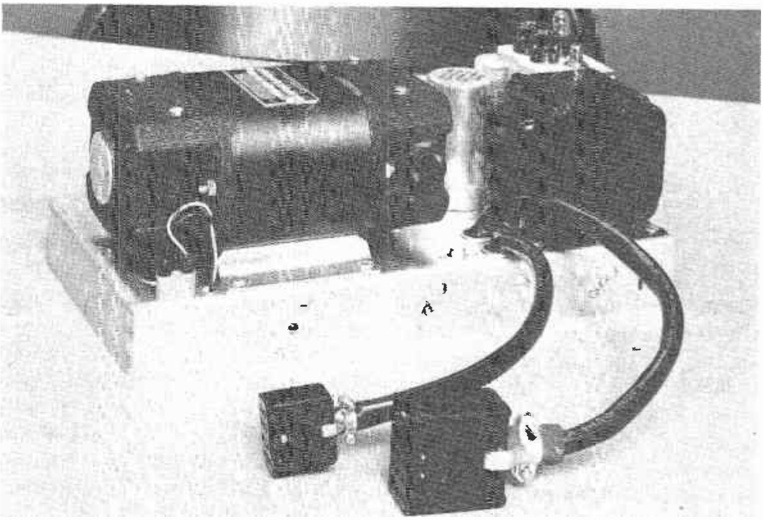


Fig. 8-12. Power supply removed from the unit in Fig. 8-11 for bench servicing. (Courtesy of Allen B. DuMont Laboratories, Inc.)

as the load varies on the high side of the dynamotor. With a resistor in series, however, the voltage drop across the resistor will increase as the load increases, dropping the applied input voltage. Conversely, the voltage drop will decrease as the load decreases, raising the applied input voltage.

DYNAMOTOR TROUBLES

A dynamotor must be kept cleaned and lubricated. Its brushes must be replaced as they wear. Any commutator unevenness, caused by friction against the brushes, must be corrected.

The dynamotor can be easily checked in the set, or by itself on the bench. The power supply in Fig. 8-11, which contains the receiver vibrator power supply and the transmitter dynamotor can be easily removed for bench servicing (see Fig. 8-12). Fig. 8-13 shows a simple bench test setup. The output voltage is measured with S1 closed and S2 open. Then it is measured with S2 closed. The voltage regulation is determined by the difference between the two readings. If the output voltage is 300 volts with S2 open and 250 volts with S2 closed, the output-voltage regulation will be +20% full-load to no load.

The value of R depends upon the output voltage and current ratings of the dynamotor. For example, if the dynamotor is rated at 100 ma at 250 volts, the resistor should be 2,500 ohms, since:

$$\begin{aligned} R &= \frac{E}{I} \\ &= \frac{250}{0.1} \\ &= 2{,}500 \text{ ohms.} \end{aligned}$$

The resistor must be able to dissipate 25 watts. Hence, a 50-watt resistor is recommended.

Ripple is measured across the output terminals by using an AC volt-

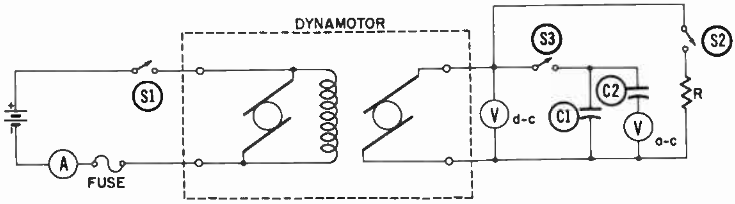


Fig. 8-13. Test setup for dynamotors.

meter with a 2 mfd or larger paper-insulated capacitor (C2) in series with the meter. An output meter that has a capacitor in series with the meter can also be used. The capacitor blocks the DC, but allows the meter to measure the ripple. Ripple as low as one microvolt can be measured with an instrument like the Fisher AC millivoltmeter. The input circuit of this instrument is shown in Fig. 8-14. Full-scale reading ranges from 1 microvolt to 300 volts. C2 and C3 form a capacitive voltage divider.

An oscilloscope can also be used for measuring the amplitude and observing the character of the ripple voltage. If the ripple is measured with the dynamotor removed, a filter capacitor (C1 in Fig. 8-13) of approximately the same value as the one in the equipment should be shunted across the high-voltage output.

Excessive ripple can be caused by poor, uneven contact by the brushes and commutator, or by a defect in the armature. The commutator should *not* be sandpapered. The armature can be sent to a motor repair shop or to the manufacturer for overhaul. If sealed bearings are employed, they should be replaced regularly. If sleeve bearings are used instead, they should be lubricated frequently (but not excessively).

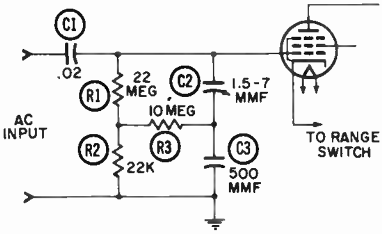


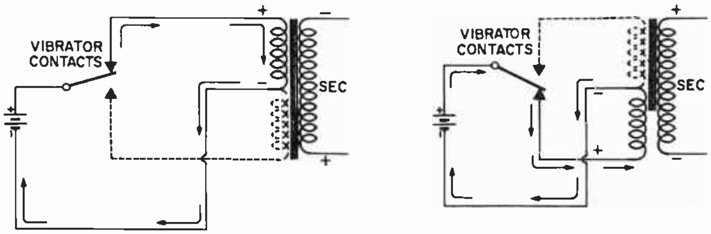
Fig. 8-14. Input circuit of a supersensitive AC millivoltmeter.

VIBRATOR POWER SUPPLIES

Like a relay, a vibrator is an electromechanical device which rapidly opens and closes its contacts. It operates more like a buzzer: an electromagnet pulls in an armature, and then releases it when the series armature contacts separate. When the armature drops back, the contacts close once more, re-energizing the magnet and pulling the armature in again.

The vibrator interrupts and reverses the current flow at 100 cps or more in the primary of the power transformer, as shown in Fig. 8-15. If the center-tapped primary of the transformer were resistive instead of inductive, the voltage across it would be a square wave. Because of inductance, however, the reversing current in the primary is AC, even though the waveform is not a true sine wave. This AC is stepped up by the transformer, in proportion to the ratio of primary to secondary turns.

Vibrators wear out and must be replaced occasionally. Contacts burn or become pitted, or even welded



(A) DC flows through one-half of primary during one half-cycle . . . .

(B) . . . and through the other half during the other half-cycle.

Fig. 8-15. How a vibrator works.

shut. The vibrating member may become fatigued and lose its resiliency. Although a vibrator can be dismantled and cleaned in order to extend its life, it is better to replace it with a new one than to chance an in-service failure.

The secondary of the power transformer is fed to a rectifier. The rectifier converts the high AC voltage to pulsating DC, which is smoothed out by a ripple filter. Vacuum tubes, gas tubes, selenium, germanium, or silicon can be used as rectifiers in a half-wave, full-wave, or voltage-doubler circuit. Fig. 8-16 illustrates a tube-type rectifier, similar to the ones in conventional AC-operated receivers. Capacitor C, shunted across the high-voltage secondary, is called a "buffer" because it bypasses high-voltage transients. Since its electrical value is critical, it should be replaced with one of the same value only. A leaky buffer capacitor can cause vibrator trouble. For this reason, some technicians make it a policy to replace the buffer when installing a new vibrator.

Fig. 8-17 is a schematic of the vibrator power supply in some General Electric mobile units. Through the use of clever circuitry, the same power transformer and six selenium rectifiers provide three different plate voltages for the transmitter. Fig. 8-18 shows how the RF-amplifier and oscillator plate voltages are derived. High voltage for the final RF amplifier is provided by the full-wave bridge rectifier (M1 through M4). Lower plate voltage for the oscillator is derived by a full-wave rectifier (M1 and M2). Fig. 8-19 illustrates how plate voltage is obtained for the transmitter multiplier stages. A full-wave rectifier (M1 and M2, and M5 and M6) provides this voltage. The solid areas show current flow during one half-cycle; the dotted arrows, the other half. Fig. 8-17 shows much more detail, including the transmit-receive switching circuits.

The simplicity of the bias rectifier power supply, which employs the same power transformer as the plate power supply, is pointed out in Fig.

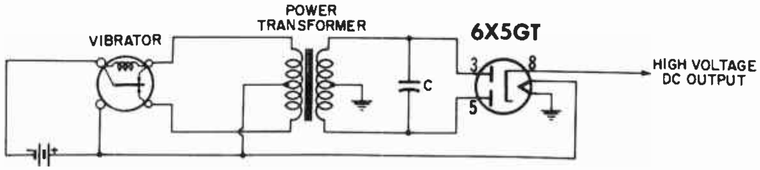


Fig. 8-16. Vibrator power supply using a vacuum-tube rectifier

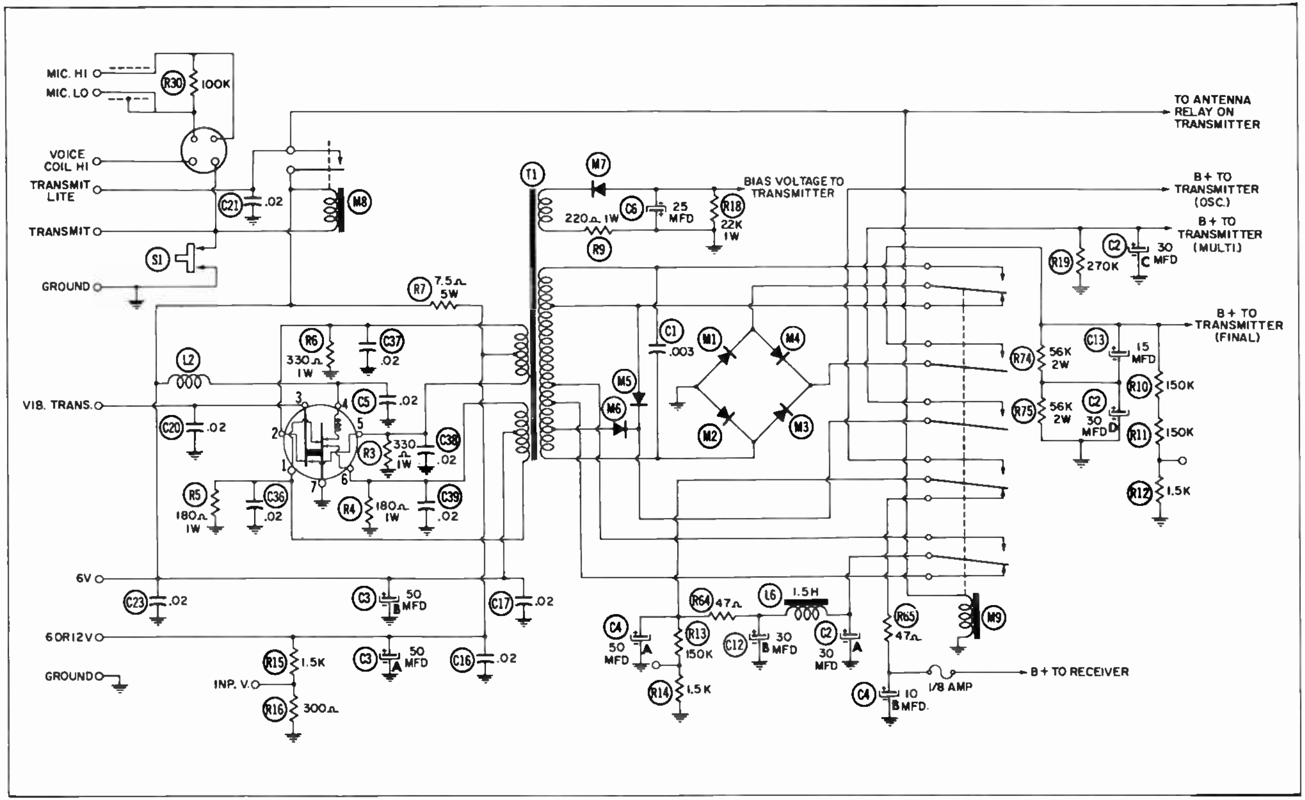


Fig. 8-17. Vibrator power supply of a General Electric mobile unit.

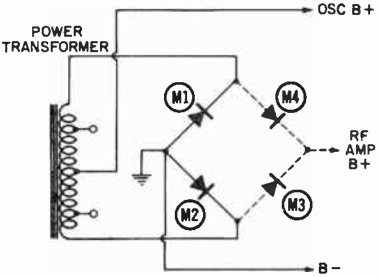


Fig. 8-18 How RF-amplifier and oscillator plate voltages are derived.

8-20. Fig. 8-21 shows how the input circuit is series-connected for 12-volt operation. For 6-volt operation, the two vibrator primary circuits are paralleled. The change from 6 to 12 volts is made in the interconnecting plugs.

TRANSISTOR POWER SUPPLIES

Transistors are widely used in power supplies, in lieu of vibrators. One reason is that they are more efficient. They should last indefinitely, since they have no moving parts or contacts. Transistors have another advantage over vibrators: they will usually "take off" when the battery voltage would be too low to start a vibrator.

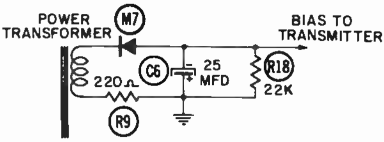


Fig. 8-20. Bias power supply employs half-wave selenium rectifier.

If employed for primary switching in place of a vibrator, the transistor is actually used in an audio-oscillator circuit. When a DC voltage is initially applied by closing switch S in Fig. 8-22, both transistors conduct, causing current to flow in the transformer primary. Since both transistors are not exactly alike, X1 may pass more current than X2. The induced voltage in the feedback winding will bias X1 to full conduction, and X2 to cutoff.

After the current through X1 rises high enough to saturate the transformer core, the feedback voltage drops to zero and then reverses its polarity. X2 starts to conduct, and X1 is cut off. When X2 saturates the core, X1 again conducts, and so on. Thus, the transistors perform the same function as a vibrator, but they do it statically.

Fig. 8-23 shows the circuitry of a transistor power supply which can be operated from a 12-volt battery. The power supply delivers 210 volts

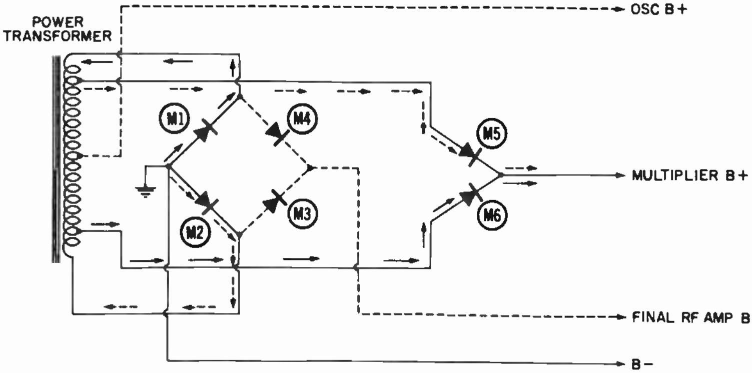


Fig. 8-19. How plate voltage is obtained for the transmitter multiplier stages.

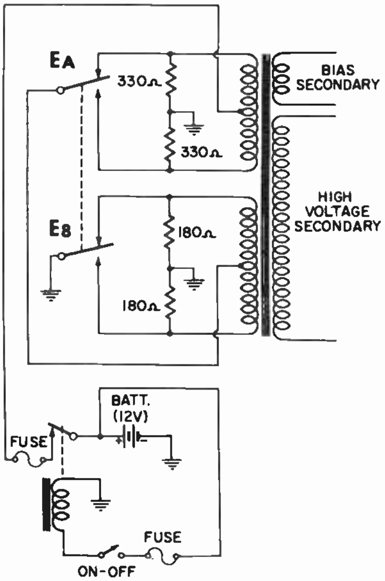


Fig. 8-21. Input circuit, showing vibrators series-connected for 12-volt operation.

to the receiver and 300 volts to the transmitter, depending upon the position of transmit-receive relay M1. The rectifier is a voltage doubler.

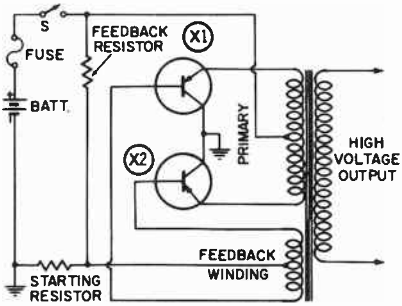


Fig. 8-22. Input circuit of transistor power supply.

Transistor power supplies like the one in Fig. 8-24 can be operated from either a 6- or a 12-volt battery. Two primary circuits are required (see Fig. 8-25). For 6-volt operation, the inputs are paralleled; for 12-volt operation, they are series connected. When transistors are used, a heat sink must be provided to carry away the heat. Fig. 8-26 shows the heat sink of a transistor power supply.

UNIVERSAL POWER SUPPLIES

Some mobile units are designed to operate from 6 or 12 volts DC,

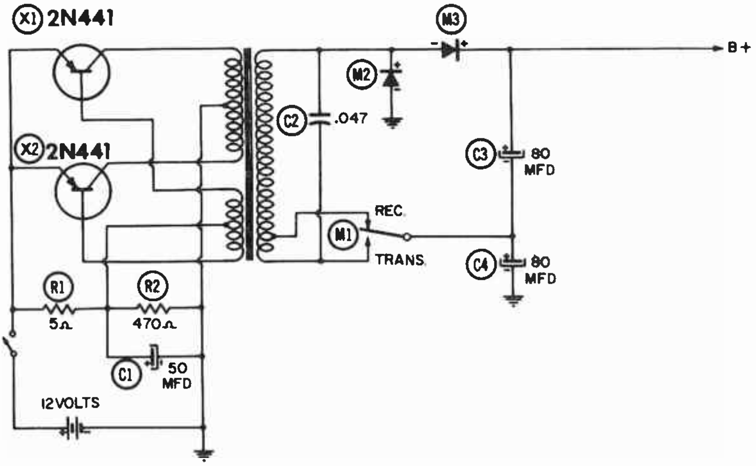


Fig. 8-23. Transistor power supply. Can be operated from a 12-volt battery.

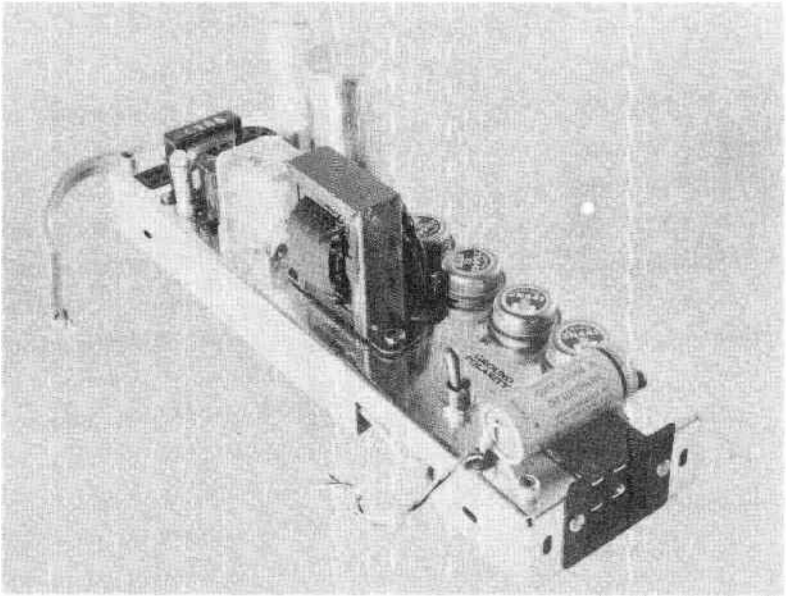


Fig. 8-24. Convertible power supply. Operates from a 6- or 12-volt battery. (Courtesy of Kaar Engineering Corp.)

or 117 volts AC, without modification. Fig. 8-27 shows the circuitry of such a power supply. The change from 6- to 12-volt operation is made by reversing the multipole plug at the set end of the battery cable. For AC operation, the battery cable is disconnected, and the plug of the AC cable is inserted into the same receptacle. The connections are changed by jumpers within the two different power plugs. Both plugs fit the same receptacle and are used one at a time.

REGULATED FILAMENT VOLTAGE

Ordinarily, filament voltage is obtained directly from the battery. Sperry, in its railroad radio power supply, provides regulated DC which operates from a 72-volt battery. In the schematic in Fig. 8-28, the full-wave rectifier and filter system can be seen. Its DC output is filtered and regulated by a series-type transistor regulator. The regulator is shunted by a 2-ohm resistor (R1), which drops the DC voltage. The transistor acts as an electronically controlled resistor in parallel with R1; it automatically adjusts the effective resistance to maintain a constant output voltage, using Zener diode M3 as a reference. Tube life is prolonged and optimum performance conditions maintained by keeping the filament voltage constant.

72-VOLT INPUT SYSTEM

Fig. 8-29 shows the three sets of primary windings on the power transformer of the Sperry power supply. The input circuit consists of three 24-volt input circuits in series. Another unusual feature of the Sperry power supply is its electronic overload protector. If the

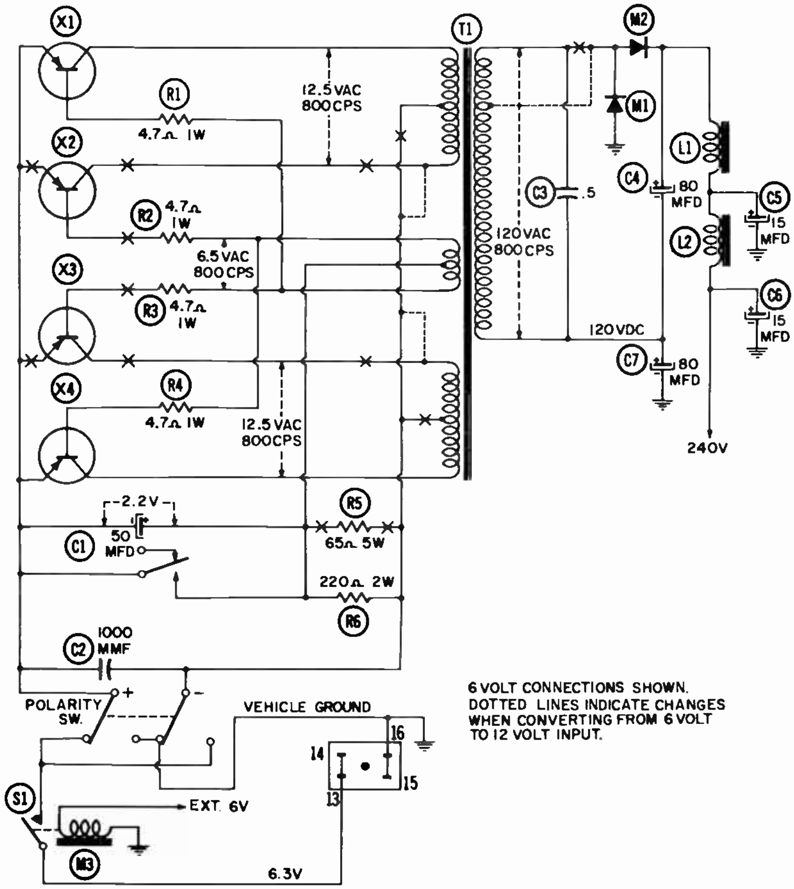


Fig. 8-25. Schematic of convertible power supply.

Fig. 8-26. Heat sink on a transistor power supply. (Courtesy of Allen B. DuMont Laboratories, Inc.)

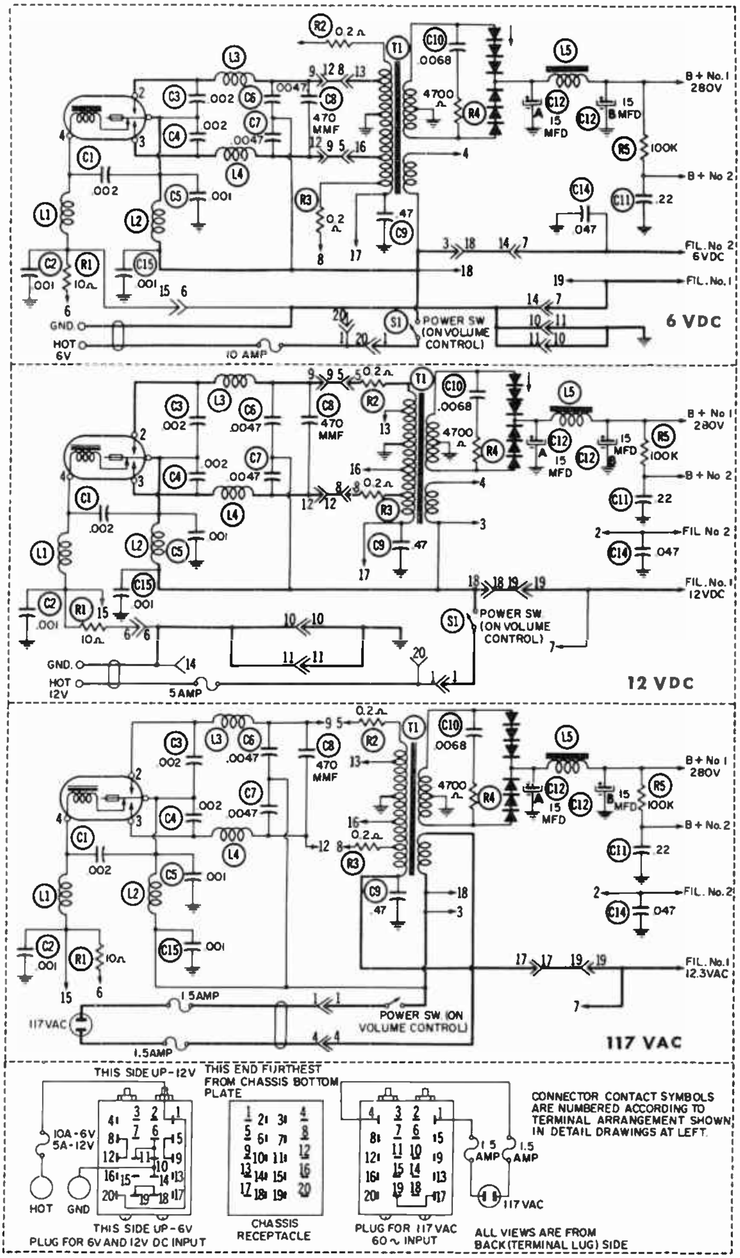


Fig. 8-27. Universal power supply for 6 or 12 volts DC, or 117 volts AC. (Courtesy of Kaar Engineering Corp.)

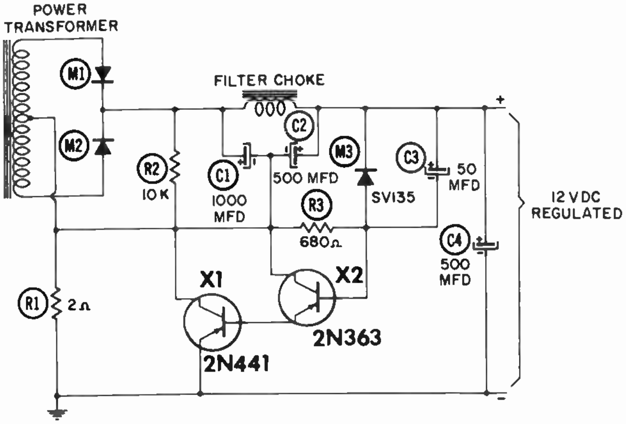


Fig. 8-28. Regulated filament power supply.

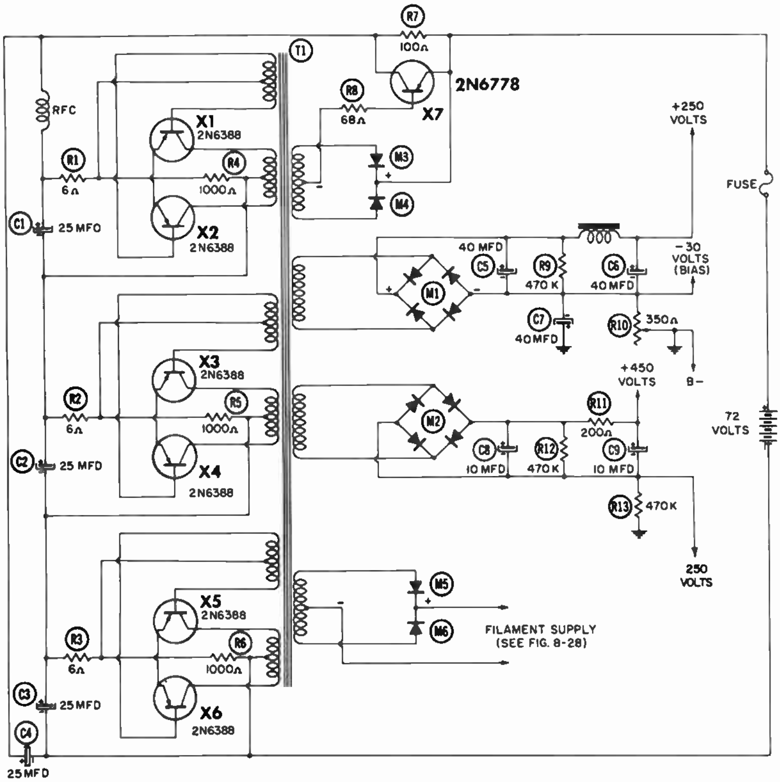


Fig. 8-29. Power supply designed for 72-volt DC input (circuits in "transmit").

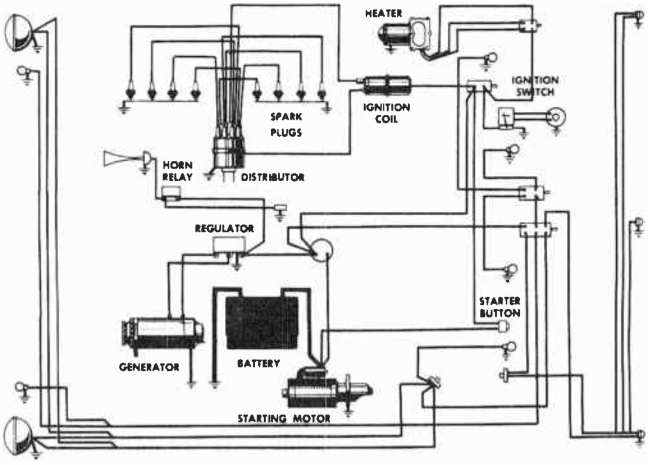


Fig. 8-30. Automobile electrical system.

bias drops, indicating an overload, transistor X7 (in series with one leg of the battery line) adds resistance to the circuit. The added resistance protects the power transformer, rectifiers, and other transistors. Note that, to obtain 450 volts for the final RF-amplifier plate supply, a 200-volt power supply is connected in series with the 250-volt receiver power supply.

AUTOMOBILE ELECTRICAL SYSTEM

The electrical power system of an automobile consists of a storage battery, charging (DC) generator, and regulator, as shown in Fig. 8-30. Since the engine drives the generator at varying speeds, its output voltage would vary widely if there were no regulator.

The voltage across a fully-charged 6-volt battery is 6.3 volts; and for a 12-volt lead-acid battery, 12.6 volts. When a load is applied across the battery, the voltage will drop. How much it drops will depend upon the load and the internal battery resistance.

Regulator

The regulator unit consists of a voltage regulator, cutout relay, and current limiter. The voltage regulator controls the generator output voltage. The cutout relay prevents current flow from the battery to the generator when the generator is idle or running at lower than threshold speed. It does this by automatically disconnecting the generator from the battery. The current limiter prevents the generator from being overloaded.

As the generator speeds up, the cutout relay is energized, and the battery is connected to the generator output. The voltage regulator starts to vibrate, opening and closing the top contact and the armature contact. As the speed increases, the vibration stops, and the output voltage reaches maximum. The armature of the voltage regulator is now pulled in closer to the pole piece. Vibration again occurs, except that the bottom and armature contacts open and close rapidly.

This occurs when the output voltage is around 14 volts (7 volts for 6-volt systems). The maximum output voltage, as determined by the voltage regulator, can be adjusted by varying the core gap. The gap is widened to raise the voltage or narrowed to lower it. This is done by loosening the contact block locking screw, and moving the carrier up or down.

When the current from the generator to the battery and the load exceeds the capacity of the generator, the current flow through the coil of the current limiter becomes great enough to open the limiter contacts. A resistor is then inserted in series with the generator field coil. The resistor reduces the field current and, hence, limits the generator output.

Fig. 8-31 shows the internal circuitry of a typical regulator. When the generator is idle or running slowly, cutout relay M1 is de-energized and its contact is open, preventing current flow from battery into the regulator and generator. As the generator picks up speed, the cutout relay is energized. It then closes its contacts because of the current flow from the generator output through the series coil of the cutout relay (which is in series with the coil of current limiter M2, ballast resistor R1, and the primary coil of voltage regulator M3. The cutout relay closes when the generator output voltage reaches 12.7-12.9 volts in 12-volt systems or 6.35-6.45 in 6-volt systems. The shunt coil of M1 holds the relay closed as long as the generator voltage remains at a high enough level.

As the generator speed increases, the armature of voltage regulator M3 starts to vibrate when the output voltage rises to 13.7-13.9 volts (half that value for 6 volts). This vibration causes the top contact and the armature contact to rapidly open and close. If earphones are connected across the *F* and *G* terminals, electrical sound created by this circuit interruption can be heard.

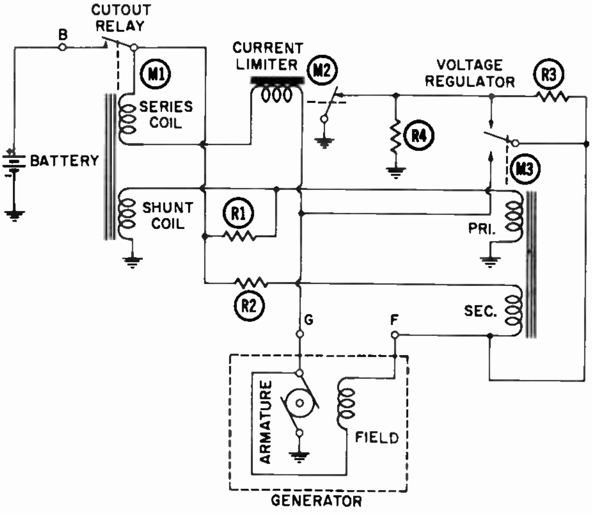
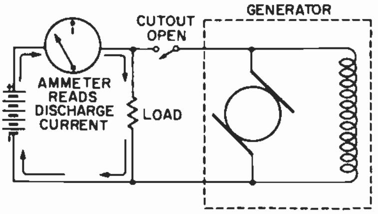
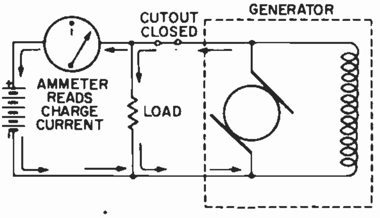


Fig. 8-31 Voltage regulator and generator system.



(A) When generator is not running, battery supplies power.



(B) When running, generator feeds load and battery consumes power.

Fig. 8-32. Current flow with generator idle and running.

Function of Battery

When the generator is not charging, power for the radio equipment is derived from the battery. At low speeds the generator puts out enough current to take over part of the job. At higher speeds, the generator supplies the power for the radio equipment, as well as the charging current for the battery.

When the battery is low and the generator is running, current flows from the generator into the battery. The amount of current is determined by the generator output and the state of charge in the battery. The positive terminal of the generator is connected to the positive terminal of the battery. As a result, the current flow through the battery is in the opposite direction from the discharge current. (See Fig. 8-32.) When the battery is fully charged, little or no charging current flows because the difference between the generator and battery voltages is now much smaller. If the voltage regulator is set too high, the battery might be damaged. Excessive voltage will also be applied to the radio equipment, shortening the life of the tubes.

The battery would not be needed if the vehicle engine were running all the time. It is used to supply power for starting, and for the load when the engine is not running.

Generators

When trouble is experienced because the generator is unable to replenish the current taken out of the battery by the radio equipment, a larger generator should be installed. If the trouble is due to the vehicle being operated regularly at low speeds, or if the engine is idling much of the time, replacement of the generator driving pulley with one of a smaller diameter will speed up the generator and, hence, increase its output.

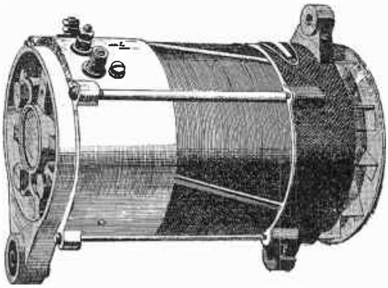


Fig. 8-33. Alternator (Delco-Remy Model 1117070, self-rectifying, 12 volts AC).

A vehicle is customarily equipped with a DC generator. When greater charging capacity is required, a DC generator of higher rating or an alternator-rectifier system may be installed. Fig. 8-33 shows an alternator containing built-in silicon rec-

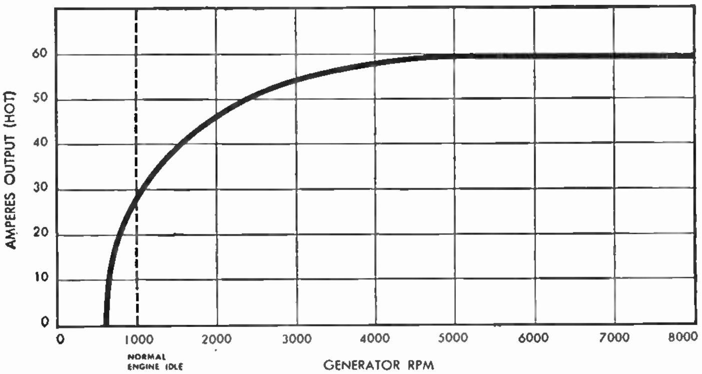


Fig. 8-34. Output capability of alternator in Fig. 8-33.

tifiers. It delivers up to 60 amperes when used in a 12-volt system. The curve in Fig. 8-34 shows its output capability in relation to the generator running speed. Note that, at engine idle speeds, the generator delivers almost half of its maximum current capability.

Fig. 8-35 is a schematic of an alternator-rectifier. The generator is a three-phase alternator in which the power-output windings are part of the stator, and the field is the rotor. Since power is derived directly from the stator windings, no heavy current-carrying moving contacts are required. Only two slip rings are needed, and the current flow through them is very small. The six silicon rectifier cells, comprising a full-wave three-phase bridge-rectifier system, are contained in the slip-ring housing.

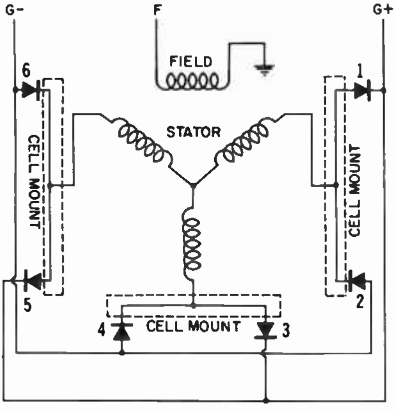
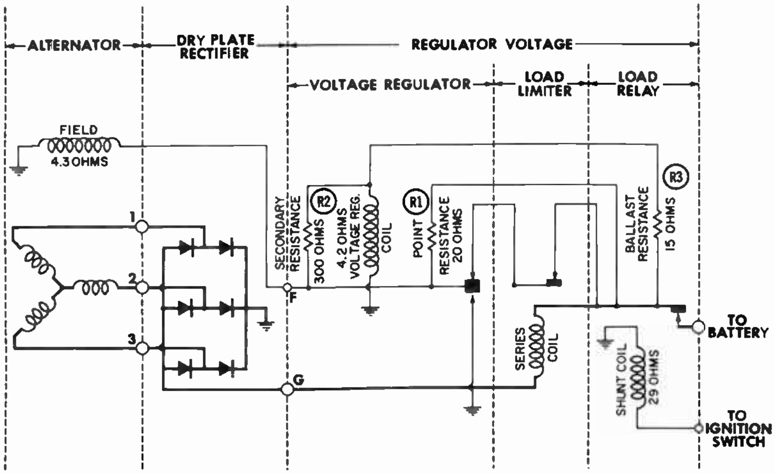


Fig. 8-35. Alternator with built-in rectifiers.

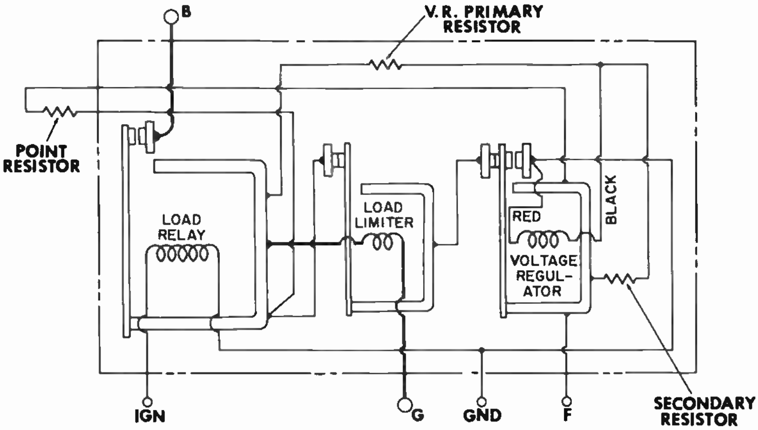
When the rotor is turned, its magnetic field also rotates, inducing a current in the stator windings. The output voltage is three-phase AC, which varies in frequency with the rotor speed. The rectifiers convert the AC to DC. The DC output has a very high ripple frequency, which is eliminated when it is shunted by the battery. A regulator varies the field current to maintain the DC output voltage constant.

In addition to the newly developed alternators with built-in rectifiers, most of those in use employ external rectifiers. Fig. 8-36 shows the circuitry of a complete alternator-rectifier system and its associated regulator (Fig. 8-36A), as well as a function drawing of the regulator alone (Fig. 8-36B).

A cutout relay is not used, since DC from the battery cannot flow back into the generator output windings because of the rectifiers. However, the field (rotor) is energized by the vehicle battery. If means are not provided for discon-



(A) Schematic.



(B) Wiring diagram of regulator.

Fig. 8-36. Alternator-rectifier system.

necting the field coil when the engine is not running, the field will continue to draw current.

A load relay automatically connects the field to the battery when the ignition switch is turned on. The relay connects the "hot" side of the battery to the ungrounded end of the field coil through R2 and R3.

Regulator Operation

When the alternator is running, the DC output of the rectifier is fed, through the coil of the load limiter and through R3, to the voltage-regulator coil. This causes the voltage-regulator armature to vibrate, opening and closing the top contact and the armature contact when regulation starts, and the bottom and armature contacts when the voltage reaches maximum. The switching action controls the field current by pulsing it.

As shown in Fig. 8-37 (a simplified schematic of the voltage regulator), the battery is connected directly to the field when the armature contact of the voltage regulator touches the top contact. When these contacts are open, R1 (a 20-ohm resistor) is in series with the field, limiting the field current to about one-fifth its maximum value. While vibrating, the top contacts alternately raise and lower the field current.

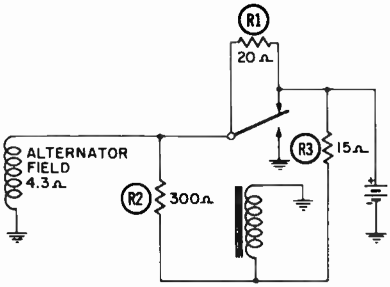


Fig. 8-37. Simplified diagram of a voltage regulator.

As the armature contact mates with the bottom contact, the field is shorted to ground. When these contacts vibrate, applied field voltage is alternately switched on and off.

The field current is steady only when the contacts are held open. As they make and break, the effective field current is determined by *time* as well as by resistance. Since neither zero nor maximum field current flows continuously, the effective field current is somewhere between, being determined by how much time each condition exists with relation to the other.

The generator output voltage should be between 13.7-13.9 volts

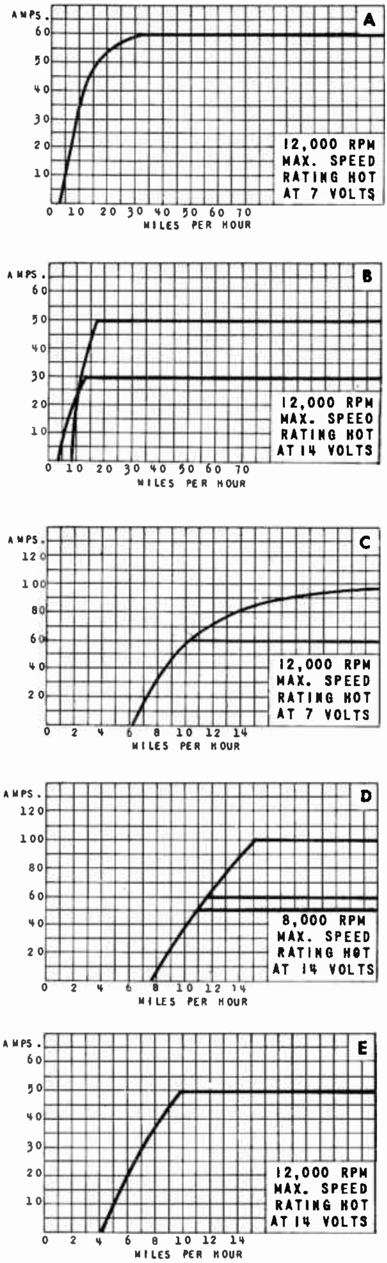


Fig. 8-38. Alternator output curves. (Engine idling at 8-10 miles per hour.) (Courtesy of the Leece-Neville Co.)

for a 12-volt system, and 6.9-7.1 volts for a 6-volt system. Fig. 8-38 shows output curves for variously rated alternators.

RAILROAD CABOOSES

In railroad cabooses equipped with radio, the power supply usually is a 12-volt lead-acid storage battery and an axle-driven alternator-rectifier. Except for the drive mechanism, the generating system is the same as for automobiles and trucks.

The Erie Railroad, however, has a 32-volt system on many of its cabooses. Axle-driven car lighting generators of the same type used on railway passenger cars are employed. Since the output voltage of a DC generator will reverse polarity when the direction of rotation is reversed, axle-driven railway generators have an automatic polarity reverser to prevent the battery from discharging while the train is backing up.

Radio equipment in cabooses may be designed for 12- or 32-volt DC operation (depending upon the caboose power supply), or for 115-volt AC operation, in which case a DC-to-AC converter is used. Fig. 8-39 depicts a vibrator-type DC-to-AC converter for locomotives and cabooses. The power supply fits into the heavy mounting, which is permanently installed. The unit can be easily removed for maintenance. Note the two vibrators. One is a standby that automatically switches in if regulator vibrator should fail.

LOCOMOTIVES

Power for radio equipment on locomotives is obtained from the engine starting battery. The battery, which may have a nominal output voltage of 64, 72, or 110 volts DC, is kept charged by the auxiliary generator. Much modern railroad equipment is designed for direct operation from a 72-volt DC source. However, there are many AC sets in use, all of which require a DC-to-AC converter. Vibrator- as well as motor-generator type converters are employed. Wide changes in DC voltage are encountered on locomotives; these changes must be considered in the operation of the equipment.

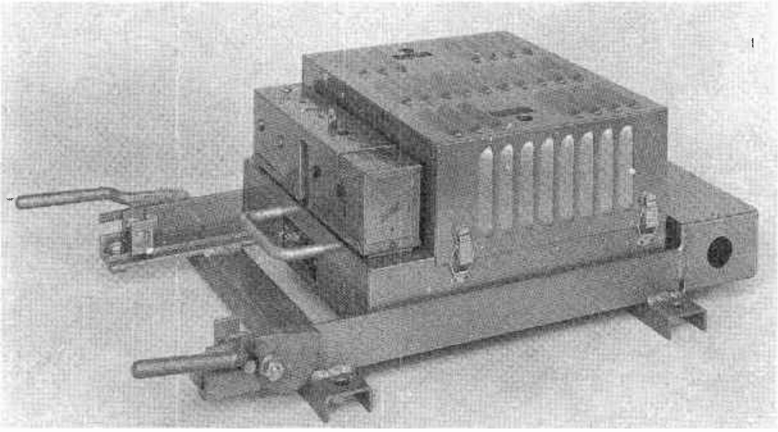


Fig. 8-39. Vibrator-type DC-to-AC converter for railroads. (Courtesy of Cornell-Dubilier Electric Corp.)

BOATS

Small boats are customarily equipped with 12-volt storage batteries; they may or may not be equipped with charging generators. Larger vessels are equipped with 32- or 110-volt batteries and means for keeping them charged. Some boats have motor-generator sets that deliver AC.

Radio equipment designed for 12- or 32-volt DC operation may be powered directly from a battery of like voltage. When the sets are AC-operated, a DC-to-AC converter is required.

MISCELLANEOUS VEHICLES

Electrically propelled vehicles, such as fork lift trucks, are equipped with storage batteries of various voltages (in the vicinity of 32 volts). For radio equipment to be operated from such a source, an AC-to-DC converter is required, or the radio unit must have a power supply designed to accommodate this voltage.

In a Johnson & Johnson plant, Motorola provided 6-volt radio equipment powered by an auxiliary 6-volt storage battery instead of the propulsion battery. In other plants, DC-to-AC converters are used. Kaar took a unique approach. Their 12-volt IMP, which has been installed on numerous lift trucks, derives its power directly from the propulsion battery, through a dropping resistor. This is feasible because the IMP draws the same current whether transmitting or receiving. Fig. 8-40 shows a lift-truck installation of the Kaar IMP. The mobile radio unit (box from which the antenna protrudes) is operated from the 32-volt battery of the truck. The box behind the radio unit contains a ballast resistor, which drops the 32 volts to 12 volts. The radio unit consumes 48 watts, whether transmitting or receiving.

Fig. 8-40. Mobile radio installed on a fork lift truck. (Courtesy of Kaar Engineering Corp.)

DC POWER LINES

In some areas, DC is still the primary power source, particularly in office buildings. Since running-in an AC line can be costly, a DC-to-AC converter is required to operate radio equipment designed for AC. A vibrator may be used, or a transistor-type inverter if it can satisfy the load requirements.

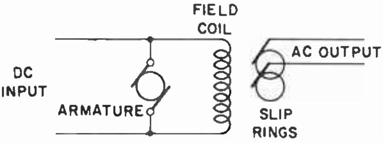


Fig. 8-41. Dual armature and common field of a rotary converter.

For continuous operation, motor generators or rotary converters are popular. In a rotary converter, a dual armature and a common field are used, as shown in Fig. 8-41. The DC input is applied through a commutator at one end of the armature, and AC is taken out through slip rings at the other end.

A motor generator is preferred over a rotary converter because two fields are provided, as shown in Fig. 8-42. R1 is adjusted to vary the speed of the motor and the frequency of the output voltage. R2 varies the AC output of the alternator.

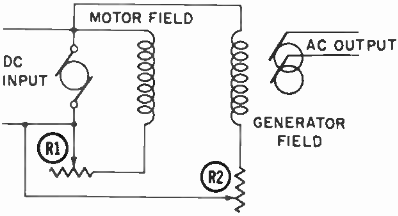


Fig. 8-42. DC-to-AC motor generator.

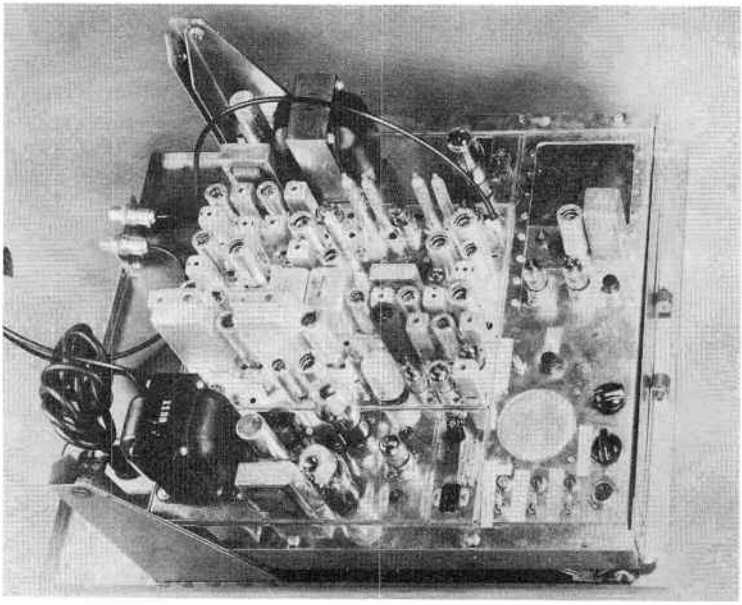


Fig. 8-43. The power supply may be an integral part of the equipment. (Courtesy of Kaar Engineering Corp.)

Automatic speed (frequency) and voltage regulators are customarily employed. These regulators may be electromechanical, electronic, or magnetic. An electromechanical device known as a Lee regulator is often used to regulate the speed. A carbon pile regulator, a popular type of voltage regulator, is capable of maintaining ±2% voltage regulation, no load to full load. Magnetic amplifiers and electronic regulators can provide much tighter regulation, however.

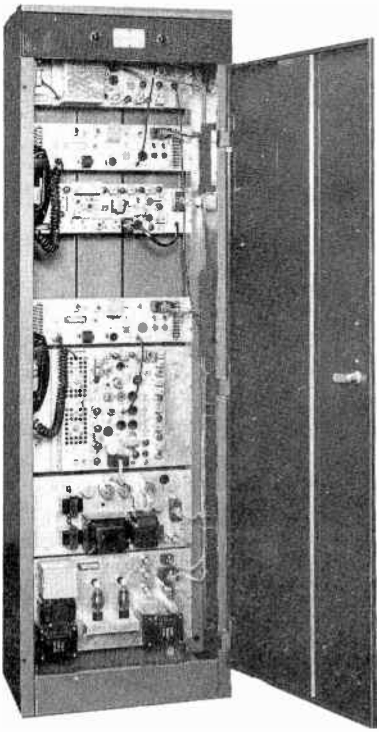


Fig. 8-44. Sometimes the power supply is a separate assembly.

AC POWER SUPPLIES

Base and fixed-station equipment is normally powered from a 115- or 220-volt, single-phase, 60-cycle power line. A transformer steps down the voltage to provide 6.3 or 12.6 volts AC for the tube filaments. The AC is stepped up and then rectified, to provide high DC voltages for the plate supply. The power supply may be an integral part of the equipment (Fig. 8-43) or a separate assembly (Fig. 8-44). In Fig. 8-43, the power supply of this UHF relay unit is at the bottom (power transformer at the left). Thyratrons, employed as rectifiers, are keyed by pulses to turn the transmitter on and off in response to an intercepted radio signal.

There are two AC power supplies in the base-station assembly in Fig. 8-44. The high-voltage transmitter power supply is at the bottom of the rack. Directly above it is the medium high-voltage power supply for the receiver and some of the transmitter stages.

Fig. 8-45 is a schematic of the AC power supply used with the RCA CSC-60 base-station units. High voltage for the transmitter is obtained from a full-wave rectifier employing two 5U4GB tubes. The tubes are paralleled so that failure of one tube will not shut down the transmitter. The high-voltage power supply normally is turned off. Actuating the push-to-talk switch operates relay M1. The contacts of M1 energize M2; its contacts open and close the AC input to the high-voltage power supply.

A capacitive input filter is used. Each filter capacitor (at both ends of the filter choke) consists of two electrolytic capacitors in series to provide increased protection against voltage breakdown. Each capacitor is shunted by a 120,000-ohm resistor which equalizes the voltage drop across each capacitor. In the "receive" position, transmit-receive re-

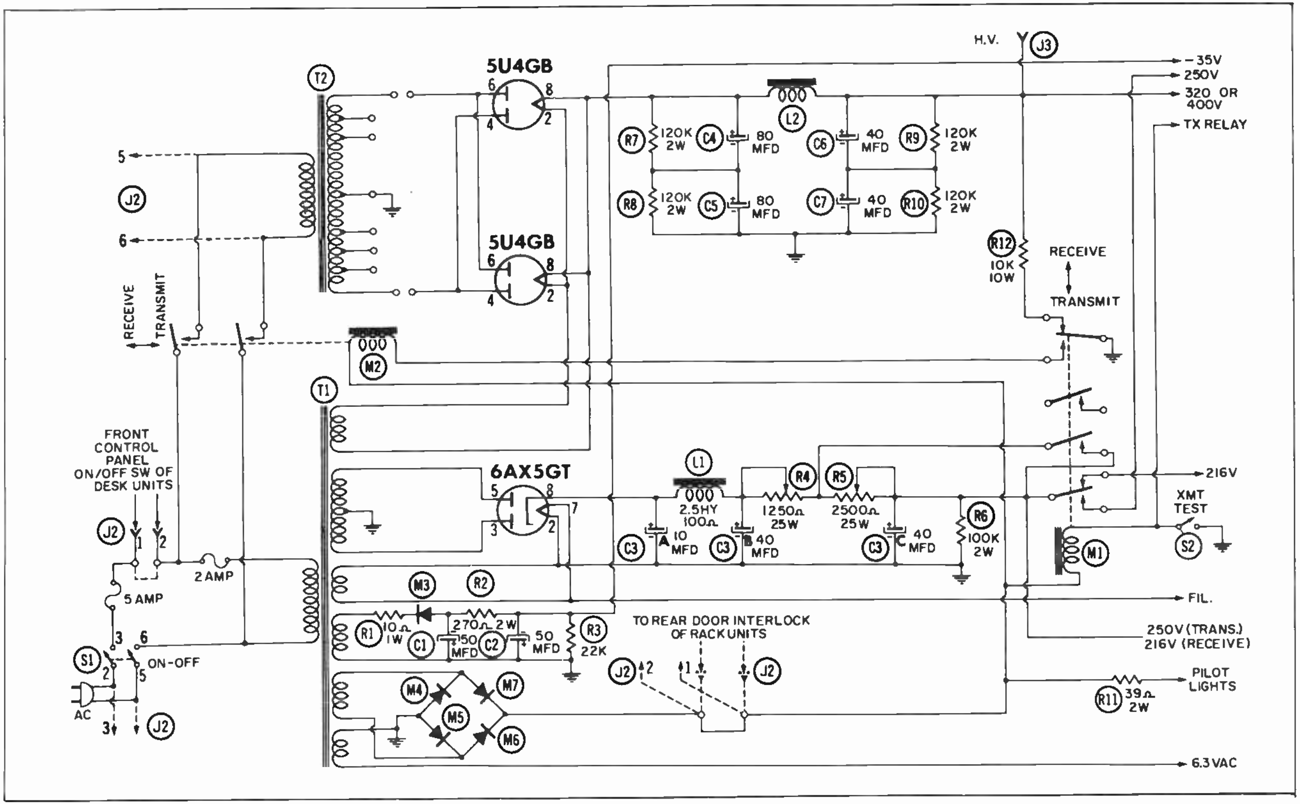


Fig. 8-45. AC power supply of the RCA CSC-60 base-station unit.

lay M1 places a 10,000-ohm resistor across the high-voltage output to bleed off the charge across the filter capacitors.

Taps on the high-voltage transformer secondary permit the high-voltage DC output to be adjusted to vary the transmitter power.

A single 6AX5-GT tube is used as a full-wave rectifier in the other plate-supply section, which furnishes 216 volts DC to the receiver and 250 volts DC to the transmitter. The output voltage is dropped by R5 during reception, and is shorted out by relay M1 during transmission.

A half-wave selenium rectifier, M3, provides DC transmitter-tube bias of −35 volts. A full-wave rectifier circuit, consisting of four selenium rectifiers, provides 12 volts DC for operation of the relays. Voltage for the "transmit" pilot lights is also obtained from this rectifier (after being dropped in level by series resistor R11). Terminals can be connected to an interlock system to prevent the transmitter from operating when the rear door of the equipment cabinet is opened.

HIGH-VOLTAGE POWER SUPPLIES

The high-voltage power supply used by Bendix for powering the final RF amplifier of a 250-watt transmitter is shown schematically in Fig. 8-46. Two 866A tubes deliver 2,000 volts DC from a center-tapped 4,800-volt power transformer.

Input from the power line is controlled by relay M1, which is actuated by the push-to-talk circuit. Relay M2 automatically opens the power-input circuit in case of overload. Excessive current causes M2 to pull in its armature; this closes its contacts, energizing relay M3. M3 opens the circuit leading to relay

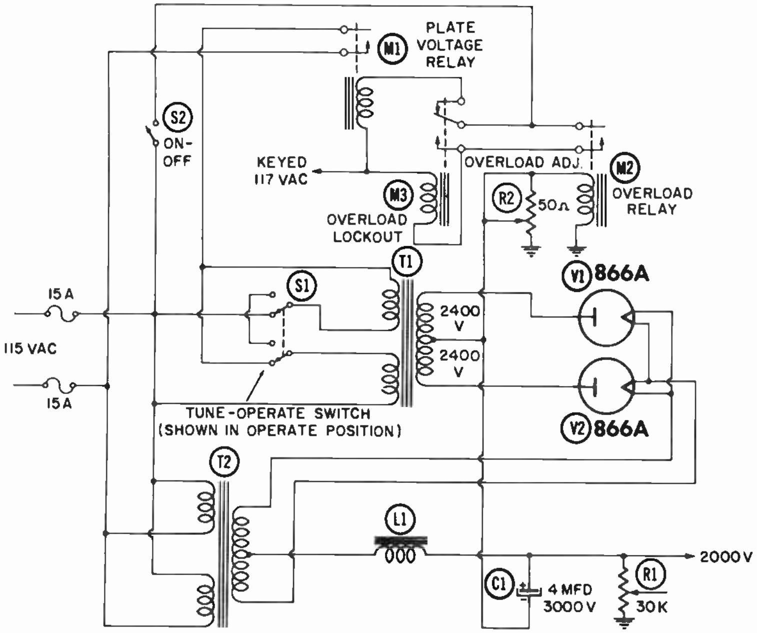


Fig. 8-46. High-voltage power supply of a Bendix 250-watt transmitter.

M1, which in turn drops out and cuts off the AC input to the power transformer. This, of course, allows M2 to drop out, releasing M3. When the push-to-talk circuit is again closed, the power supply will turn on. But if an overload still exists, M2 and M3 will pull in, and M1 will drop out. Thus, the overload protector is automatically reset. M2 permits the overload tripping point to be adjusted.

Switch S1 connects the two transformer primaries in series to reduce the plate voltage when the transmitter is tuned, and in parallel when the transmitter is operated.

SELENIUM RECTIFIERS

Selenium rectifiers are used in the General Electric Model 4EP4A3 transmitter power supply. As shown in Fig. 8-47, a full-wave bridge selenium rectifier (M3-M6) is fed from the secondary of transformer T2 at 350, 375, or 545 volts (depending upon the tap selection), to provide high-voltage DC for the final RF amplifier of the transmitter. Operation of the push-to-talk switch actuates relay M1, which turns on the AC input to T2.

Plate voltage for the receiver (250 volts) and for the oscillator and multiplier stages of the transmitter is provided by another full-wave bridge selenium rectifier (M8-M11). A third full-wave bridge selenium rectifier (M12-M15) provides low-voltage DC for operation of the relays. Transmitter bias is obtained from half-wave rectifier M7. Primary AC input is fused, and power-amplifier plate supply is protected by a ½-amp fuse in the B+ leg.

AC POWER LINES

The most common source of power for operation of base and fixed-station equipment is single-phase, 60-cycle AC, which is provided by utility companies at a typical level of 115 volts. The line voltage may vary from 105-130 volts, depending upon the area and the time of day. Large transmitters may require 220 volts AC.

In a three-wire, 220-volt system, the center wire is grounded, and half the full voltage is obtained between either outside wire and the center (neutral) wire.

It is important to maintain a constant line voltage because a low line voltage reduces the transmitter power output and receiver sensitivity, and a high line voltage reduces tube life. Tube filament voltages should be maintained at ±5% of their ratings.

If the radio equipment is designed so that 6.3 volts are applied to the filaments when the line voltage is 117 volts (the most common design center), the filament voltage will be 6.05 volts when the line voltage is 115 volts. When the line voltage drops to 110 volts, the filament voltage will be only 5.82 volts. If the line voltage rises to 130 volts, the filaments will have 6.81 volts applied—far more than the 5% tolerance.

A resistor should not be used to reduce the line voltage, because the voltage applied to the equipment will change when the load is varied. For instance, if a 5-ohm resistor is connected in series with the AC input to drop the line voltage by 5 volts to a receiver drawing 115 watts, the voltage will drop about 14 volts when the transmitter, rated at 345 watts input, is turned on.

Where the line voltage is constant but is too high or too low, an autotransformer can be installed to raise or lower it. On the other hand, where the line voltage varies widely, a voltage regulator should be in-

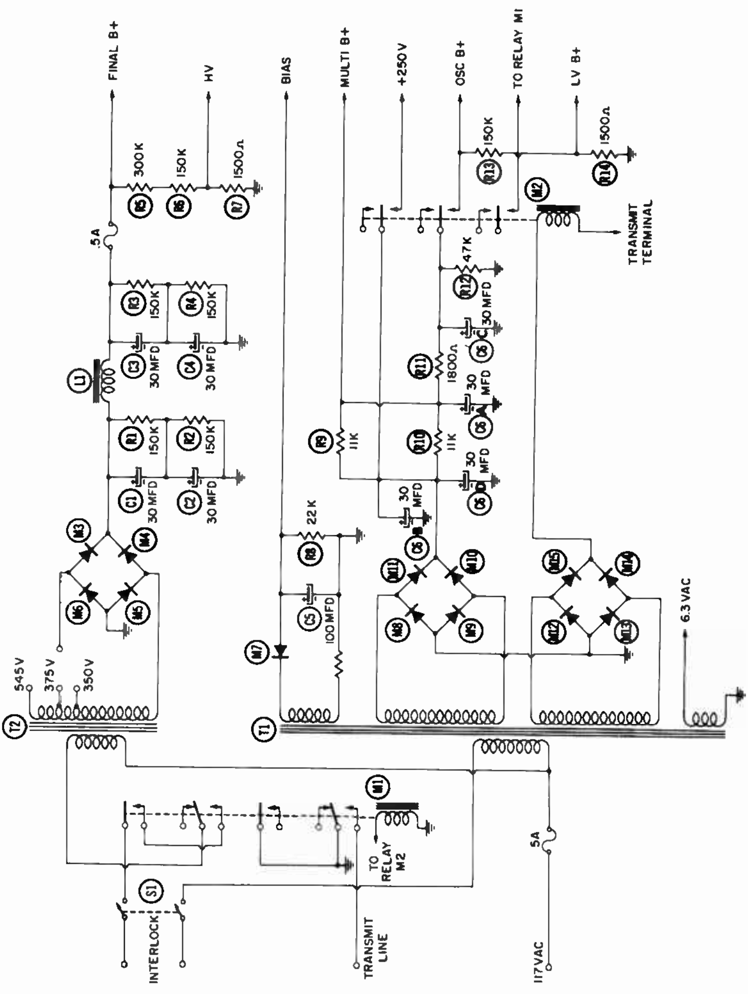


Fig. 8-47. Transmitter power supply of the General Electric Model 4EP4A3.

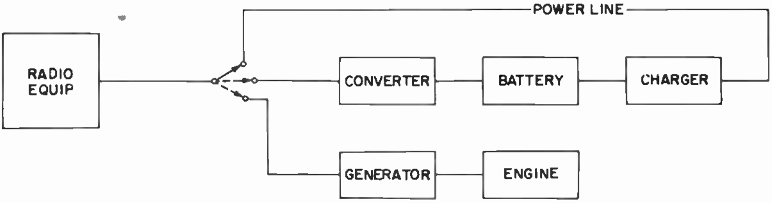


Fig 8-48. A converter is the power source during the interval before the generator starts.

stalled between the line and the radio equipment. There are several types available which will hold the line voltage constant in spite of line and load variations.

Above all, suitable outlets and wiring should be available for powering the radio equipment. Extension cords should not be used. Instead, outlets should be provided near the equipment. They should be connected directly to the power-distribution fuse box, not across a branch circuit used for other purposes. This will assure better voltage regulation and less noise.

STANDBY POWER

In many applications, interruptions to radio communications cannot be tolerated. Therefore, standby electrical power must be available, to take over if the regular power fails.

Most commonly used for this purpose is a gasoline-engine generator. Some must be started manually. Others have automatic starting and transfer equipment. In case of power-line failure, the generator starts up automatically, and the input of the radio equipment is transferred from the power line to the generator. After the utility power is restored, the engine turns off, and the radio equipment is reconnected to the line.

If the equipment cannot be allowed to go off during even the short time required for the standby

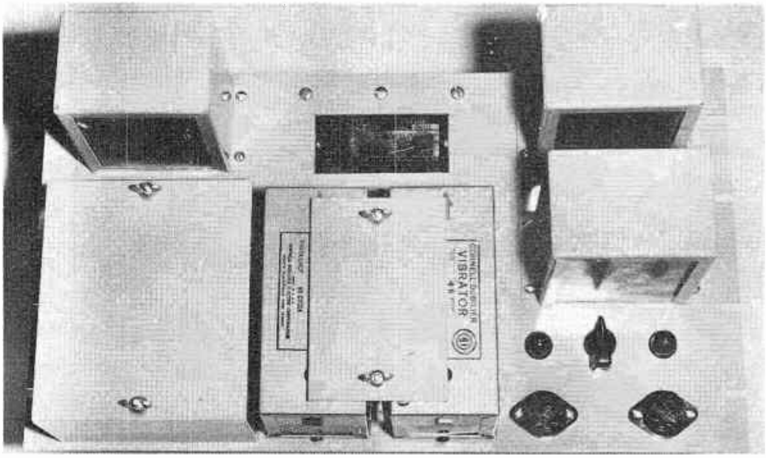


Fig. 8-49. Standby vibrator power supply. (Courtesy of Cornell-Dubilier Electric Corp.)

generator to start, other means must be provided. Fig. 8-48 shows such a setup. Power is ordinarily obtained from the line. In case of power failure, the equipment is fed from an instant-starting DC-to-AC converter (See Fig. 8-49), which is powered by a storage battery. When the engine-driven generator reaches operating speed, the converter shuts off, and the generator provides AC to the radio equipment. The standby vibrator power supply in Fig. 8-49 operates from a 48-volt battery bank. Note the two vibrators (lower center foreground). One is normally in use; the other is automatically switched into the circuit if the first one fails.

Although some delay does occur in this system, there is no break in power with a continuous-power generator system. As shown in Fig. 8-50, the radio equipment is powered at all times from an AC generator. This generator is driven by an AC motor fed from the power line. Coupled to the AC motor and generator is a DC motor.

When the utility power fails, relay M1 drops out, connecting the DC motor to the battery. Since the motor is already rotating, it requires no time to start. The transfer from AC to DC input is almost instantaneous; so the AC generator continues to run at full speed, unaware of any power failure.

Although not shown in the diagram, a magnetic amplifier closely regulates the output voltage of the AC generator. A regulator keeps the speed of the DC motor steady, so that the AC generator output will remain constant at 60 cps. The diagram shows a separate battery charger. However, the DC motor can be used as a battery charging generator under normal conditions, and converted to function as a motor if the line power fails.

Radio equipment designed for 12-volt DC operation can be used where utility power is unreliable. As shown in Fig. 8-51, the power line feeds an automatic battery charger, the DC output of which feeds the radio equipment and charges the

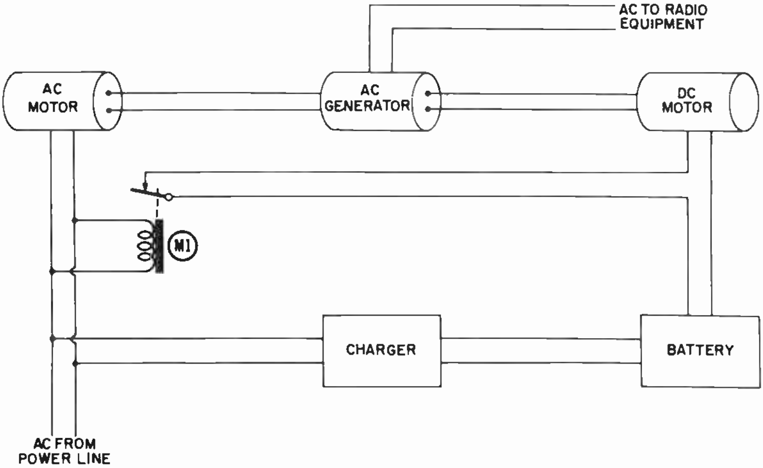


Fig. 8-50. Continuous-power generator.

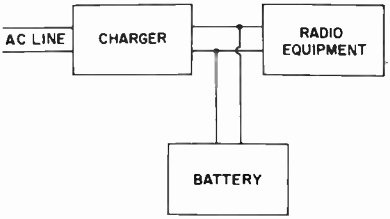


Fig. 8-51. Power system for areas where power is unreliable.

battery. If the power fails, the battery automatically takes over the load and serves as the power source until the power is restored or the battery becomes discharged.

Now that transistor power supplies are available, this scheme is more practical than when vibrators had to be depended upon. At isolated locations, the use of nickel-cadmium batteries circumvents lead-acid battery problems caused by low temperatures.

As the transistor art develops, the power requirements of radio equipment become lower and lower. In the near future, full reliance upon batteries as a primary power source appears to be a distinct possibility.

CHAPTER

9

Servicing

SERVICING mobile radio equipment—like any other radio equipment—can be divided into preventive maintenance, field servicing, and shop servicing. In the following, we will examine troubles that can be cured by each of these methods.

INOPERATIVE SET

If the mobile radio does not function at all, the trouble may be a blown fuse or defective wiring. Ordinarily, a lamp on the control head glows whenever the set is turned on. Another lamp glows whenever the transmitter is actuated by operation of the press-to-talk button on the microphone.

If the "Power On" lamp does not glow, either there is no power or the lamp is burned out. Lack of power indicates a broken connection, a blown fuse, or a dead battery. If the vehicle motor can be started, the battery obviously is not the cause of the trouble. The next step is to check the fuse. This is done by visual inspection (if it is a glass-enclosed fuse), or by momentarily shorting out the fuse with a screwdriver (radio equipment switch turned on). If sparking occurs when the fuse is shorted, the fuse is blown.

But don't continue to short out the fuse! Instead, install a new one. If it blows, take the vehicle to the shop. The fuse will not blow if the equipment and the associated cables are in satisfactory condition. Should the "Power On" lamp glow, but the radio remains inoperative, the next step is to advance the squelch control to the fully unsquelched setting. If no noise is heard from the speaker, it, the receiver, or the speaker connections may be out of order.

ANTENNA TROUBLES

Noise, but no or very weak signals, indicates trouble in the antenna system. Noise will ordinarily be heard, even with the antenna disconnected and the squelch set in the unsquelched position, because background noise in a sensitive receiver is generated within the set itself. This noise diminishes or disappears when a signal is received.

Antenna troubles could consist of a broken connection, a short between the inner conductor and shield braid in the coaxial cable, or excessive cable losses, which occur when the inner insulation (dielectric) has absorbed an excessive amount of moisture. The antenna can be checked out quickly. A 12-volt lamp or pilot light, a socket for the lamp, a battery clip, a small alligator clip, and two lengths of wire will form a simple test set, as shown in Fig. 9-1. When the battery clip is connected to the "hot" (ungrounded) battery terminal, and the alligator clip is connected to the metal shell of the antenna plug at the set end of the coaxial cable, the lamp should light. (Disconnect antenna plug from set first.) If the lamp does not light, the shield braid of the cable may not be properly contacting the plug shell or the point at the antenna end to the car body.

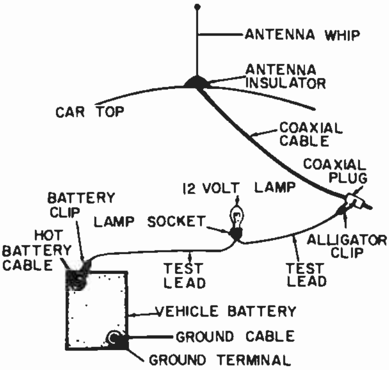


Fig. 9-1. Using a lamp to test for opens and shorts in the antenna system.

To determine that the center conductor of the coaxial cable is not open and is actually contacting the vertical antenna radiator, connect the test lead (with the small alligator clip) to the antenna whip. The lamp should not light. If it does, there is a short in the cable or plug, or at the antenna. Now short the center pin of the antenna plug to the shell with a screwdriver blade. The lamp should light. If it doesn't, the center conductor of the cable is open, or there is an open connection at the plug or at the base of the antenna.

A test made with a field-strength meter is more conclusive. When connected to a short piece of wire which serves as a pickup antenna, the meter should indicate current flow when placed within a few feet of the radio antenna (transmitter turned on). If the test is negative, chances are the transmitter is inoperative or the antenna system is defective.

Incidentally, a person does not need a commercial radio operator's license to check and repair the receiver section of a mobile unit. Nevertheless, most commercial equipment is equipped with a lock to discourage tampering. (See Fig. 9-11.) Unauthorized persons should respect the lock because it is possible to misadjust the equipment so that it will transmit illegally.

DEFECTIVE TUBES

An unlicensed person can legally remove and replace the tubes in the set. However, if the transmitter should then operate in an unlawful manner, he and the licensed operator in charge of the system can both be held responsible.

In the absence of a tube tester, a burned-out tube can be identified by touching each tube. If the set has been turned on for several minutes, all operative tubes should feel warm. A tube that does not appear to be lit should be suspected of being burned out. However, some tubes glow very dimly; furthermore, the coating on the glass envelope may make it difficult to determine whether the tube is lit or not, especially in bright sunlight.

Although new tubes can be substituted one at a time to find an inoperative one, this practice is not recommended. The interelectrode capacitance of each tube varies slightly. This can affect the tuning when a replacement tube is plugged into a critical circuit. The equipment is tuned at the factory to provide optimum performance from the original tubes. Therefore, the associated tuning controls must be readjusted to compensate for this difference in interelectrode capacitance between new and old tubes.

In an emergency, of course, one or more tubes can be replaced until the set can be serviced.

VIBRATOR

Since the vibrator is a mechanical device, its contacts may fail and moving parts may become fatigued. For this reason, it has a limited life. Fig. 9-2 shows where the vibrator is usually located. Although anyone can replace it, a new vibrator can be quickly damaged if defective equipment is causing excessively high current to flow through it. If a new vibrator does not restore performance, some other part or parts within the set are to blame.

TEST EQUIPMENT

For field service, the standard test equipment found in any shop is required. A volt-ohm-milliammeter is a necessity. A test meter designed to work with the make and model of the set to be serviced should also be available. Some test meters, like the one in Fig. 9-3, can be adapted to several makes and models.

In addition, a field-strength meter should be available for checking transmitters. A battery-operated signal generator will be useful for checking the receiver. An AC-operated signal generator can be used when there is utility power, or when a DC-to-AC converter is available to permit operation from a vehicle battery.

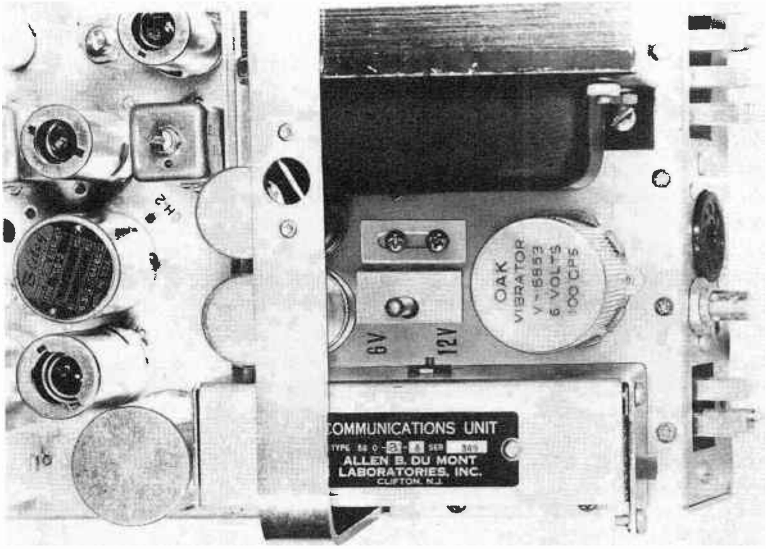


Fig. 9-2. The vibrator is usually near the power transformer. (Courtesy of Allen B. DuMont Laboratories, Inc.)

A battery-operated military surplus BC-221-AK frequency meter can also be used for determining that the transmitter oscillator and frequency-multiplier stages below 20 mc are working. The instrument will also measure the frequency of these stages. Unfortunately, its upper frequency limit of 20 mc restricts its usefulness for servicing VHF and UHF radiotelephones. In addition to acting as a signal detector and frequency meter, the BC-221-AK is also useful as an accurately calibrated signal generator. Some types emit a CW (unmodulated) signal; others, a tone-modulated AM signal.

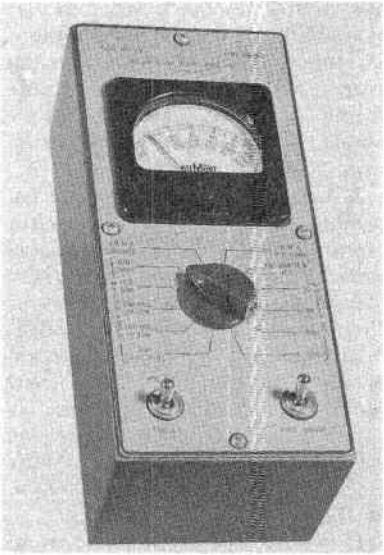


Fig. 9-3. Test meter for mobile radio servicing. (Courtesy of Allen B. DuMont Laboratories, Inc.)

Platt Electronics Corporation, one of the firms selling surplus BC-221-AK units, has introduced a modified version (Fig. 9-4) incorporating an electronic-eye tuning indicator for visual zero-beat indication.

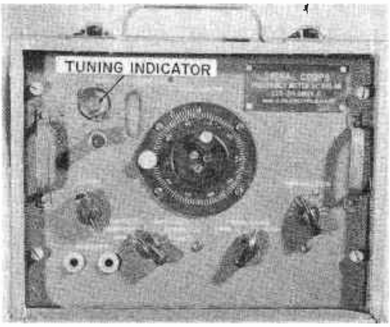


Fig. 9-4. Modified BC-221-AK frequency meter with tuning eye (upper left, above Gain control). (Courtesy of Platt Electronics Corporation.)

Another frequency meter, the D-W-E Model 1021, looks like the BC-221. It can be used as both a signal generator and a frequency meter in the field, since it operates from self-contained batteries. The Model 1021 will measure frequencies between 125 kc and 1,000 mc, to an accuracy of ±0.005% at room temperatures. It will also deliver an RF signal of 100 microvolts or more into a 50-ohm load between 125-250 kc, 2.5-5 mc, and 65-130 mc, or at least 50 microvolts at any frequency between 125 kc and 1,000 mc. The output signal can be amplitude-modulated by an internal 900-cycle oscillator.

In the absence of a portable signal generator or power to operate one, an off-the-air signal will have to be relied upon as the signal source. If a battery-operated VTVM or a suitable test meter is used, the limiter voltage (or AVC voltage in AM sets) can be monitored while new tubes are being tried, to determine which, if any, need replacement.

A field test instrument is easy to build. Fig. 9-5 is a suggested schematic of a grid-dip meter which can serve as a signal generator, frequency meter, and signal monitor. The Colpitts oscillator circuit is tuned by a two-gang midget variable capacitor shunted across coil L. The size of L and C1A-C1B depends upon the frequencies to be covered. The meter is a DC microammeter.

When the coil is held near a tuned circuit of one of the transmitter stages (transmitter turned off), the grid current will dip, as indicated by the meter when it is tuned to the resonant frequency of the circuit being tested. With the instrument several feet from the transmitter and a pair of headphones plugged into the phone jack, a beat note will be heard when the device is tuned past the signal being emitted by the transmitter. When tuned exactly to the transmitter frequency, the beat note will disappear, but will be heard again as the tuning dial is turned in either direction from zero beat.

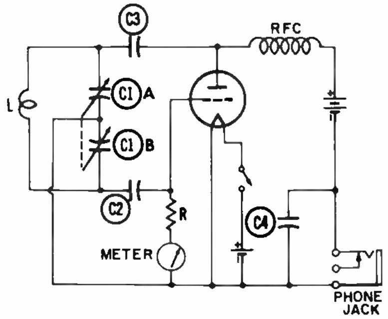


Fig. 9-5. Simple grid-dip meter is a signal generator, frequency meter, and signal monitor.

This instrument will roughly measure transmitter frequency if the tuning dial is calibrated. This measurement is not accurate enough to meet FCC requirements. However, it will indicate whether the transmitter is functioning, and will give an approximate operating frequency.

Since the circuit is an oscillator, it can also be used as a signal generator for checking receivers. The strength of the signal is varied by moving the device nearer to or farther from the receiver.

INOPERATIVE RECEIVER

If the receiver is dead, the obvious points to check first are (1) availability of power, (2) vibrator, (3) tubes, (4) crystal, (5) antenna system, and (6) control system, consisting of cables, speaker, microphone, volume and squelch controls, and On-Off switch.

A blown fuse indicates internal trouble, such as a shorted capacitor or stuck vibrator. If the fuse blows with the vibrator removed, there may be a short in the input power circuits, which include the wiring, relays, and input-voltage bypass capacitors. If the fuse blows only when the vibrator is in place, try a new fuse again, but remove the rectifier tube if there is one. Many receivers use selenium, germanium, or silicon rectifiers.)

If the fuse blows with the vibrator in place and the rectifier tube out of the set, the trouble is apparently due to (1) a blown buffer capacitor across the high-voltage winding of the power transformer, or (2) a defective power transformer.

With both the vibrator and the rectifier in place, blowing of fuses indicates (1) a short or overload in the receiver circuits, (2) a shorted tube, or (3) a shorted capacitor. If it is (3), the radio should be taken to the shop.

When the squelch is set to the fully unsquelched position, noise should be heard from the speaker, even with the antenna disconnected. If no sound is heard, a defective tube could be the reason. New tubes can be tried, one at a time, until the trouble is corrected. At this time, the background noise should burst through the speaker.

A defective receiver crystal can disable the receiver, of course. If available, spares ground to the right frequencies can be tried. Any defects beyond tubes and crystals indicate shop repairs.

If background noise is heard, but voice signals are not coming through or are deep in the noise, the trouble may be in the antenna system. In the case of a 152-174 mc band receiver, an 18-inch piece of wire can be jammed into the center contact of the antenna receptacle to serve as a makeshift antenna. For 450-470 mc sets, use a 6-inch wire; and for 25-54 mc band sets, an 8- to 9-inch wire stretched out. If voice signals are now heard, the trouble obviously is in the antenna system.

With a low-range ohmmeter, check for a short by measuring the resistance between the outer pin and the shell of the coaxial connector at the set end of the antenna cable. This should check "open" unless an antenna with a shorted matching stub is used. A short should be indicated when the ohmmeter leads are connected to the body of the vehicle and the shell of the coaxial connector. The same is true when the leads are connected to the antenna whip and the center pin of the coaxial connector.

INOPERATIVE TRANSMITTER

A dead transmitter can be caused by lack of power, even if the receiver is working. When the press-to-talk button on the microphone is pressed, the "Transmitter On" pilot lamp should glow and one or more relays should operate. As the button is pushed in and out, the relays should click. If they don't, the trouble could be in the press-to-talk switch or the microphone cord.

If the transmitter has a separate vibrator, a new one should be tried; or, if a dynamotor furnishes the transmitter plate voltage, it should run when the press-to-talk button is operated. If it doesn't, the trouble could be in the relay through which the input power is applied, or in the dynamotor itself. (See Fig. 9-6.) If the dynamotor runs, measure the transmitter plate voltage with a DC voltmeter at the dynamotor output terminals, a metering tip jack, or a metering socket. When the battery polarity is reversed, the polarity of the dynamotor output voltage will also be reversed, as evidenced by a negative instead of positive transmitter plate voltage. Needless to say, the dynamotor won't work this way.

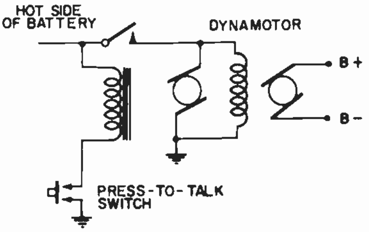


Fig. 9-6. A relay controls the dynamotor input.

When a suitable test meter is used, grid drive current should be noted at all stages (except the oscillator, of course). If none exists at the first multiplier stage and the plate voltage is normal, the trouble is in the oscillator. In FM transmitters it could be in the phase modulator, which is usually between the oscillator and the first doubler.

New tubes should be tried in the oscillator and phase-modulator stages. If operation is still not restored, the crystal could be at fault. In multichannel transmitters, the trouble can be localized to a particular crystal or oscillator by trying the other channels. The defect could be in the frequency-selector circuit which, if open, could disable one or all oscillators. (See Fig. 9-7.)

Grid drive on the first multiplier stage, but none on a succeeding stage, indicates trouble in the driven stage or the one preceding it. Substitution of new types is suggested.

If all stages from the first multiplier to the final amplifier have grid drive and the final RF amplifier draws plate current, tuning of the plate circuit of the final amplifier should produce a dip at the resonant point and an increase in current as the antenna trimmer is adjusted. Improper reaction to tuning of the final amplifier plate and antenna circuits suggests antenna system troubles. Since the antenna relay is part of the antenna system, contact troubles here could prevent proper operation.

With a dummy load (see Fig. 9-8) or RF wattmeter of the termination type connected to the antenna receptacle, the final amplifier and antenna circuits should tune up properly. If not, the trouble may be in the antenna relay or transmitter.

If the antenna is connected, but the transmitter output won't tune up properly, chances are the antenna system is at fault. Even if the antenna checks out with an ohmmeter, as explained earlier, the coaxial cable may have a leaky insulation. In that event, the only cure is to replace the cable. The antenna whip should be examined for any obvious defects. The insulator that isolates the antenna whip from the vehicle body or bumper may have become encrusted with foreign matter, which can cause excessive leakage. Of course, the antenna whip won't load properly if it is too long or too short for the operating frequency.

The radiating ability of the antenna can be checked by placing the field-strength meter a few feet from the vehicle. The meter reading should be checked at various distances and in two or more directions while the transmitter is on.

If any repairs or tuning adjustments are made which could affect the frequency of transmission or widen its modulation deviation (FM), the transmitter frequency and modulation deviation should be

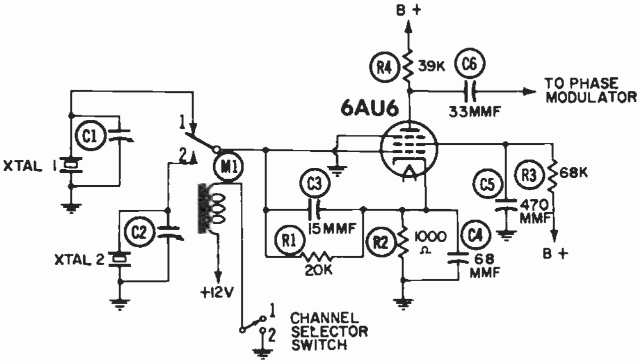


Fig. 9-7. Two-frequency oscillator. A relay selects either channel.

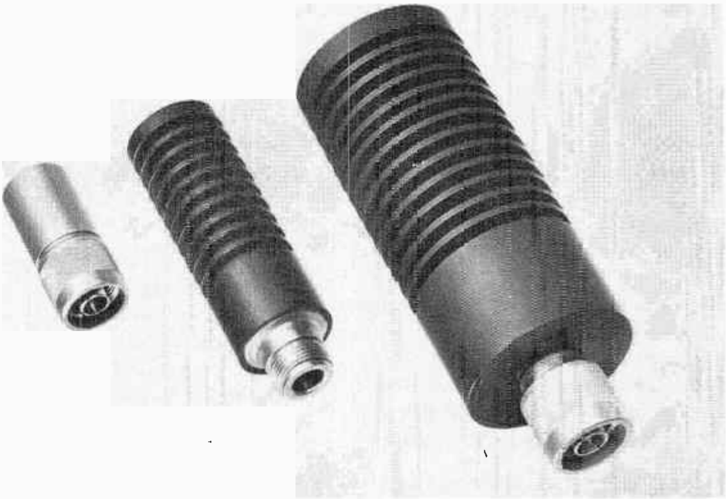


Fig. 9-8. Dummy antenna loads, by simulating an actual antenna system, dissipate the power produced by the transmitter. (Courtesy of Sierra Electronic Corp.)

measured at once—or at the earliest date, if it cannot be done on the spot.

FIELD SERVICING OF BASE STATION

If spares are available, the transmitter and receiver at a base, fixed, or relay station should be replaced while the original equipment is being serviced. Of course, some emergency repairs can be made without replacement of the original equipment. When spares are not available, repairs will have to be made at the station site, unless the owners are willing to shut down the station while the equipment is taken to the shop.

If neither the transmitter nor the receiver is operative, the obvious points to check first are (1) availability of power, (2) antenna system, (3) control system, and (4) all equipment common to both the transmitter and receiver.

If power is available but none is reaching the equipment, a fuse could be blown, or there may be trouble in the power-input circuits. When a new fuse blows, the receiver rectifier tube (if one is used) should be removed and a new fuse tried. If the fuse blows again, suspect the power transformer in the receiver power supply. If the fuse blows only with the rectifier tube in place, a shorted tube in the receiver could be the trouble, but more likely it is a shorted capacitor.

An inoperative receiver, but one with power reaching it, indicates tube, crystal, or component failure. When the receiver is unsquelched, noise should be heard from the speaker with the antenna connected or disconnected. If noise is heard, but voice signals are absent or very weak, a piece of wire may be connected (6-inch for 450-470 mc band, 18-inch for 152-174 mc band, and 8- to 9-foot for 25-50 mc band) to the center pin of the antenna receptacle. If signals are now heard, the antenna system is probably faulty.

To check the antenna relay, temporarily connect the antenna cable to the receiver antenna connector (if there is a separate one). If the receiver works now, the relay is at fault.

Since AC power is generally available at base stations, a tube tester can be used for checking tubes on the job. Signal generators, oscilloscopes, frequency meters, modulation meters, and other test equipment can also be used at base-station sites, permitting the following maintenance procedures to be employed.

PREVENTIVE MAINTENANCE

Although some mobile-system operators believe in leaving their equipment alone until it fails, most of them believe in the old adage that "an ounce of prevention is worth a pound of cure." A preventive-maintenance program is only as effective as its application. It should consist of clearly defined procedures, repeated at regular intervals.

The FCC requires that the frequencies, degree of modulation, and power input to the final-amplifier stage of all transmitters be measured and the findings recorded in the station's log at regular intervals, not to exceed six months. This is a bare necessity, to meet legal requirements in order to avoid suspension of a station license, or punishment. The equipment deserves more.

Even though the FCC is not concerned with receivers, the owner is, or should be.

Mobile Units

The vehicle in which a mobile radiotelephone is installed is part of a mobile station. The body of the vehicle is part of the antenna system. The battery, charging generator, and even the engine are part of the radio system, since they are necessary components of the electrical power source.

Therefore, one phase of a preventive-maintenance program is inspection of the vehicle. The procedures include:

1. Measure battery voltage with engine not running, but with receiver turned on.
2. Repeat Step 1 with transmitter operating.
3. Measure battery voltage with engine running fast enough to charge the battery.
4. Inspect radio power-input cable connections and fuse.
5. Inspect cable to control head.
6. Inspect speaker and its cable.
7. Inspect microphone, its cable, and connector plug.
8. Inspect antenna cable and connector.
9. Inspect antenna, particularly where it connects to coaxial cable and the bond to the car body or bumper.
10. Inspect distributor and spark-plug suppressors (if used), and bypass capacitors used for noise reduction.

If the battery voltage falls appreciably when the transmitter is operating (engine not running), the battery may be nearing the end of its life, or the charging system is not doing an adequate job. With the engine running at a fair clip, the voltage across a 6-volt battery should not exceed 7.2 volts (14.4 volts for a 12-volt battery). If higher, the life of the radio tubes and vibrators will be reduced.

Frayed cables should be repaired by taping over worn insulation. If too frayed, the cables should be replaced. If the microphone cable or the connections at the plug or at the other end are in poor shape, it is easier to replace the complete microphone assembly with a spare and make repairs later in the shop, where it is more convenient to do so.

If the antenna whip looks as if it has been exposed to the elements for too long, replace it. Remember that HF, VHF, and UHF signals travel on the surface of a conductor, not through the core. If the surface of the whip is coated with "gunk," or if it is corroded or rusted, it will be an inefficient radiator.

If the insulator at the base of the antenna whip is cracked, replace it. Or if it is coated with dirt, scrub it clean with a stiff brush and a good solvent. Too many watts and microvolts may be leaking off to ground.

Although it is the auto mechanic's job to keep a car running, it is the radio technician who is often blamed if dirty spark plugs or a noisy charging generator impairs the radio performance. It takes only a few minutes to wipe the dirt from the insulation of spark plugs. Should generator brushes or commutator need service, the owner should be so advised, since this is clearly beyond the duties of the radio technician.

After the vehicle itself and the radio antenna, cabling, and control devices have been checked out, attention should be devoted to the radio equipment. When spares are available, a freshly serviced communications unit (transmitter-receiver-power supply) should be installed and the original unit taken to a shop for routine preventive maintenance.

If this is not feasible, the vehicle should be driven to the shop, where the required equipment is available. The paces through which the radio equipment should be put include:

1. Clean chassis, using compressed air to remove accumulated dust.
2. Test tubes and replace those that do not meet standards.
3. Test vibrators. If in service more than three months, replace.
4. Retune transmitter.
5. Peak up receiver, antenna, and RF and mixer trimmers.
6. Measure the transmitter frequency.
7. Measure transmitter modulation.
8. Measure transmitter power input to the final RF stage.
9. Measure transmitter output with RF wattmeter.
10. Reconnect mobile unit to antenna, and tune transmitter for maximum output while watching indication on field-strength meter. Also repeak receiver antenna trimmers.

Base Station

Preventive maintenance at the base station must be performed at the site, since the set obviously cannot be readily moved to a shop. The transmitter and receiver chassis can be taken to the shop of course, if spares are available or standby equipment is provided.

The procedures involved in a preventive-maintenance program for a base station include the following:

1. Measure power-line voltage.
2. Start a standby power generator (if there is one). Check its output voltage under load, noting time required for standby power source to start and reach full operating level.

3. Check and clean contacts of automatic standby power control equipment.
4. Test all tubes in transmitter, receiver, and associated equipment, replacing those that do not meet prescribed standards.
5. Clean all chassis with bellows or compressed air.
6. Check and clean all relays.
7. Retune transmitter.
8. Measure transmitter power output with RF wattmeter.
9. Measure transmitter frequencies.
10. Measure transmitter modulation.
11. Realign receiver.
12. Measure receiver sensitivity.

If the base station is remote-controlled over a telephone line, the remote-control equipment and the termination equipment at the base-station site should be cleaned and checked out to determine that it functions correctly. All tubes should be tested and relay contacts cleaned.

When a radio link is used for remote control of a base station, Steps 1 through 12 should also be followed, since the radio link consists essentially of two fixed stations.

The antenna system seldom needs service, but should nevertheless be inspected. If a pressurized hollow-line transmission line is used, the pressure should be checked to determine whether there are any leaks. Solid dielectric line may absorb moisture and, in time, might require replacement. Even though the antenna is usually rather inaccessible, it nevertheless should be kept clean. When moisture-absorbent material accumulates on the surface of the antenna elements, some of the RF current might flow through this material, instead of along the surface of the antenna elements, resulting in lower efficiency. Even an antenna requires replacement after prolonged exposure to the elements.

If aircraft warning lights are installed on antenna towers, the control equipment, wiring, and lamps must be inspected, cleaned, and replaced when so indicated.

SHOP REQUIREMENTS

Adequate test equipment must be available before mobile equipment can be serviced. "Adequate" means a sufficient "quantity" as well as satisfactory "quality." It is also necessary that field conditions be simulated. (See Chapter 10.)

Power

Before AC-operated equipment can be serviced, it is obvious that 115-volt AC power must be provided. However, the line voltage may be higher or lower than 115 volts at some locations. To duplicate such high- or low-line voltage conditions, a *Variac* or Superior variable autotransformer will provide AC at any level between 0 and 130 watts.

Various DC voltages must also be available. In today's vehicles the power source is a 12-volt battery shunted by a charging generator; this voltage may vary between 11.6 and 14.5 volts. Older vehicles have 6-volt batteries, the voltage varying between 5.8 and 7.2 volts. Radio equipment on fork lift trucks operate from 24-, 32-, or 36-volt batteries. Railroad radio equipment on cabooses are powered by a 12- or 32-volt battery. Most diesel locomotives are equipped with 72-volt batteries, the voltage of which may exceed 80 volts at times.

If a shop's activities are confined to 6- and 12-volt sets, a pair of 6-volt storage batteries, plus a battery charger, will suffice. Fig. 9-9 shows how they are connected. If the two meters illustrated are provided, the technician will know what voltage is being applied, as well as how much current is being consumed. The ammeter can be a valuable indicator for diagnosing defects, since excessive current readings will warn of trouble in the equipment.

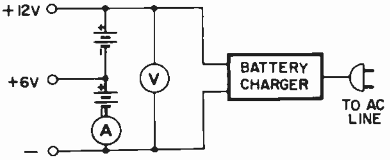


Fig. 9-9. This 6-12 volt shop power supply uses two 6-volt storage batteries.

The battery charger performs two functions: (1) It is used for recharging the battery. (2) When turned on with the radio equipment connected, it boosts the voltage to simulate conditions in a vehicle when the engine is running and the battery is down enough that it consumes charging current.

An adjustable rectifier power supply can be used instead. There are several available which can be adjusted to deliver any voltage between 0 and 15 volts or more. This makes it possible to simulate both low-battery and maladjusted voltage-regulator conditions, as well as normal conditions.

Special rectifier power supplies are available for checking railroad and fork-lift radio equipment. In more elaborately equipped shops, where several voltages are required at one or more test locations, a custom motor-generator set can be used. Bogue Electric Manufacturing Company, for instance, manufactures special motor-generator sets to order which can deliver 6, 12, 24, 32, and 64 volts DC, or almost any other combination. Magnetic amplifier regulators hold the voltages constant at whatever level the voltage control is set.

When low-voltage DC is distributed from a common source to two or more bench locations, fuses should be provided at each location, and the wiring should be heavy enough. The voltage drop can be considerable; so No. 4 or even heavier wire should be used. To minimize the voltage drop, use individual lines from the power source to the test locations, instead of bridging the outlets across a common line.

Shop Antenna

Although a vehicular antenna cannot be duplicated, a dummy load like one of the types shown in Fig. 9-8 can be used to simulate an antenna system. Some shops have rigged up indoor antennas consisting of a one-quarter wave vertical whip mounted in the center of a square sheet of wire mesh, as illustrated in Fig. 9-10. The wire mesh serves as a ground plane. The pilot lamp on the antenna whip indicates when a transmitter is putting out power into the antenna.

Test Jig

Suitable test jigs must be provided for testing base and mobile equipment in the shop. When the mobile unit has a built-in speaker, and front-panel volume and squelch controls (like the one in Fig. 9-11), all that are needed are a microphone equipped with a plug that matches the set, plus a power cable with a plug that matches the power receptacle on the unit.

However, in mobile units designed for use with a remote-control head (see Fig. 9-12), the head is not ordinarily removed from the ve-

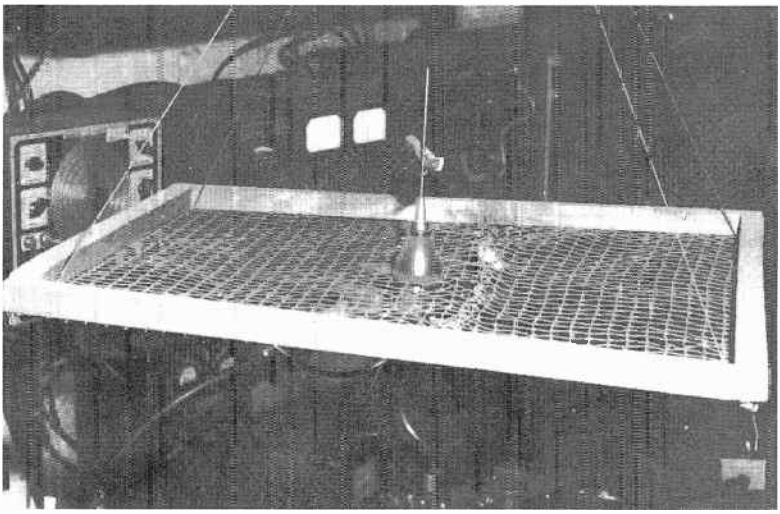


Fig. 9-10. Indoor test antenna.

hicle when the set is brought in for servicing. For this reason, a control head, microphone, speaker, and appropriate cables and plugs must be provided or duplicated at the shop.

Unfortunately, all control heads are not alike. Hence, a Motorola control head may not be suitable for use with a General Electric set. When several makes and models are to be serviced and it is not feasible

Fig. 9-11. A mobile unit with all controls on the front panel. (Courtesy of Motorola Communications and Electronics, Inc.)

to provide control heads for each, a universal test jig can be designed.

It is possible, however, to make one control head do for several makes and models. This is done by making up a patch panel which will permit the connections to be changed to meet the requirements of various sets.

TRANSMITTER MEASUREMENTS

The following are generally provided to enable voltage and current measurements when the transmitter is operating: tip jacks into which a DC milliammeter, microammeter, voltmeter, or VTVM can be connected to reach various circuit points; a multipole connector into which the plug of a special test set is inserted; or a phone jack into which a DC milliammeter or microammeter is connected and which is wired to a circuit-selecting switch.

Fig. 9-12. Control head and mike for remote control of a mobile unit. (Courtesy of Motorola Communications and Electronics, Incorporated.)

It is necessary to be able to observe variations in grid current in all stages except the oscillator, because the preceding stage is tuned; and in the plate (or cathode) current in the final RF amplifier stages, because its plate and antenna circuits are tuned. All stages except the final RF amplifier are ordinarily tuned for maximum grid current in the following stage. The plate circuit of the final RF amplifier is tuned for minimum (dip) plate (or cathode) current. Antenna circuit tuning increases the final RF-amplifier current.

The FCC requires that the power input to the final RF stage must be below the maximum value specified in the station license. Power input in watts is determined by multiplying the plate voltage by the plate current (amperes).

Some base-station transmitters are equipped with built-in meters to facilitate tuning and to provide continuous indication of transmitter performance. An external meter is required in all commercial mobile units and most base-station equipment.

Grid Drive

The grid current can be measured by inserting a DC milliammeter in series with grid leak R1, as shown in Fig. 9-13. When the signal from the preceding stage swings positive (making the grid positive with respect to the cathode), conduction occurs between the grid and cathode, and current flows through R1. Actually, the grid and cathode function as a diode.

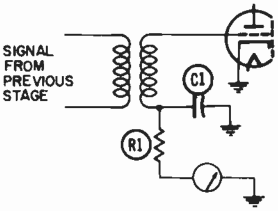


Fig. 9-13. Grid drive can be measured with a DC milliammeter in series with grid resistor.

If we look at the grid and cathode of the tube as a switch (S) in series with a resistor (R2), as shown in Fig. 9-14, the switch will be closed during the positive half cycle. A battery is shown as the signal source. Current obviously will flow through the circuit, and the meter will so indicate.

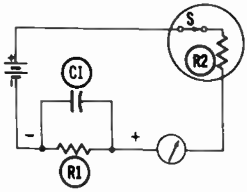


Fig. 9-14 Grid and cathode act as a closed switch when grid is positive with respect to the cathode.

A voltage will also be developed across R1, and capacitor C1 will be charged to the same potential as the drop across R1. When the input-signal cycle reverses, the tube no longer conducts because the grid is now negative with respect to the cathode. Thus, as shown in Fig. 9-15, S opens and current no longer flows through the loop. However, a small current will flow through R1 and C1 discharges through it. C1 will not discharge completely, however, because the cycle will reverse before that can happen.

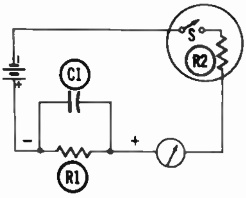


Fig. 9-15. Grid and cathode act as an open switch when the grid is negative with respect to the cathode.

When the grid again swings positive, the negative DC voltage across C1 now opposes the positive signal voltage, since the voltages are in series and of opposite polarities. Grid current flows only when the positive signal voltage exceeds the bias voltage across C1. On negative swings, this bias voltage is added to the negative signal voltage, since they are in series and of like polarity.

Grid current can also be measured by connecting a voltmeter across the grid resistor. Fig. 9-16 is a simplified schematic of a tripler stage having cathode as well as grid-leak bias. A tip jack is provided for measuring the grid drive in terms of voltage drop across a small part of the total grid-circuit resistance. Under typical operating conditions, a reading of 0.7 volt will be obtained with a 20,000-ohm-per-volt DC voltmeter set on the 0-3 volt scale, when the meter is connected across R2 (TP and ground).

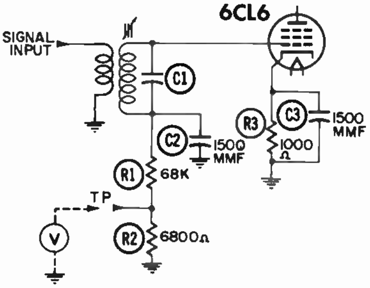


Fig. 9-16. Tripler stage provided with a tip jack for measuring grid drive.

A VTVM, if used to measure the voltage across R2, would indicate a slightly higher voltage because it would have less shunting effect on R2. The voltage across R1 and R2 is about 8.6 volts which, when added to the voltage drop across cathode resistor R3, is the actual bias voltage.

In some transmitters the circuit is slightly different (Fig. 9-17), but the net result is the same. During the positive half cycle, the grid is positive with respect to the cathode, and current flows through R.

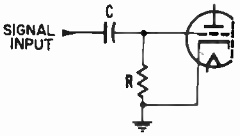
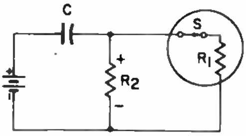
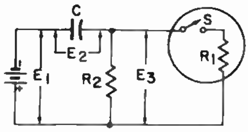


Fig. 9-17. Another form of grid circuit.

As shown in Fig. 9-18A, the tube looks like an electronic switch. During the positive half cycle of the input signal, current flows through capacitor C until it is charged. During the negative swing (Fig. 9-18B), grid voltage E3 is equal to the negative value of input signal E1 plus voltage E2 stored in capacitor C. The grid-to-cathode circuit is open, since the grid is more negative than the cathode.



(A) When grid is positive.



(B) When grid is negative.

Fig. 9-18. Action of circuit in Fig. 9-17.

Plate Current

The FCC is interested in the power input to the final RF-amplifier stage of a transmitter. The power input in watts is equal to the plate voltage times the plate current (in amperes). Plate voltage is measured with a DC voltmeter, a DC microammeter with a series resistance which converts it into a voltmeter, or a DC VTVM.

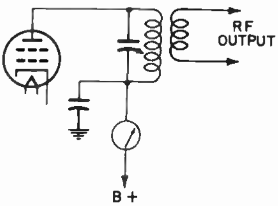


Fig. 9-19. Plate current can be measured by inserting a DC milliammeter in the plate-supply line.

Plate current is measured by inserting a DC milliammeter in series with the B+ lead, shown in Fig. 9-19. If three test jackets are provided, the plate current can be determined by measuring the voltage drop across TP1 and TP2 (Fig. 9-20), and dividing by R in ohms. The plate voltage is measured across TP2 and TP3.

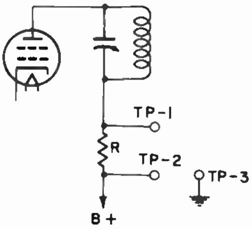


Fig. 9-20. Voltage drop between TP1 and TP2, divided by R, equals plate current.

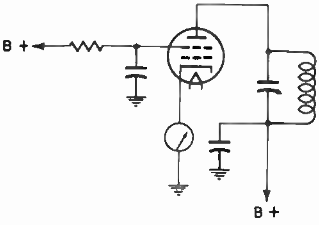


Fig. 9-21. Milliammeter in series with cathode will indicate combined plate and screen current.

Inserting a DC milliammeter in series with the cathode (Fig. 9-21), or measuring the voltage drop across a resistor in series with the cathode (Fig. 9-22), will also give the current. A 20,000-ohm-per-volt meter set on the 0-3 volt scale will normally indicate 1.3 volts in the transmitter where this circuit is used. The current is 130 ma, since:

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

$$= \frac{1.3}{10}$$

$$= 0.13 \text{ ampere.}$$

Input Power

The true input power is arrived at by deducting the screen current from the cathode current. The screen current is determined by measuring the voltage drop across screen voltage dropping resistors R2 and R3 (as shown in Fig. 9-22), and dividing this voltage by the total resistance ($I = \frac{E}{R}$). If the total resistance is 20,000 ohms (R3 set at 13,200 ohms), and the voltage across it is 300 volts, the screen current will be 15 ma.

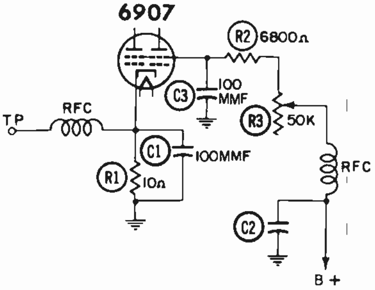


Fig. 9-22. Cathode current can be found by metering the voltage drop across R.

$$I = \frac{300}{20{,}000} = .015 \text{ amp.}$$

Assume the cathode current is 130 ma and the plate voltage is 640 volts. The 15-ma screen current is deducted from the 130-ma cathode current. The plate input power then is 0.115 (amp) × 640 (volts) = 73.6 watts.

RF power output is of concern to the technician. It can be measured with an RF wattmeter connected across the antenna connector of the transmitter. Some RF wattmeters are of the thru-line type, as shown in Fig. 9-23. Others, of the termination type, are provided with an internal dummy load to dissipate the power delivered by the transmitter.

RF wattmeters actually measure the voltage across the antenna load, even though their scales are calibrated in watts. If the signal across a 50-ohm load is 20 volts, the power will be 8 watts, since:

$$W = \frac{E^2}{R}$$

$$= \frac{20 \times 20}{50}$$

$$= \frac{400}{50}$$

$$= 8$$

RECEIVER METERING

Limiter

A tip jack or metering socket terminal ordinarily is provided for measuring the bias developed at the first limiter stage (limiter voltage) in FM receivers, or the AVC voltage in AM receivers. This is the most important test point in the receiver, since it provides go/no-go as well as qualitative information. Other test points include the first local-oscillator multiplier circuits, the discriminator, and sometimes the second-limiter bias.

Limiter voltage, as the bias voltage is called, is developed at the

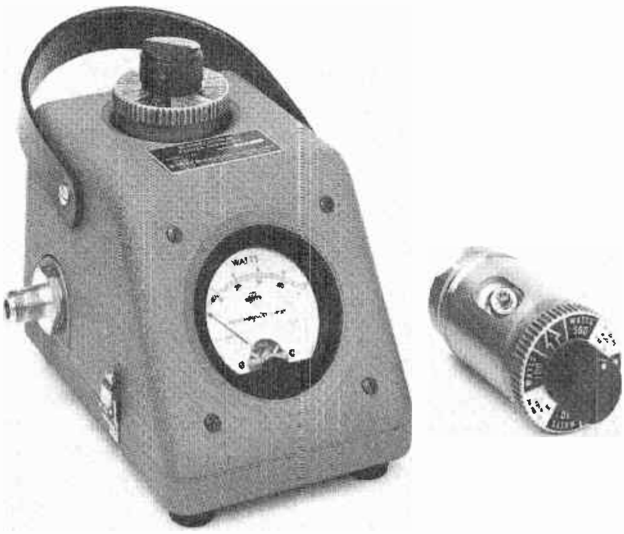


Fig. 9-23. RF wattmeter for measuring transmitter power output. (Courtesy of Sierra Electronic Corp.)

first limiter, across a resistor in the grid circuit. This limiter (bias) voltage exists in a high-gain receiver even when no signal is being received. This is due to the noise generated in the front-end of the receiver. This noise is a signal, as far as the limiter is concerned.

When a signal is received, the limiter voltage increases proportionally to the signal level. In an AM receiver, the same is true: the AVC voltage increases or decreases with signal strength.

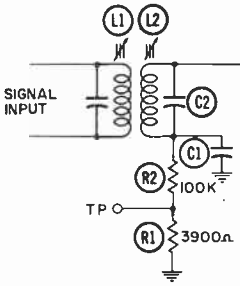


Fig. 9-24. Limiter voltage is measured across one of the grid resistors.

Because the limiter grid current (diode current in AM AVC circuits) is very small, it is more practical to measure this current with a VTVM or high-input resistance DC voltmeter than with a DC milliammeter or microammeter connected in series with the grid resistor.

In a typical receiver, the limiter (or AVC) voltage is measured across a resistor in series with another larger resistor (R1 and R2) in Fig. 9-24. In this actual circuit, R2 is 100,000 ohms and R1 is 3900 ohms. The voltage across R1 under typical conditions is 0.3 volt when measured with a 20,000-ohm-per-volt voltmeter.

A 0-50 DC microammeter can be used as the indicator by connecting it to the limiter-circuit test jack through a series resistor. If the series resistor is 100,000 ohms, the microammeter actually becomes a 0-5 volt

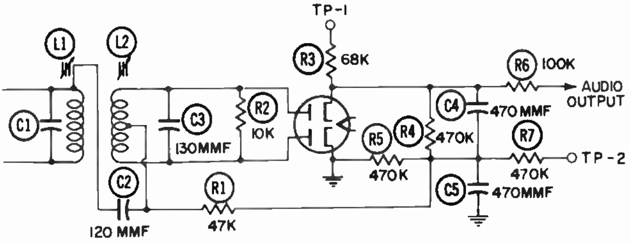


Fig. 9-25. Test points permit external metering of the discriminator balance.

DC voltmeter. The shunting effect of the meter and added resistance across R1 in Fig. 9-24 drops the limiter voltage slightly. The meter will indicate this reduced value. However, it has no significant effect on operation.

Discriminator

All receivers have (or should have) some means for external metering of the discriminator balance (TP1 in Fig. 9-25). L2 is tuned for zero voltage at TP1, and L1 is tuned for maximum reading at TP2. Connecting a meter at TP2 gives the technician a reference against which he can make receiver adjustments.

The secondary of the discriminator transformer ordinarily is adjusted for zero when the signal is exactly at the desired frequency. In a superheterodyne receiver, this is the IF fed without modulation to the discriminator. This measurement is best made with a VTVM, which can be set to zero at center scale so that positive and negative variances from zero can be noted.

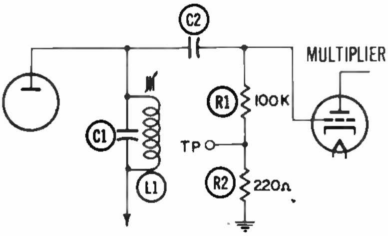


Fig. 9-26. Grid voltage is measured at TP in this local-oscillator circuit.

Some manufacturers suggest that the secondary of the discriminator transformer be adjusted for zero when an on-frequency signal is fed to it, and the primary be adjusted so that the voltage at this point is of equal value (but opposite polarity) when the test signal is ±5 kc from the on-frequency for narrow-band sets, and ±15 kc for wide-band sets.

After the primary has been adjusted for equal-opposite polarity voltages, the secondary should be retrimmed for zero against an on-frequency signal.

Other manufacturers suggest that, in the discriminator circuit of Fig. 9-25, the primary be tuned for maximum voltage (measured at point TP2) and the secondary for zero at TP1.

Oscillator Adjustment

When the local oscillator consists of more than one stage and tuning adjustments are provided, it has the same basic circuitry a transmitter has. As shown in Fig. 9-26, provision is made for metering the grid voltage at TP. The preceding stage is tuned for maximum grid voltage and then backed off a bit, since the circuit might tend to be unstable when set to the top of the peak. Grid drive is measured at the succeeding stages as tuning adjustments are made. (Follow the procedures in the appropriate instruction manual.)

AM Receivers

The same basic metering is required in AM receivers. Instead of limiter voltage, AVC voltage is metered to measure the relative signal level, which rises to a peak when all circuits are tuned to an on-frequency signal.

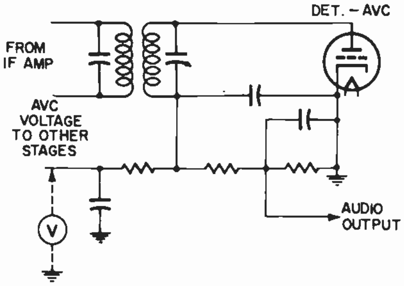


Fig. 9-27 AVC voltage is measured between AVC bus and ground when there is no TP.

When an AVC metering point is not provided, a VTVM (or high-resistance voltmeter) can be connected to the AVC bus and ground, as shown in Fig. 9-27. A DC milliammeter can also be connected in series with the B+ lead of an AVC-controlled stage. The plate current falls as the signal level rises, because of the AVC action. (See Fig. 9-28.)

RECEIVER ALIGNMENT

The alignment instructions published in the appropriate service manual should be followed. Although known, the basic alignment techniques may not apply to all receivers, particularly those equipped with tunable IF filters. Loading resistors may have to be added to some of the coils (as outlined in the service manual) when tuning adjustments are made.

IF Circuits

The IF circuits are aligned first, starting with the limiters or discriminator (or AM detector) and working toward the front-end of the receiver. A signal generator that can be accurately tuned to the various intermediate frequencies is required for IF and discriminator alignment.

For FM receivers, a signal generator with means for frequency modulation is preferred, although an AM signal generator (operated unmodulated) can be used instead. With an FM signal generator, an AC voltmeter can be placed across the receiver audio output to indicate the output. With an AM signal generator, a DC VTVM or 20,000-ohm-per-volt voltmeter should be used as the ouput indicator and the limiter voltage monitored. Adjust-

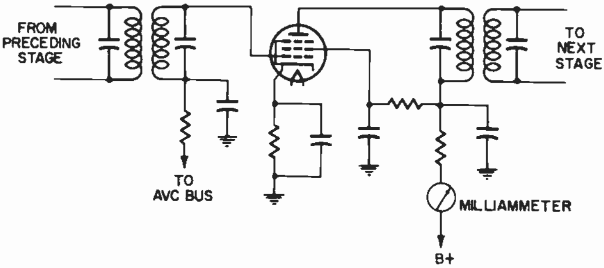


Fig. 9-28. Plate current of an AVC-controlled stage can be metered and related to the signal level.

ment of the discriminator requires a DC VTVM.

When IF circuits are aligned, the heterodyne oscillators are generally disabled to prevent interaction and consequent misleading results. This can be done by pulling the oscillator tubes (when they are independent), or by removing the receiver crystals. Obviously, the third local oscillator, must be reactivated before the IF amplifier preceding it can be tuned, and so on. The signal-generator output is fed through a small isolating capacitor (0.005 mfd) to the grid of the mixer immediately preceding the IF amplifier section to be aligned (unless the service manual specifies otherwise). The signal-generator output should be kept very low and should be reduced as the receiver output increases, to prevent overloading of the receiver. The alignment tool (of the type specified in the service manual) should be insulated to prevent body capacity effects.

Mixer-Oscillator

Again it is stressed that the appropriate service manual should be referred to for specific instructions on how to align the mixer and heterodyne oscillator circuits. The results of mixer tuning adjustments are, as with IF alignment, monitored at the receiver output or limiter circuit. Although it is possible to observe the results of tuning at some other point, it is customary to adjust tuning circuits with respect to the over-all receiver performance.

This is not true, however, with heterodyne oscillators. Here the adjustment is critical in regard to oscillator stability, but has only a slight effect on receiver sensitivity. When heterodyne oscillator stages are tuned, the results are monitored by measuring the currents within the oscillator-multiplier circuits.

The heterodyne oscillator circuits are aligned first, before the mixer input is resonated to the desired frequency. A mixer (as many as three in a single receiver) can actually serve as a complete IF amplifier section in a double- or triple-conversion receiver. The mixers are tuned for maximum output, each to its designated frequency. In some receivers, one of the intermediate frequencies may be different for various operating frequencies. Therefore, refer to the appropriate service manual before making any adjustments.

RF Stages

The RF stages are tuned for maximum audio output or limiter (or AVC) voltage in the receiver. The signal, at the lowest usable level, is fed to the antenna receptacle through a coaxial cable and with an appropriate load, as specified by the receiver as well as the signal-generator manufacturer.

Only a laboratory-grade signal generator will do. Low-priced signal generators intended for servicing home AM or FM radios will not do, even if they can be tuned to the appropriate mobile band. In the first place, the accuracy of frequency calibration, the frequency stability, and the ability to attenuate the output signal to a low enough level (less than a microvolt) without excess signal leakage leave much to be desired. Chapter 10 provides detailed information on various suitable signal generators.

Even with a top-grade signal generator, the calibration of the tuning dial should not be depended upon. Some shops employ crystal-controlled signal generators for the various operating frequencies. However, since a mobile radio shop must have an accurately calibrated frequency meter, one of the continuously tunable types (such as Lampkin or Gertsch) can be used for setting the signal generator right on frequency. This is done by zero-beating the signal-generator and the frequency-meter signals. In fact, the frequency meter can be used as a signal generator.

After the RF stages and all receiver tuning circuits have been aligned as specified in the instruction manual, the antenna adjustments (if provided in the receiver) and tuning circuits of the first RF stage input should be retrimmed. The receiver must be connected to an antenna. Although final adjustment is preferably made with the receiver connected to its own antenna, this is not always feasible. Antenna systems can be provided in the shop, one for each band, and the final input trimming made against a signal from a distant station. The discriminator adjustment can now be rezeroed against an off-the-air signal from a local station, if this is practical.

SENSITIVITY MEASUREMENT

The over-all sensitivity of a receiver can be measured by applying a signal to the input and noting the result at the output. FM receivers are rated at so many db (generally 20 db) quieting with a certain signal level applied at the input.

The squelch is disabled by adjusting it so it will remain open with no signal applied. An AC voltmeter is connected to the receiver audio output (with no signal applied), and the noise level is measured. An unmodulated input signal is applied and its level increased until noise level drops 20 db (voltage drops to 10 per cent of the original value).

Receiver performance (AM or FM) can also be determined by applying a modulated signal and measuring the resultant audio output. This will give information on the number of microvolts (or fraction of a microvolt) that will produce so many milliwatts (usually 10 to 50 mw) audio output. If the signal input is advanced, the amount of signal required to produce full rated audio output can also be determined. AM receivers are also rated according to the microvolts of input required for a 6-db signal-to-noise ratio to be obtained.

If the audio output of a receiver is rated at 1 watt, the voltage across a 4-ohm output (with a speaker or 4-ohm dummy load connected) will be 2 volts, since:

$$\begin{aligned} E &= \sqrt{WR} \\ &= \sqrt{4} \\ &= 2 \end{aligned}$$

At 10 milliwatts the voltage is 0.2 volt, and at 50 milliwatts, 0.45 volt. When a noise quieting test is made, the initial audio output, if 1 volt, should drop to 0.1 volt for 20-db quieting.

SELECTIVITY MEASUREMENT

An over-all sensitivity test is sometimes difficult to make because of the problem of accurately determining the output frequency of the RF signal generator. For instance, when determining the width of the flat top of the resonance curve, one must be able to set the signal generator accurately to a few kc on each side of the center operating frequency.

Therefore, selectivity of the IF amplifier can be measured more readily, because the signal generator is more easily set at the lower frequencies. For instance, in checking out a 290-kc IF amplifier with a 10-kc flat top, it should be possible to set the signal generator accurately to 285 and 295 kc.

The measurement is made by feeding the signal to the grid of the mixer ahead of the IF amplifier. The limiter voltage (DC) is then metered with a VTVM, or the audio output voltage, with an AC voltmeter. The signal generator is set to the IF center frequency. The signal level required to produce a certain amount of limiter or audio voltage is then noted. The signal generator (unmodulated) is next set 5 kc higher than the center IF, and the signal level is adjusted to produce the same limiter reference voltage. The signal generator is then set 5 kc lower, and the signal level is again adjusted to produce the same limiter voltage. If the curve is a true flat top, the signal level should be the same for all three test points.

The tests should proceed further, of course, so that the amount of attenuation can be determined at various increments of frequency. At ±50 kc, for example, the signal-generator output is advanced to produce the same limiter voltage as the one at the center frequency. For instance, if the output voltage of the signal generator must be increased 100 times, the attenuation of signals ±50 kc removed from the center frequency will be 40 db.

TROUBLESHOOTING

Signal tracing is a good system for localizing troubles. An easy way is to open the squelch and apply an audio signal (from a signal generator) to the grid of the first audio stage (through a capacitor to prevent possible conflict with DC conditions), and note whether noise can be heard from the speaker.

Then, working back from the discriminator to the mixer, feed a modulated IF signal to the inputs of the various stages, changing the signal-generator frequency as required. To determine whether the heterodyne oscillators are functioning, feed an unmodulated signal (tuned to the applicable local-oscillator injection frequency) to the grid of each mixer, starting with the last one.

A frequency meter (such as the Lampkin 205D, BC-221, or an electronic counter) can be used for determining the existence and frequency of each local oscillator. The signal is picked up through a small capacitor at each mixer grid.

The various DC operating voltages should be measured with a VTVM. (A 20,000-ohm-per-volt VOM can be used unless service manual definitely specifies a VTVM.) A new instrument, known as the 428A clip-on milliammeter, was recently introduced by Hewlett-Packard. It can be used for measuring the direct-current levels without having to disconnect any leads. This instrument is particularly recommended for servicing transistor circuits, since it will not endanger the transistors.

Receivers should be checked with the normal input voltage applied, as well as at reduced and higher-than-normal voltages, to simulate actual operating conditions.

RELAY MAINTENANCE

A relay, like any other device with moving parts, is subject to wear. In simplex radio systems, transmitter control and antenna relays, as well as the keying relays used in remote-control circuits, are operated frequently. Unless hermetically sealed, they will gather dust, which impairs their electrical as well as mechanical function. Besides, metal fatigue may change their operating characteristics.

Relay contacts exposed to air will become contaminated. When contacts carry enough current that sparking occurs, the dust will be burned off. Eventually the contacts may become pitted.

Relays used for switching "dry circuits" suffer more often from contact trouble than do relays used for handling power. This is due to the absence of sparking. A dust film, even ever so minute, can stop or seriously impede current flow from one contact to another. Typical of dry circuits are those which carry low-level audio and RF to receiver inputs. The currents are often in the microampere range, and voltages may be in the millivolt or microvolt range.

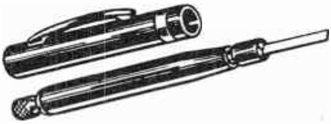


Fig. 9-29. Contact burnisher for cleaning relay contacts. (Courtesy of P. K. Neuses, Incorporated.)

It is therefore obvious that relay contacts exposed to the air must be cleaned regularly. They should never be sandpapered or filed. Instead, a burnishing tool (Fig. 9-29) should be used. It is not ordinarily sold at radio parts stores, but is available from P. K. Neuses, Inc., Arlington Heights, Illinois, makers of a kit containing several types of burnishing blades. It can also be bought from telephone supply houses.

The contacts are cleaned by being gently burnished (be careful not to bend the contact springs). If the contacts are burned or pitted, the relay should be replaced with a new one or, if economically feasible, overhauled and new contacts and contact springs installed.

Relays can also be cleaned ultrasonically by immersing them in a suitable detergent. If the relays are not of the plug-in type, they must be removed from the equipment, unless the assembly on which the relay is mounted is small enough to fit into the cleaning tank.

The adjusting screws, which affect the sensitivity and drop-out threshold of the relay, should not be touched except by someone who knows what he is doing. Relay maintenance is a skill unfamiliar to most radio technicians. Moreover, whenever in doubt about the reliability of a relay, it is better to replace it than to chance failure of the equipment.

CHAPTER

10 Setting Up the Shop

THE mobile radio service shop should be inside a screen room that excludes outside interference and provides shielding against radiation of signals from the shop. Many military posts and manufacturers' test departments and laboratories have screen rooms for testing two-way radio equipment. They are expensive because a truly effective screen room requires total shielding on all four sides, and at the top and bottom. Moreover, special means must be provided to prevent leakage through door frames and other openings. The power lines fed to the screen rooms must also have appropriate filters.

Enclosing the test area in a copper-screened room will go a long

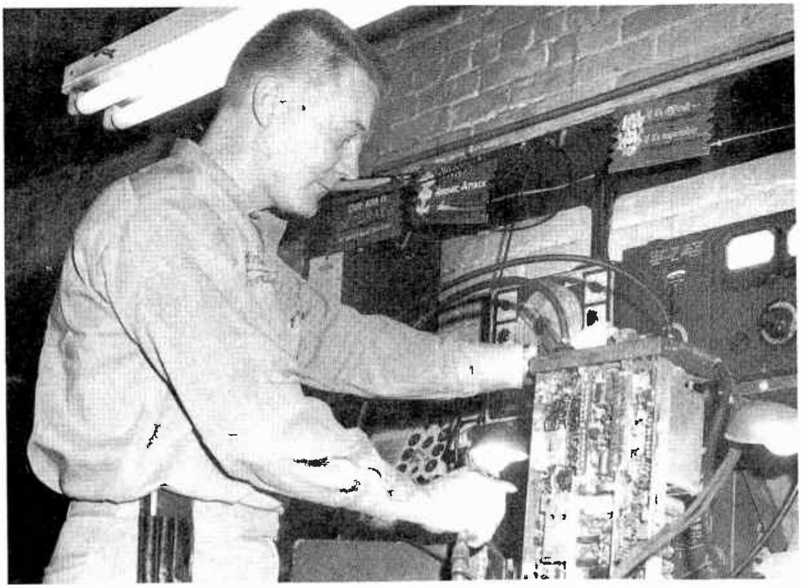


Fig. 10-1. Blowing out dirt with compressed air. (Photo by Jacques Saphier.)

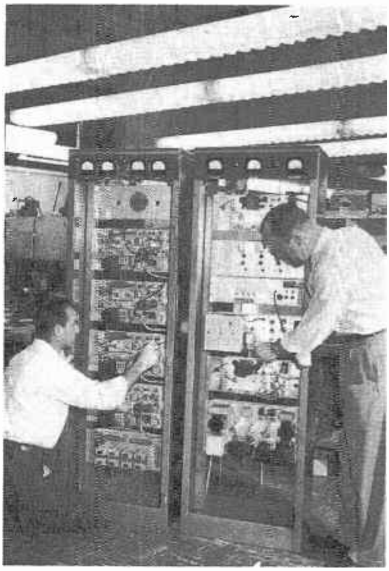


Fig. 10-2. Fluorescent lighting provides over-all, even illumination. (Courtesy of Allen B. DuMont Laboratories, Inc.)

way toward reducing outgoing and incoming interference. In lieu of sheet metal or fine-mesh copper screen, fine-mesh chicken wire will provide some degree of shielding. All pieces of the screening material should be bonded together electrically. One point of the shield should be grounded through the shortest heavy conductor.

Most shops, however, are not shielded. For this reason, care must be exercised, when transmitters are tested, to minimize radiation of signals which might cause illegal (or unneighborly) interference.

Workbenches of the proper height should be provided. Compressed air should be available, so that technicians can blow away dirt from equipment prior to servicing. Fig. 10-1 shows a technician using air to clean a chassis. Note the air nozzle at the end of the hose. If compressed air is not available, a pair of fireplace bellows will do.

LIGHTING

Without adequate lighting, it is difficult to see into tight corners inside equipment. Although fluores-

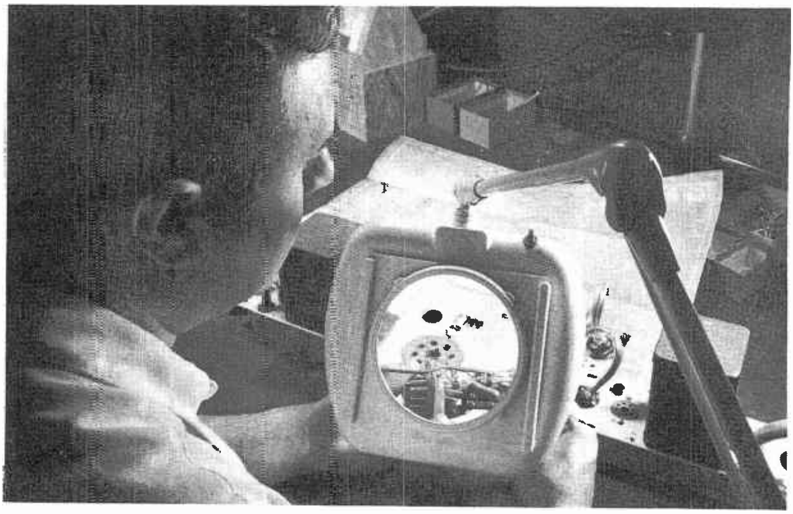


Fig. 10-3. Illuminated magnifying glass permits small parts to be inspected. (Courtesy of Curtiss-Wright Corp.)

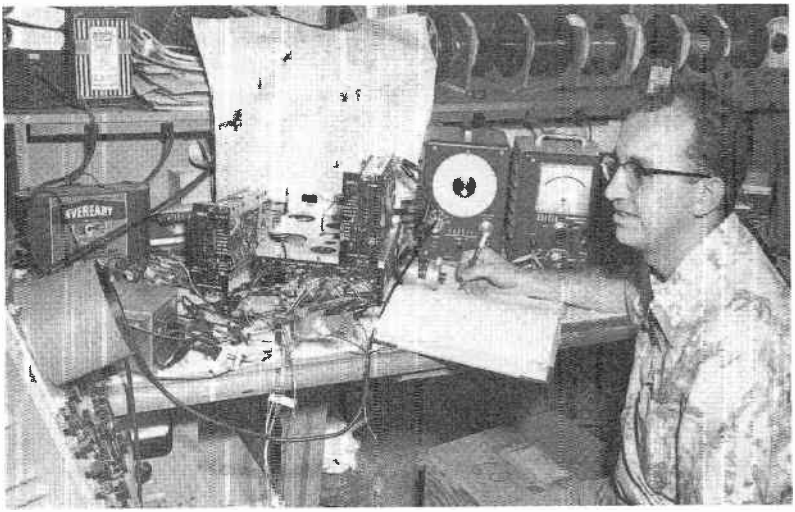


Fig. 10-4. Strip-type outlets above the bench make a large number of AC outlets available. (Courtesy of Donner Scientific Co.)

cent lighting permits better identification of color codes, incandescent lights do not produce radio interference as the cooler-running fluorescent lights do. Fluorescent lights may be all right for over-all lighting, but they should not be placed near a receiver being tested. Fig. 10-2 shows how fluorescent lighting provides even illumination over wide areas. An illuminated magnifying glass (Fig. 10-3) can also be of immense help.

POWER

Utility power (115 volts AC) should be available at all work locations for operation of test equipment, soldering irons, and portable lighting, as well as AC radio equipment to be serviced. Strip-type outlets just above the bench level (Fig. 10-4) provide AC outlets every few inches along the bench.

One or more DC voltages must also be made available for operation of mobile units. Most vehicles are now equipped with 12-volt batteries. Both 6- and 12-volt power can be provided from a pair of 6-volt storage batteries floated by a charger (as explained in Chapter 9), or a rectifier like the one in Fig. 10-5 can be used. Rectifier power supplies are available in many voltage and current ratings. Most have controls for setting the output voltage, and meters for reading the current and voltage. Some, like the one in Fig.

Fig. 10-5. Rectifier power supply delivers up to 20 volts DC, as well as 6 or 12 volts DC. (Courtesy of Electronic Instrument Co., Inc.)

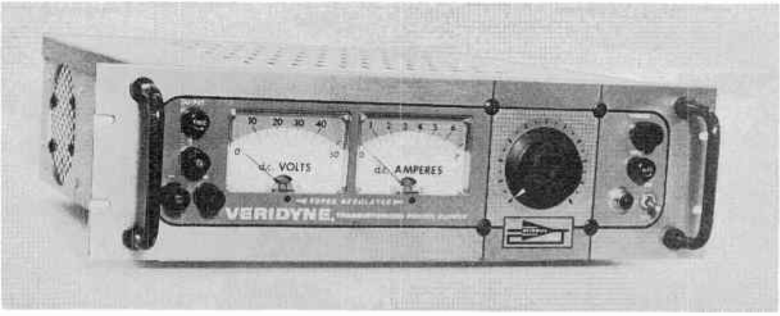


Fig. 10-6. Transistorized power supply provides an output voltage within an accuracy of 0.01%. (Courtesy of Consolidated Avionics Corp.)

10-6, contain automatic voltage regulators which hold the output voltage to as close as 0.01 per cent.

The power supply in Fig. 10-7 provides 0 to 16 volts DC at up to 25 amperes, or 0 to 84 volts DC at 6 amperes, as well as 0 to 130 volts AC at 6 amperes. Thus, it enables servicing of vehicular as well as railroad and marine radio equipment. As shown by the schematic in Fig. 10-8, the output voltage is varied by a *Variac* autotransformer ahead of the power-transformer primary.

Custom-built power supplies like the one in Fig. 10-9 can be obtained for larger shops. Several independent rectifier power supplies are

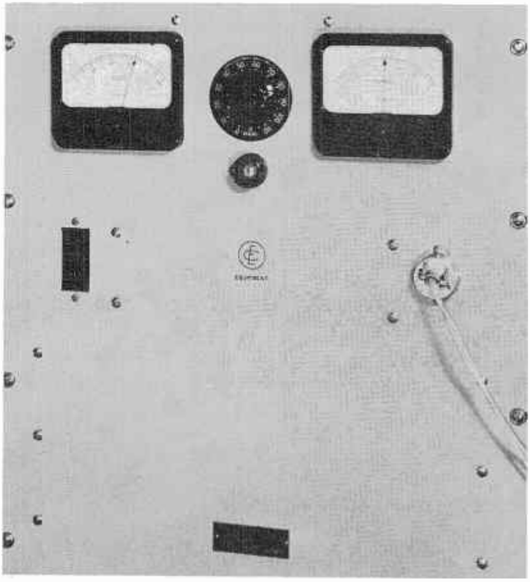


Fig. 10-7. Variable power supply for servicing mobile radio equipment. (Courtesy of E-C Equipment, Inc.)

mounted in a rack cabinet. Six DC voltages, as well as regulated 115 volts AC, are furnished by the supply.

TEST EQUIPMENT

In a shop in Concord, California, the test equipment is installed on an overhead conveyor which can be slid to any position over a long workbench. Thus, one set of test equipment can be used at several work positions. Some shops put equipment on double-decked carts. One cart can be equipped with a frequency meter, modulation meter, and RF wattmeter for transmitter checking; and another, with signal generators and other equipment for checking and aligning receivers.

Shelf space on which test equipment can be placed should be provided above the benches. Note the tidy appearance of the bench in Fig. 10-10. Fig. 10-11 shows another shop with an L-shaped bench and good natural lighting to augment the lamps over the bench. Pegboard (Fig. 10-12) can also be used for suspending test equipment within arm's reach.

TUBE TESTERS

In addition to a general-purpose tube tester, the mobile radio shop should have some means of checking tubes for grid emission and interelectrode leakage. At a military electronics shop, the reliability of airborne radar equipment was bettered by more than 400 per cent when tubes were checked on a special grid-circuit tester, as well as on a general-purpose tester. Many tubes that checked "good" on a general-purpose tester failed to pass the grid-emission test. Fig. 10-13 shows a laboratory-grade general-purpose tube tester, and below it, a grid-

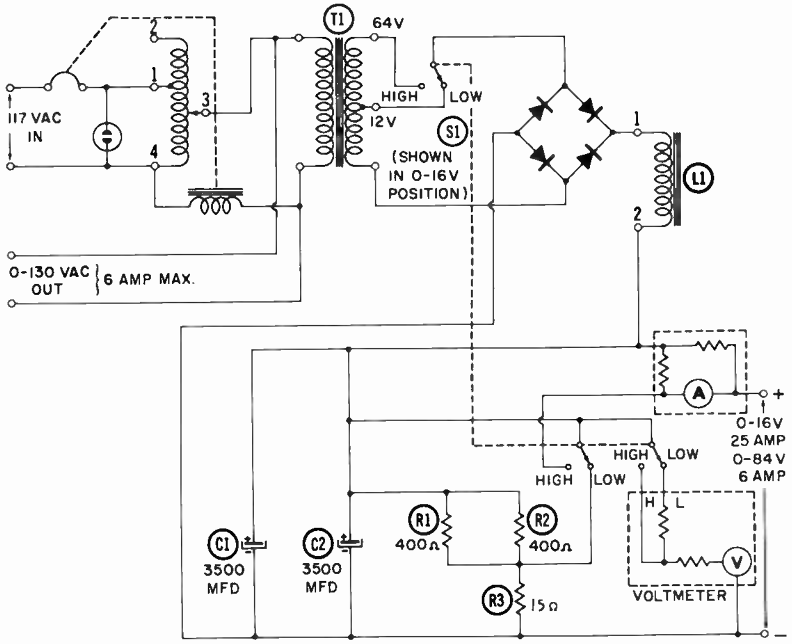


Fig. 10-8. E-C Model 12-64 shop power supply.

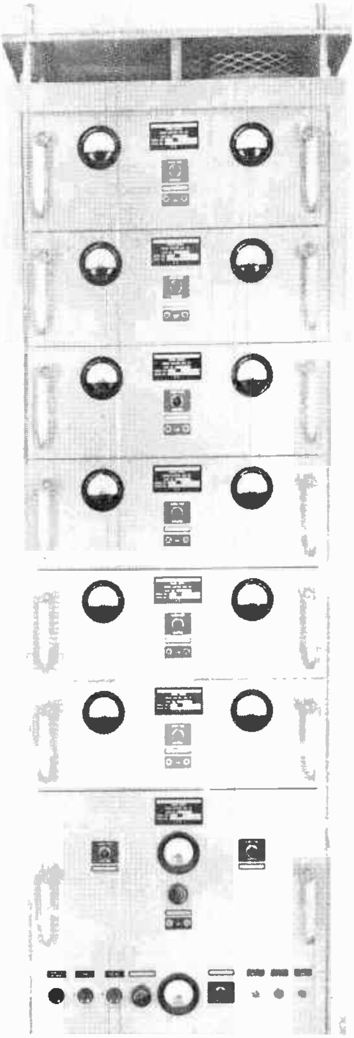


Fig. 10-9. Custom power supply for larger shops. (Courtesy of Bogue Electric Manufacturing Co.)

circuit tester for checking grid and interelectrode emission.

There are many kinds of tube testers on the market, some more critical than others. All of them test for short circuits, and indicate the relative merit in terms of dynamic mutual conductance, transconductance, plate conductance, or emission. The simplest test is for cathode emission. A meter indicates the amount of current flow in the cathode. In some testers, an AC signal is applied to the tube. The performance of the tube under simulated operating conditions is then measured in terms of dynamic mutual conductance.

Opinions vary as to which tube testers are the most effective. An expensive laboratory-type tube analyzer may cost $1,000 or more. There are technicians who claim that it will reveal any defect within a tube. However, the typical mobile radio shop operator is in no position to buy such a tester. Fortunately, there are many less expensive ones which will do an adequate job.

Some technicians feel they can get by with a simple emission-type tube tester. To weed out the bad tubes that were undetected by the tube tester, they also perform an operating test in the set. This is done by substituting new tubes, one at a time, and noting any change in performance. A weak RF signal is applied to the receiver input. Performance changes are then observed with a meter connected to the limiter (AVC bus in AM sets) or audio output. Obviously, more tubes can be culled during the first part of the operation if a highly critical tube tester is used.

Unfortunately, no transmitter tube testers are available through service industry channels. Most transmitter tubes are therefore tested on regular tube testers. However, RF amplifier tubes operate at high voltages. For this reason, they do not get much of a test in an ordinary tube tester. These tubes are generally tested on a transmitter, by measuring the transmitter

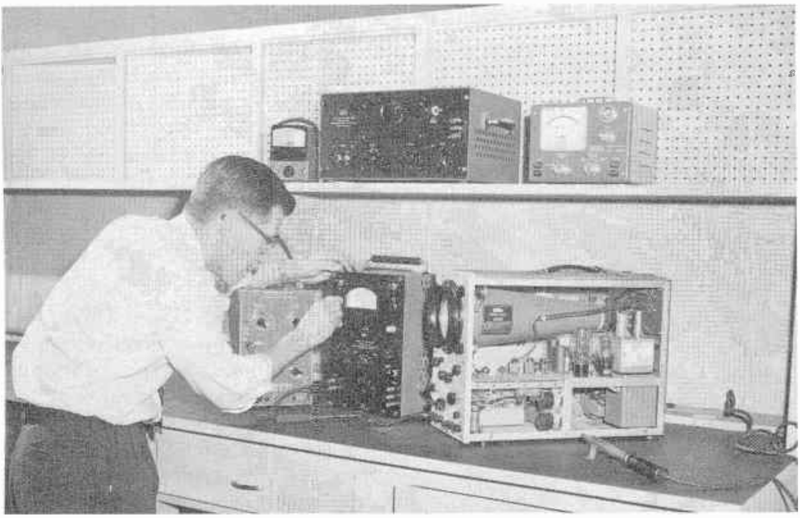


Fig. 10-10. A shelf above the bench is handy for test equipment. (Courtesy of Ault Associates.)

output with an RF wattmeter and noting any change.

TRANSISTOR TESTERS

In 1958 one of the leading radio-TV manufacturers stated in its instruction manuals that no known "adequate" transistor testers were available. Since then, commercial transistor testers *have* appeared on the market. One of these, shown in Fig. 10-14, will test transistors in

Fig. 10-11. This well-lighted shop has an L-shaped bench. Note the abundant test equipment. (Courtesy of Spoelstra Communications.)

Fig. 10-12. Pegboard behind the bench permits test equipment to be suspended within reach. (Courtesy of Freeport Communications, Inc.)

their circuits. A signal from a reference oscillator is applied to the transistor, as shown in the block diagram in Fig. 10-15. The transistor, biased for Class-B operation because of the impedance across its base-emitter, will conduct only when the input-signal level exceeds the work function of the emitter-base diode. In addition to *beta* testing of transistors, the instrument will also measure the collector-current parameter with the transistor removed from the equipment.

FREQUENCY METERS

Transmitter frequency can be measured roughly with Lecher wires or a calibrated receiver, or with a simple absorption-type wavemeter like the one in Fig. 10-16. Coil L and tuning capacitor C1 are tuned to resonate at the transmitter frequency by observing the meter reading. When they are tuned to the transmitter frequency, the meter reading will be maximum. The dial can be calibrated in megacycles. However, it cannot be calibrated accurately enough, nor read as closely as required. Thus, such an instrument is useful only for approximate measurements.

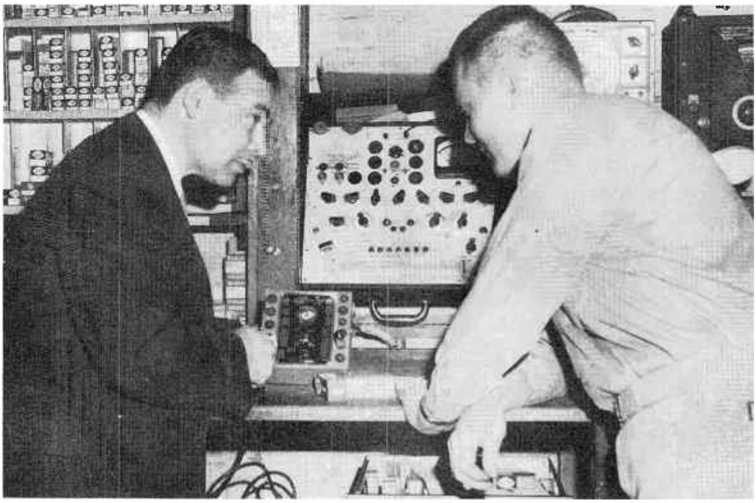


Fig. 10-13. Laboratory-grade general-purpose tube tester (top). Below it, a grid-circuit tester for checking grid emission and interelement leakage (Courtesy of Mobile Communications.)

Fig. 10-14. In-circuit transistor tester. (Courtesy of Philco Corporation.)

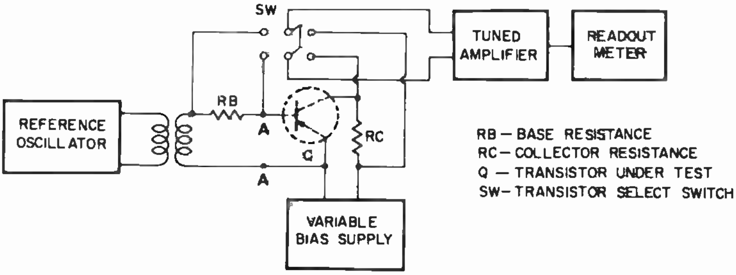


Fig. 10-15. Block diagram of transistor tester in Fig. 10-14.

The FCC requires that the frequencies of transmitters operated between 50 and 1,000 mc be maintained within 0.005 per cent of the assigned frequency, and those in the 25-50 mc band, within 0.002 per cent. However, transmitters operated at less than 3 watts input to the final RF amplifier, between 25 and 1,000 mc, are required to maintain a frequency stability of only 0.005 per cent.

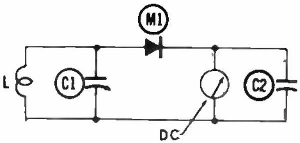


Fig. 10-16. Simple absorption-type wavemeter.

At 460 mc, for example, the center frequency must be kept between 460.0023 and 459.9977 mc (plus and minus 2,300 cps of 460 mc). At 160 mc, only 800 cps leeway is allowed. Measurement of such frequencies to determine that they are within these tight limits requires precision apparatus. The measuring instrument must have an even higher frequency stability, so that any errors in the instrument will not lead to erroneous readings.

HETERODYNE FREQUENCY METERS

Frequency can be measured precisely with a heterodyne frequency meter. The transmitter signal, picked up by a simple receiver, is compared with the frequency of a variable oscillator, as illustrated in Fig. 10-17. When the two signals are on the same frequency, no beat note will be heard. Any difference between the two will result in a beat note. For instance, if the transmitter is supposed to be tuned to 160 mc, but zero beat is obtained when the frequency meter is tuned to 160.0005 mc, the transmitter frequency is 500 cps (0.5 kc) too high.

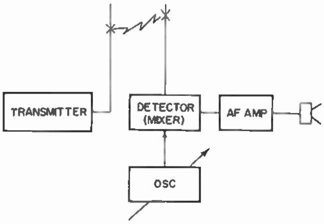


Fig. 10-17. Heterodyne method of measuring transmitter frequency.

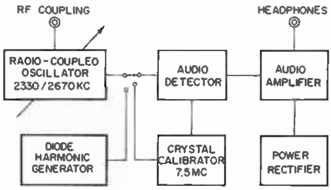


Fig. 10-18. Model 105-B frequency meter. (Courtesy of Lampkin Laboratories, Inc.)

Fig. 10-18 is a block diagram of the Lampkin Model 105-B frequency meter. This instrument contains an accurately calibrated variable-frequency oscillator which can be tuned over the very narrow range of 2,330-2,670 kc. The 4-inch dial must be revolved 40 times to cover this frequency range. Since the dial has 200 divisions, 8,000 separate markings can be indicated.

The transmitter signal is picked up by a piece of wire acting as an antenna, which is connected to the RF input jack. The transmitter signal and a harmonic of the oscillator signal are mixed in the detector. When they are close in frequency, an audible beat note will be heard in the headphones. This beat note is amplified by the audio amplifier within the instrument. When the oscillator is tuned to zero-beat with the transmitter signal, the dial is read and the frequency determined by referring to a calibration chart. A 7.5-mc crystal calibrator is provided, against which the tunable oscillator dial calibration can be checked near the middle of the tuning range. The instrument can also be checked against a standard signal from the Bureau of Standards radio station WWV.

This instrument is intended for measurement of transmitter frequencies from 100-175 mc. However, it can be used at higher frequencies, by measuring the frequency of one of the multiplier stages within the transmitter. It can also be used as a signal generator for measuring the frequency of a signal being intercepted by a radio receiver. This is done by beating the oscillator signal of the instrument against the received signal.

The Gertsch FM-3 frequency meter (Fig. 10-19), also of the continuously tunable types, can be used for measuring any frequency between 20-1,000 mc. It is also useful as a signal generator throughout its tuning range, as well as below 20 mc. The instrument indicates fre-

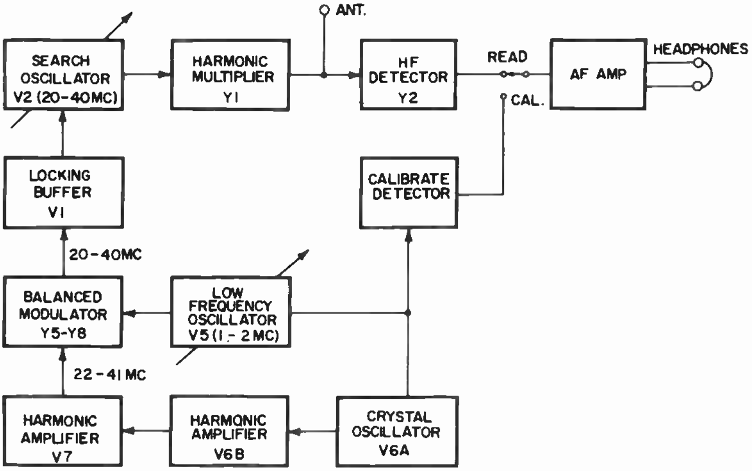


Fig. 10-19. Gertsch Model FM-3 frequency meter.

quency by interpolating between known crystal harmonic frequencies by means of a calibrated oscillator (V5), which is tunable from 1-2 mc. Another oscillator (V2), known as the search oscillator, tunes from 20-40 mc. Its output is fed, through a diode-type harmonic multiplier (Y1), to the antenna terminal and the high-frequency diode detector (Y2).

Fig. 10-20. DuMont Model 5890 frequency meter. (Courtesy of Allen B. DuMont Laboratories, Inc.)

The search oscillator is tuned so that its fundamental signal (20-40 mc) or one of its harmonics is matched to the incoming signal. This is done by listening for a beat note as the oscillator is tuned past the transmitter frequency to be measured, and then adjusting for zero beat. By means of a selector, the proper *crystal* harmonic is selected and the low-frequency oscillator is tuned, until the difference frequency from the balanced modulator (Y5-Y8) approaches the search-oscillator frequency. The tuning is continued until zero beat is obtained. The frequency is then read directly from the tuning dials.

The DuMont 5890 frequency meter (Fig. 10-20) is also of the heterodyne type. However, it employs a crystal-controlled, instead of a continuously tunable, oscillator, the frequency of which is compared with the unknown. A 24-position

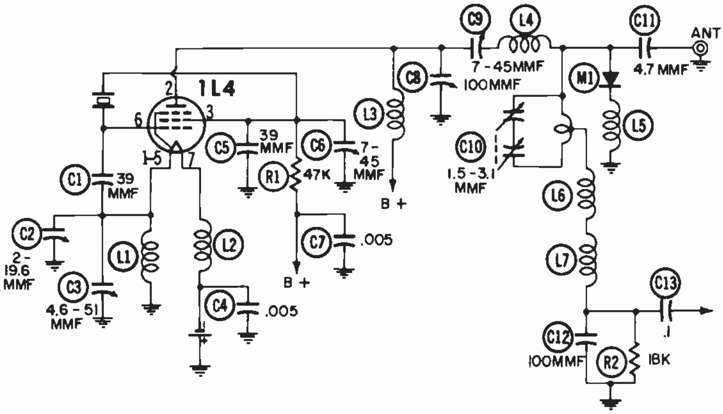


Fig. 10-21. Heterodyne oscillator and mixer of Model 5890.

crystal-selecting switch enables measurement of up to 24 transmitter frequencies between 25 and 470 mc. From one to twenty-four crystals may be installed in the instrument. A telescoping antenna (not visible) is provided for picking up the transmitter signal, in addition to the cable shown. The **T** connector at the end of the cable is inserted into the antenna lead-in when a larger transmitter signal voltage is required. An attenuator, between the **T** connector and coaxial plug, prevents the full transmitter power from reaching the instrument.

Fig. 10-21 is a simplified schematic of the heterodyne oscillator and mixer. The transmitter signal is picked up by the telescoping antenna and mixed with a harmonic of the heterodyne oscillator in diode M1. The resultant beat signal is then developed across R2. The crystal frequency is trimmed by C2 and C3, which are set to a point specified in the calibration chart, while C8 and L3 are tuned to the desired harmonic of the crystal.

Fig. 10-22 is a simplified schematic of the indicator circuit. Transistors X1 and X2 are amplifiers. X3 and X4 are limiters that square off the beat-frequency signal to form pulses of constant amplitude.

The 0-100 DC microammeter measures the DC at the output of diodes M1 and M2, the average value of which depends upon the spacing of the pulses. The meter provides a direct reading of the difference in frequency between the transmitter signal and the crystal-controlled reference signal. At full scale, this difference is 5 kc.

There are two frequency-measurement positions; the one shown in Fig. 10-21 can indicate frequency differences of 5 kc. In the other position, R11 (Fig. 10-22) is replaced by a 250-ohm variable resistor. The maximum frequency difference, up to 15 kc, can be read directly on the meter by tripling the reading.

Although Fig. 10-21 shows only one crystal, the control and screen grids actually are connected to a 24-position switch. The switch selects any of one to twenty-four crystals, the harmonics of which, from the third to the forty-eighth, are used for measuring frequencies between 25 and 480 mc.

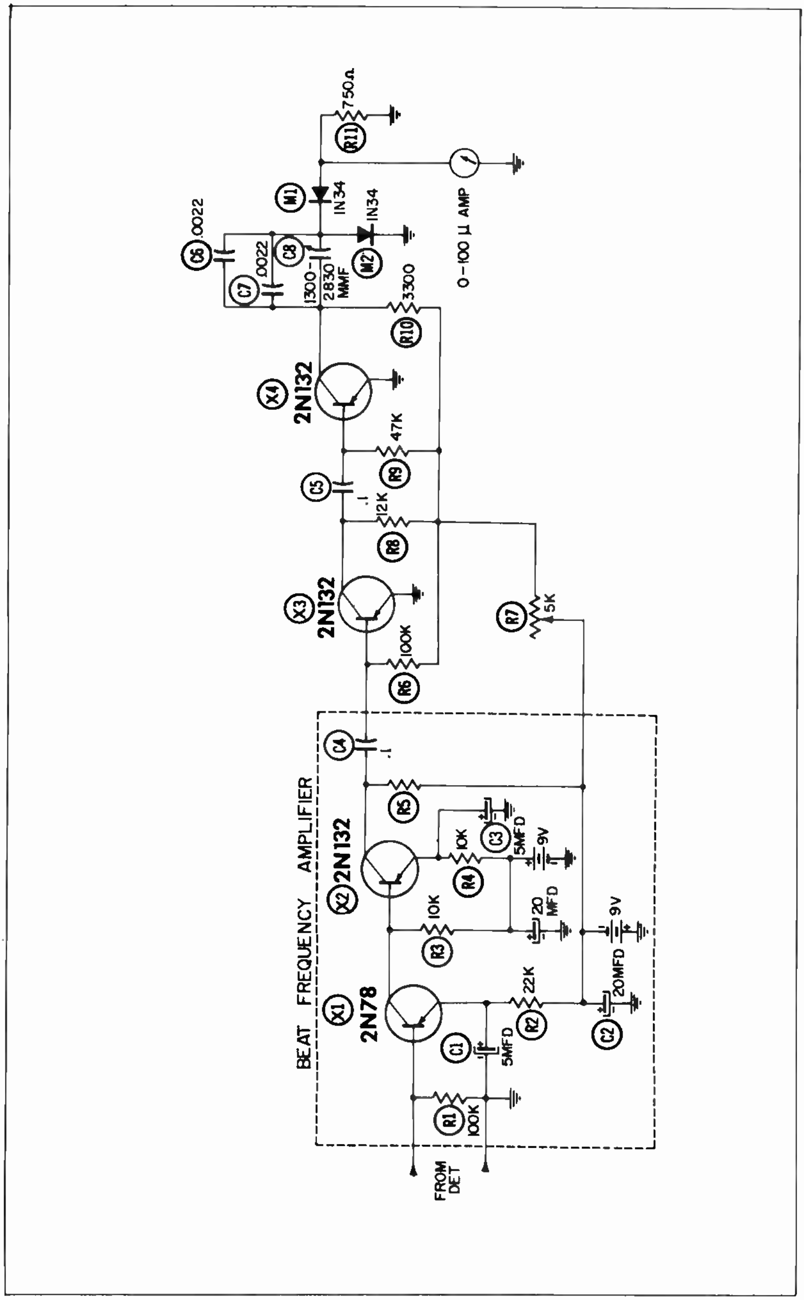


Fig. 10-22. Indicator section of Model 5890.

COUNTER-TYPE FREQUENCY METERS

Some electronic counters provide a direct reading of the transmitter frequency. The signal is fed through a signal gate, which is opened and closed precisely by a time-base generator. (See Fig. 10-23.) If set for one second, the counter will count the number of cycles during that period, and display the frequency in kilocycles on a visual indicator.

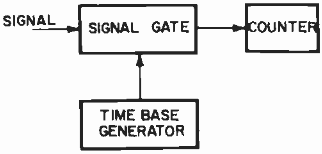


Fig. 10-23. Basic electronic counter.

Fig. 10-24 shows the Hewlett-Packard 524B electronic counter being adjusted. It will accurately measure frequencies between 10 cps and 20 mc, to an accuracy of 0.0002 per cent. The basic instrument will measure any frequency up to 10 mc. A signal of at least one volt must be applied to its one-megohm input. The frequencies of crystal oscillator and multiplier stages below 10 mc can be measured with this instrument.

Converters can be mounted into the instrument for reading the higher frequencies. The 525A frequency converter extends the range to 100 mc; the 525B converter enables reading of frequencies between 100 and 220 mc.

With a 525A converter, the input signal may be as small as 0.01 volt (10 millivolts); with the 525B, a minimum signal of 0.02 volt (20 millivolts) is required. Both converters have a 50-ohm input.

Either converter has a dial divided into increments of 10 mc. The dial is tuned to maximum indication of its electron eye. When measuring 156.525 mc, for example, it is set to *150*. The six illuminated numerals will show the number *6525.00* if on the exact frequency.

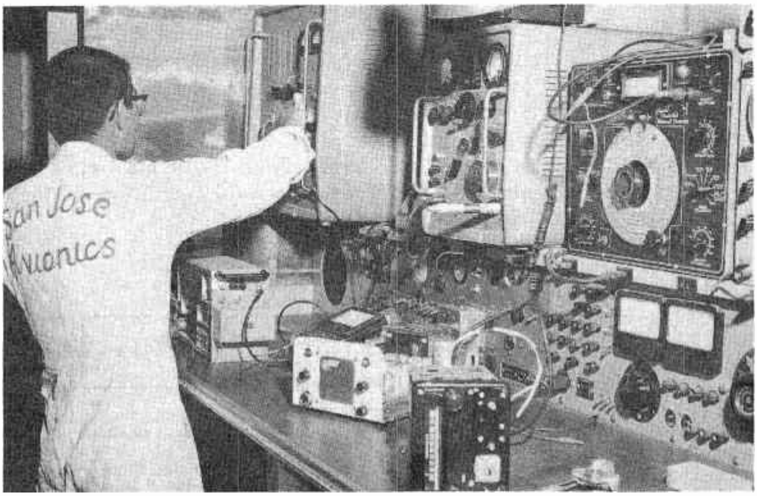


Fig. 10-24. The technician is adjusting the controls of an electronic counter. (Photo by Cyril Glunk.)

If the frequency is 156.5249623 mc, the dial will indicate *150* (mc), and the glowing digital indicators, *6524.96* (kc). The first of the two meters on the panel will indicate *2*, and the second, *3*.

A control holds the display from one-tenth of a second to ten seconds. At the end of the hold time, the instrument will automatically make a new measurement, so that any frequency drift can be noted.

When a converter is not used (for signals below 10 mc), a probe will be needed to get a signal of at least one volt from the transmitter stage through a small capacitor. When a converter is used (enabling frequency measurement with only one or two per cent as much signal), the coupling can be much looser. A dummy load or a small pickup coil brought near the final RF tank or transmitting antenna should suffice. An RF attenuator and a **T**-connector arrangement (Fig. 10-20) can also be used to tap off some of the transmitter signal for feeding the counter.

MODULATION METERS

FCC regulations require measurements to be made, to determine that the bandwidth of a transmitted signal does not exceed the bandwidth authorized for the station. In narrow-band (split-channel) systems, maximum transmitter deviation is ±5 kc for FM. If the assigned frequency is 162.525 kc, the signal will vary from 162.520 (−5 kc) to 162.530 (+5 kc). Allowing ±0.0002 per cent maximum center-frequency drift, the edge of the FM signal could drop as low as 162.5192 kc and swing almost to 162.531 kc when the transmitter center frequency drifts to its maximum limit on the high side.

Broad-band FM transmitters are permitted to deviate ±15 kc. Thus, the signal occupies 30 kc of bandspace on the assigned transmitter frequency. Allowing for some transmitter frequency drift, a broad-band transmitter occupies a channel 40 kc wide; a narrow-band transmitter, only 20 kc.

Several instruments are available for measuring the deviation of FM transmitters. Some are incorporated into frequency meters; others are separate instruments. Fig. 10-25 is a block diagram of the Lampkin Model 205A FM modulation meter (actually a superheterodyne receiver equipped with a vacuum-tube voltmeter). It will measure the modulation of FM transmitters operating on any frequency from 25-500 mc. Instantaneous peak deviation is indicated on a direct-reading 0-25 kc (peak) meter. Its local oscillator, tuned from 26-49 mc, relies upon harmonics for operation at higher frequencies.

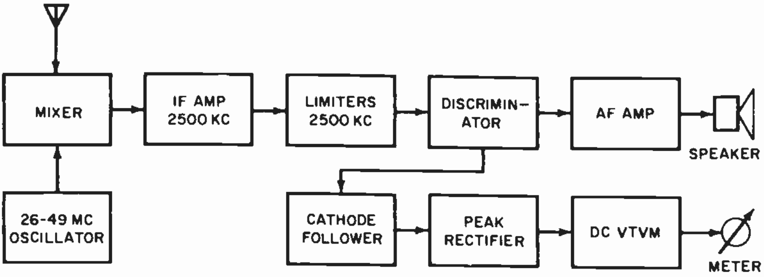


Fig. 10-25. Lampkin Model 205A FM modulation meter.

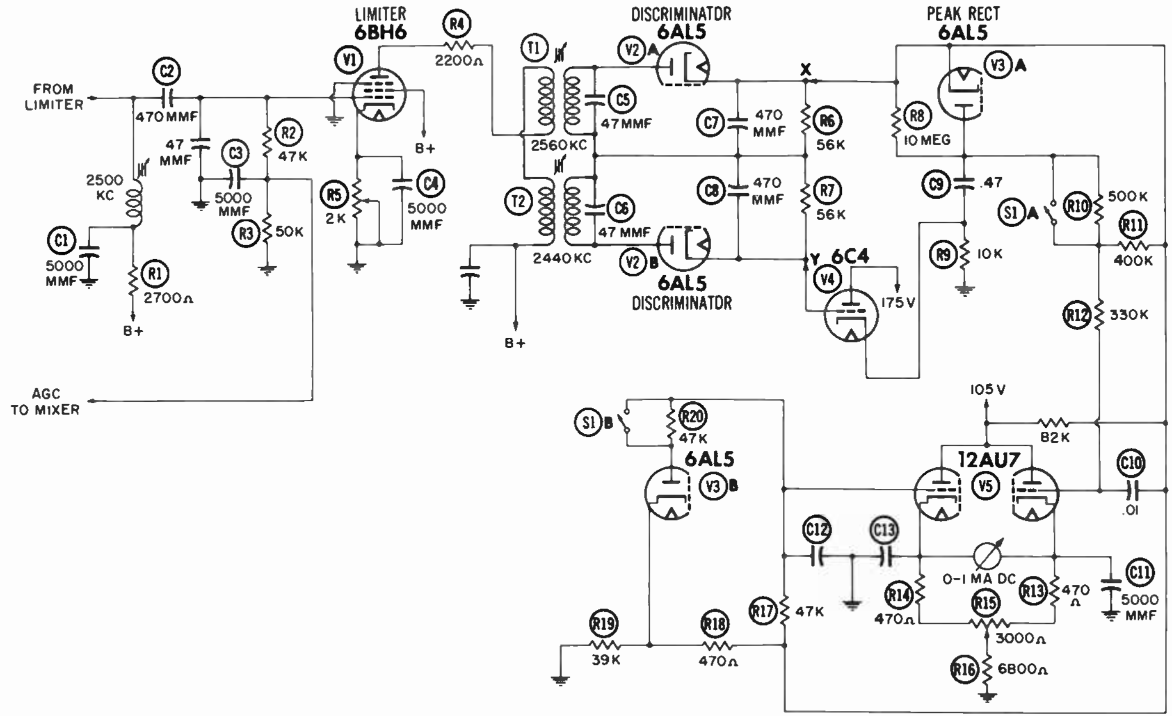


Fig. 10-26. Metering circuits of Model 205A.

The instrument depends upon an increase in the discriminator output voltage as the frequency deviation increases. A staggered-tuned discriminator is used. T1 is tuned to 2,560 kc, and T2, to 2,440 kc (Fig. 10-26). The discriminator is fed by limiter V1, which delivers a constant-amplitude, 2,500-kc square wave to T1 and T2. The audio output of the discriminator is fed to peak rectifier V3A, cathode follower V4, and balanced triode vacuum-tube voltmeter V5. V4, the cathode follower, provides a low source impedance, and thus a fast rise time, on voice peaks. It charges input capacitor C9 in about one-half cycle at 3,000 cps, which takes about one-half second to discharge. Thus, the instrument quickly responds to modulation peaks; and the slow discharge time of C9 holds the indication long enough that it can be read easily.

The meter is a 0-1 DC milliammeter calibrated 0-25 kc. It is used in a balanced triode vacuum-tube voltmeter circuit, which is balanced to zero with potentiometer R15. Diode V3B reduces zero drift due to line-voltage changes. The 105-volt B+ is regulated by regulator tube VR105 (not shown in this simplified schematic).

The instrument reads positive frequency deviation from center frequency when the metering circuit is connected to the discriminator. A switch (not shown) reverses connections *X* and *Y* to enable reading of the negative deviation peaks. An audio amplifier and speaker (not shown) are also included for aural monitoring of the signal being measured. The instrument has two deviation ranges, 12.5 and 25 kc full scale. Switches S1A and S1B are as shown for 25-kc, full-scale indication; they are closed, shorting out resistors R10 and R20, for 12.5-kc, full-scale indication. Not shown in the diagram are the switching circuits that enable tuning and zero-setting of the instrument.

The DuMont frequency meter described earlier in this chapter is also used for measuring frequency deviation. This is done by tuning the reference crystal to the exact transmitter center frequency. The resultant deviation can then be read on the meter.

The Gertsch DM-1 peak modulation meter is a complete superheterodyne receiver, except that it has no local oscillator. The local-oscillator injection signal is obtained from an FM-3 frequency meter, to enable measurement of the deviation of FM transmitters operated on any frequency from 20-1,000 mc. A frequency deviation of up to 15 kc for full-scale reading can be read on the front panel of the meter. The instrument can be combined with the Gertsch FM-3 frequency meter, both of which can be battery operated.

AM MODULATION MEASUREMENT

The AM transmitter bandwidth depends upon the modulation frequency. With voice modulation (limited to 3,000 cps), the signal includes the basic carrier (operating frequency) plus the upper and lower sidebands, each 3 kc wide. Thus, the transmitted signal, when modulated at 3,000 cps, is 6 kc wide. To allow for some frequency shift, an AM transmitter is assumed to occupy a bandwidth of 8 kc.

Overmodulation in an FM transmitter causes the signal to deviate more widely, and thus, to occupy a wider band. On the other hand, splatter and distortion occur when an AM transmitter is overmodulated. The signal may then occupy a much wider band than it should and thus cause interference. FM voice transmissions become louder as the modulation is increased, because of the wider swing of the transmitter frequency. The same is true of an AM signal, except that the increase in loudness is due to an increase in power, not to the bandwidth of the signal. However, there is a limit to how much the power can be increased by modulation before heavy distortion will occur. When the power is fully modulated (100% modulation), the effective range of the transmitter is at maximum.

When an AM transmitter is modulated, its power output increases. Modulation can be checked by watching for an increase in power output, as indicated by an RF wattmeter or field-strength meter, while speaking into the microphone.

With an RF power monitor (such as the Sierra Model 164 described later in this chapter), the modulation percentage can be determined by reading the transmitter power output when unmodulated (Pcw) and modulated (Pm). The percentage of modulation is equal to 141 (Pm/Pcw — 1).

Overmodulation can be detected by noting the quality of the speech transmission while listening to the transmitted signal. Or a simple overmodulation detector (Fig. 10-27) can be constructed. It uses a diode, the negative output of which feeds the grid of an electron-eye tube. Terminal *A* is connected to the plate of the modulator tube or at the output of the modulation transformer, and *B* is connected to the transmitter chassis ground. Normally, this point is positive; but during overmodulation, the voltage swings negative on peaks. As a result, diode V1 conducts, causing current to flow through R1 and a negative voltage to be applied to the grid of the electron-eye tube. The eye will blink on overmodulation peaks.

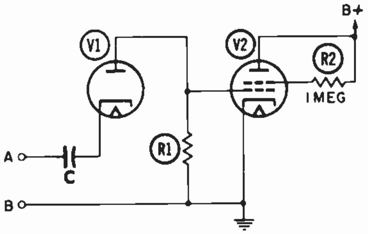


Fig. 10-27. Simple overmodulation indicator.

The percentage of modulation can be measured with an oscilloscope. The vertical-deflection plates of the scope are fed RF from the transmitter. This is done by placing a pickup coil (L) near the final RF tank, as shown in Fig. 10-28. The horizontal plates are connected to the output of the modulator. When modulation is 100%, a sharp-pointed, straight-sided triangle will appear on the scope screen. The AF and RF signals are fed directly to the deflection plates of the CRT, not through the scope amplifiers. Detailed information on using an oscilloscope to measure modulation can be found in amateur radio handbooks.

RF POWER METERS

Transmitter output power can be measured with an RF wattmeter. The wattmeter acts as a dummy

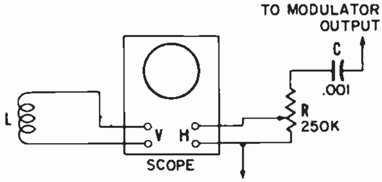


Fig. 10-28. Measuring modulation with an oscilloscope.

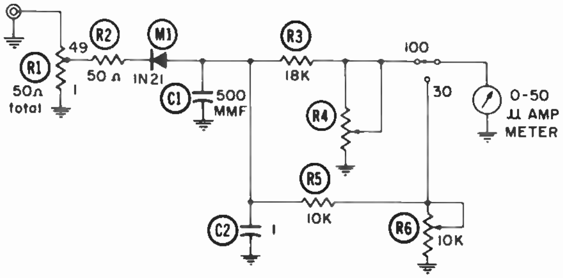


Fig. 10-29. Termination-type RF wattmeter.

load in place of the antenna, or it can be inserted into the antenna transmission line. Fig. 10-29 is a schematic of the Sierra Model 185A termination wattmeter. R1 is the dummy load into which the transmitter output is fed via a coaxial line. A portion of the voltage developed across R1 is obtained at a tap one ohm above ground. This voltage is fed to a rectifier, which converts the RF to DC so it can be read with a DC microammeter (the scale of which is calibrated in watts). A two-position switch enables selection of full-scale readings of 30 or 100 watts. R4 and R6 are variable calibration resistors.

Fig. 10-30 shows a "thru-line" type of RF wattmeter. The technician is tuning the transmitter for maximum power output by observing the wattmeter reading. Note the 50-ohm dummy load plugged into the receptacle (at the left side of the instrument).

The Sierra Model 164 bidirectional power monitor can be used

Fig. 10-30. Using a "thru-line" type of RF wattmeter. (Photo by Jacques Saphier.)

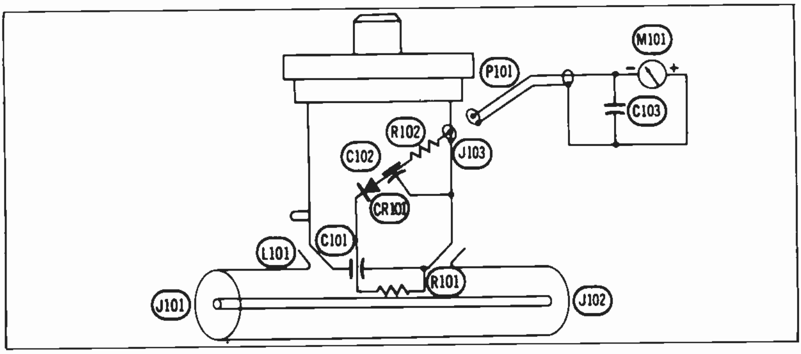


Fig. 10-31. Sierra Model 164 power monitor.

for measuring reflected and incident power up to 1,000 watts, at frequencies from 2 to 1,000 mc. The VSWR (voltage standing-wave ratio) and power absorbed by the antenna can also be determined from the incident and reflected power readings. The instrument consists of a peak voltmeter which measures the voltage across a 50-ohm impedance. Fig. 10-31 is a schematic of the Model 164.

Various plug-in elements determine the frequency range and the full-scale metering ranges. When set one way the element measures incidental power; set the other way (power flows toward the transmitter), it measures reflected power.

The power absorbed by the antenna system is equal to the difference between the incident and the reflected power. If the incident power is 50 watts, for example, and the reflected power is 5.5 watts, the power absorbed by the load (antenna system) is 44.5 watts.

SIGNAL GENERATORS

Signal generators (formerly called oscillators) provide a voltage whose frequency, character, and amplitude are known. In this way, receiver circuits can be aligned and receivers checked against a known standard.

In the early days of radio, the signal generator was a crude affair. Almost any device which generated a radio signal of approximately the proper frequency was used. As the art developed, the standards for test signals became more rigid. During World War II, radio service technicians at military bases became indoctrinated into the use of precise signal sources. They were required to align receivers so that the dial calibrations agreed with the frequencies received. Receivers had to meet specified standards of sensitivity in terms of so many microvolts input for so many audio volts output. Selectivity, AVC action, and image rejection were among the tests that had to be made. Any receivers not conforming to these standards were rejected for military use.

The same thinking applies to mobile radio. Receivers are expected to provide a usable output with signal levels of less than one microvolt. The receiver bandpass must be adequate to accept an FM signal without excessive distortion, but with ample rejection of adjacent and co-channel signals.

In the hands of an expert, even an electric shaver will do as an emergency signal generator. When held close to the antenna lead-in, an electric shaver creates enough "hash" to enable an expert to align the circuits so that the receiver will be highly sensitive. Given the proper tools, the expert can do a far better job. With around one million mobile units in service, there aren't enough true experts around who can service them without adequate instruments. Fortunately, adequate instruments are available to enable even a newcomer to do a fine job.

Four known frequencies are required to align a triple-conversion superheterodyne receiver. ("Known" means that the frequency of the test signal must be known within very close limits. Approximately on frequency won't do.) To align the receiver section of a Kaar TR500 mobile unit, for example, it is necessary to align the third IF amplifier to 1,500 kc, the second IF amplifier to 10 mc, the first IF amplifier to 50 mc, and the RF section to the assigned frequency (somewhere between 450 and 470 mc).

Since the 1.5-mc (1500-kc) signal fed into the third mixer is fairly large, an ordinary signal generator will do for aligning the third IF amplifier section, provided its frequency calibration can be relied upon. The same signal generator may suffice for aligning the second IF amplifier to 10 mc, because its calibration can be checked against WWV. Even the third IF amplifier can be tuned to 50 mc with some of the lower-priced signal generators, if the frequency calibration is dependable and its output attenuator will reduce the signal level enough.

However, to align the front-end to a specific channel in the 450-470 mc band, a laboratory-grade signal generator is required because it is necessary that (1) the test signal can be reduced to less than one microvolt, (2) its frequency can be set accurately, and (3) it will remain put long enough for the alignment to be made.

Although there are low-priced signal generators (from $28.50 to over $100) that will produce test signals for the 25-50 and 152-174 mc bands, they differ vastly from more adequate signal generators priced from $200 to $2,000. The differences are in frequency calibration, frequency stability, and the ability to attenuate the output to less than one microvolt. The output control might indicate that the output should be one microvolt or so, but leakage around the attenuator and through the instrument case may result in a much larger signal.

At 455 kc (the IF of most home radio receivers and the low IF of some communications receivers), it is relatively easy to design a signal generator with the required stability and signal attenuation. It is still easy at, say, 10 mc. Above 25 mc, however, a high-grade instrument is required.

There are many signal generators which meet the requirements of mobile radio servicing. Prices start at around $200 and extend upwards to $2,500. During World War II, when most Allied planes were equipped with SCR-522 VHF two-way radio units, only the military 804B VHF signal generator was available, even to military establishments. As a result, engineers at the Sacramento Air Depot (now known as McClellan Air Force Base) designed their own. One of the first successful units was designed by David Scott, who is now on the staff of Hewlett-Packard Co. Scott's stable signal generator was unique at the time, because its output could be successfully attenuated to the 1-

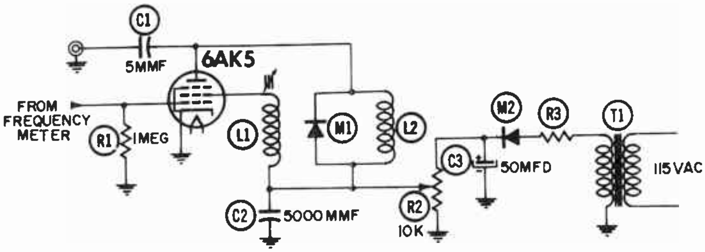


Fig. 10-32. Circuit of attachment for Lampkin frequency meters.

microvolt region. A piston-type attenuator slid in and out, moving the output pickup coil closer to or farther from the oscillator tank.

From the standpoints of frequency stability and accuracy of calibration, tunable heterodyne-type frequency meters such as the Lampkin, Gertsch, and Wayne-Divco make excellent signal generators. The military BC-221 is also excellent below 20 mc.

A signal generator, the output of which can be attenuated to a very low value, is preferable for measuring frequency sensitivity and for general shop use. However, an attachment for the Lampkin 103-A, 103-B, and 105-B frequency meters extends the output signal range to 500 mc and provides means for attenuating the signal. Thus, when used with the Lampkin 450-mc harmonic generator, the frequency meter converts the generator into a combination frequency meter and a variable-output signal generator that will cover all three landmobile radio bands.

The schematic in Fig. 10-32 shows the simple circuitry. The output of the frequency meter has a 6J7 tube in an oscillator circuit. The fundamental frequency of this circuit can be tuned from 2,330-2,670 kc. This output is fed to the grid of a 6AK5 tube. The amplifier is broadly tuned by L1 to 7,500 kc. Crystal diode M1 clips and distorts the signal voltage to generate high-order harmonics. The output signal is fed from the plate of the 6AK5 to a coaxial connector. At 450 mc this signal is about 10 microvolts. Above 20 mc it can be cut down to less than one microvolt by adjusting potentiometer R2, which controls the level of the screen voltage applied to the tube.

Unlike most signal generators, which are AC operated, the DuMont 5890 frequency meter (which also functions as a signal generator) can be operated from dry batteries. For aligning RF circuits, it can produce up to 24 frequencies between 25-470 mc (determined by the crystal selected by the frequency selector). It can also be used for aligning RF circuits at frequencies between 100 kc and 25 mc (the frequency again being governed by the crystal selected). Hence, a tuning adjustment is not needed.

Three signal output jacks are provided. Two are coaxial types, one for the high and one for the low output, plus a tip jack for the high-level IF output signal. As shown in the simplified schematic of Fig. 10-33, the IF output can be obtained at (1) the pin jack, fed directly through C1 from the screen of the oscillator tube; (2) the high-output jack, fed from the plate of the tube; or (3) the low-output jack,

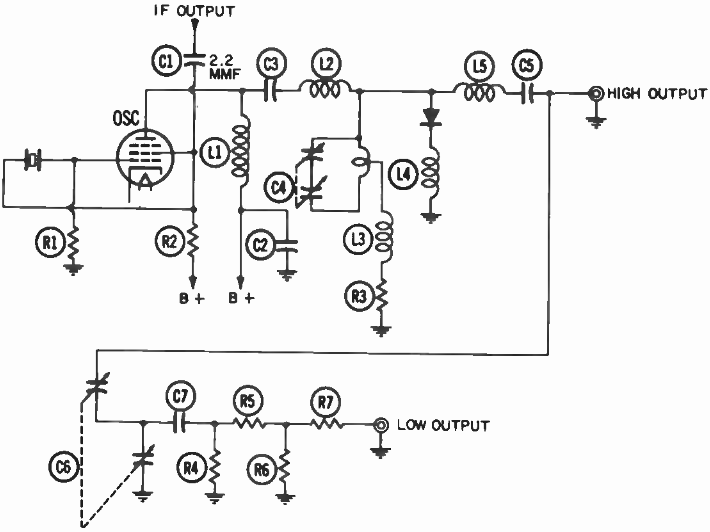


Fig. 10-33. DuMont frequency meter used as crystal-controlled signal generator.

fed through a voltage-divider type capacitive attenuator C6 and a resistive attenuator network consisting of R4, R5, R6, and R7. At least 1,000 microvolts are available at the pin jack, and 200 microvolts, at the high-output jack. The attenuator varies the output at the low-output

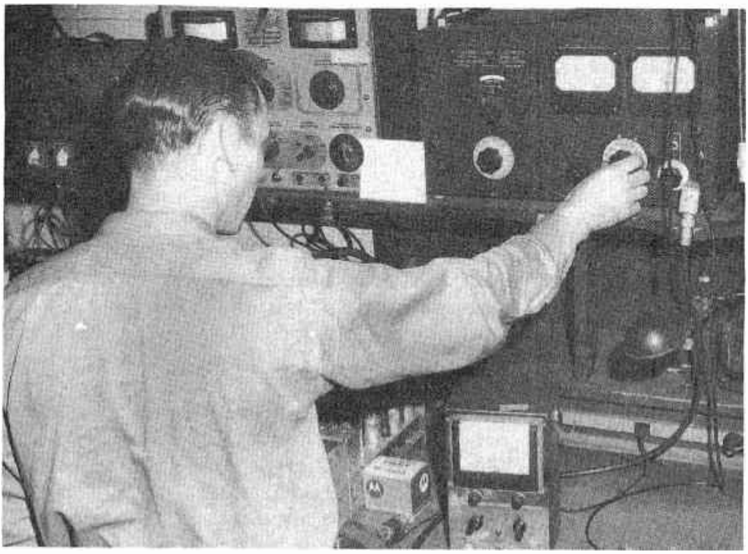


Fig. 10-34. This signal generator delivers a signal between 5 and 475 mc. (Courtesy of Mobile Communications.)

jack from around 0.5 to 2 microvolts.

The signal generator in Fig. 10-34 can be set to any frequency within its six bands, between 5 and 475 mc, with an accuracy of ±0.5%. The RF output can be set to any desired level between 0.1 microvolt and 100,000 microvolts by means of a mutual-inductance type piston attenuator. An internal oscillator can be set to amplitude modulate the RF signal at either 400 or 1,000 cps, from 0 to 30%. An external audio oscillator like the one in Fig. 10-35 will modulate the oscillator at any frequency from 50 to 10,000 cps.

Fig. 10-35. This audio oscillator delivers a true sine-wave signal. (Courtesy of Donner Scientific Company.)

Fig. 10-36 is a block diagram of the Measurements Corporation Model 80-R standard signal generator. Two meters are provided. One indicates the modulation percentage, and the other, the reference output level above the amount of attenuation caused by the attenuator. The output is taken from a Type N connector, through a 50-ohm cable terminated in a 50-ohm load. The cable has binding posts which can be connected to the receiver under test. The manufacturer recommends the use of a 6-db pad at the output to isolate the attenuator system from the effects of standing waves, which may be present when the load is of uncertain impedance.

Fig. 10-37 is an external view of another Measurements Corporation signal generator, the Model M-560. It has six bands. Three bands provide continuous coverage from 25 through 54 mc. The other three cover 140-174, 400-470, and 890-960 mc. The signal for the last band is the second harmonic of the oscillator when tuned between 445-480 mc. The dial calibration is accurate within 0.5%. The output voltage can be adjusted from 0.1 to 100,000 micro-volts by the use of a mutual-inductance attenuator of the wave-guide-below-cutoff type.

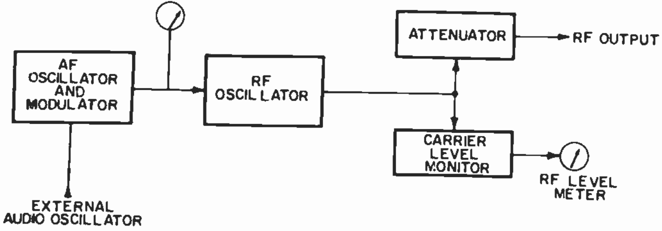


Fig. 10-36. Measurements Corporation Model 80-R standard signal generator.

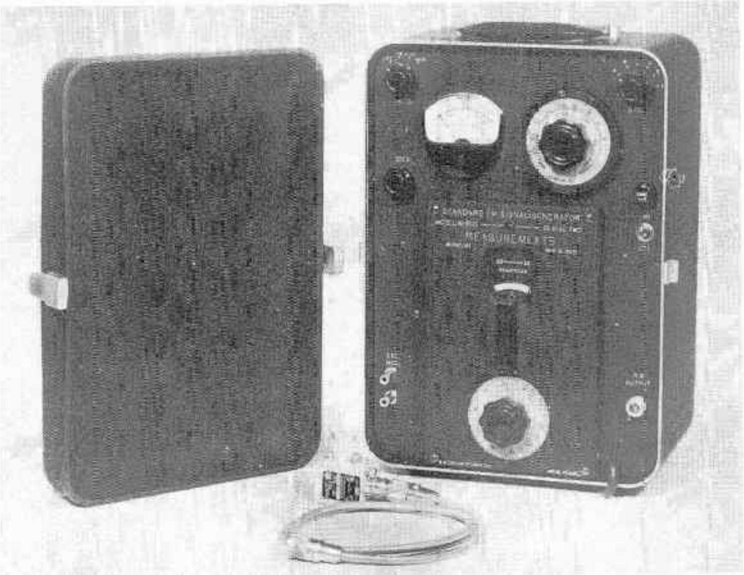


Fig. 10-37. The Model M-560 FM signal generator covers the landmobile bands. (Courtesy of Measurements Corporation.)

Fig. 10-38. The Model 1066A signal generator produces a CW, AM, or FM signal. (Courtesy of Marconi Instruments, Ltd.)

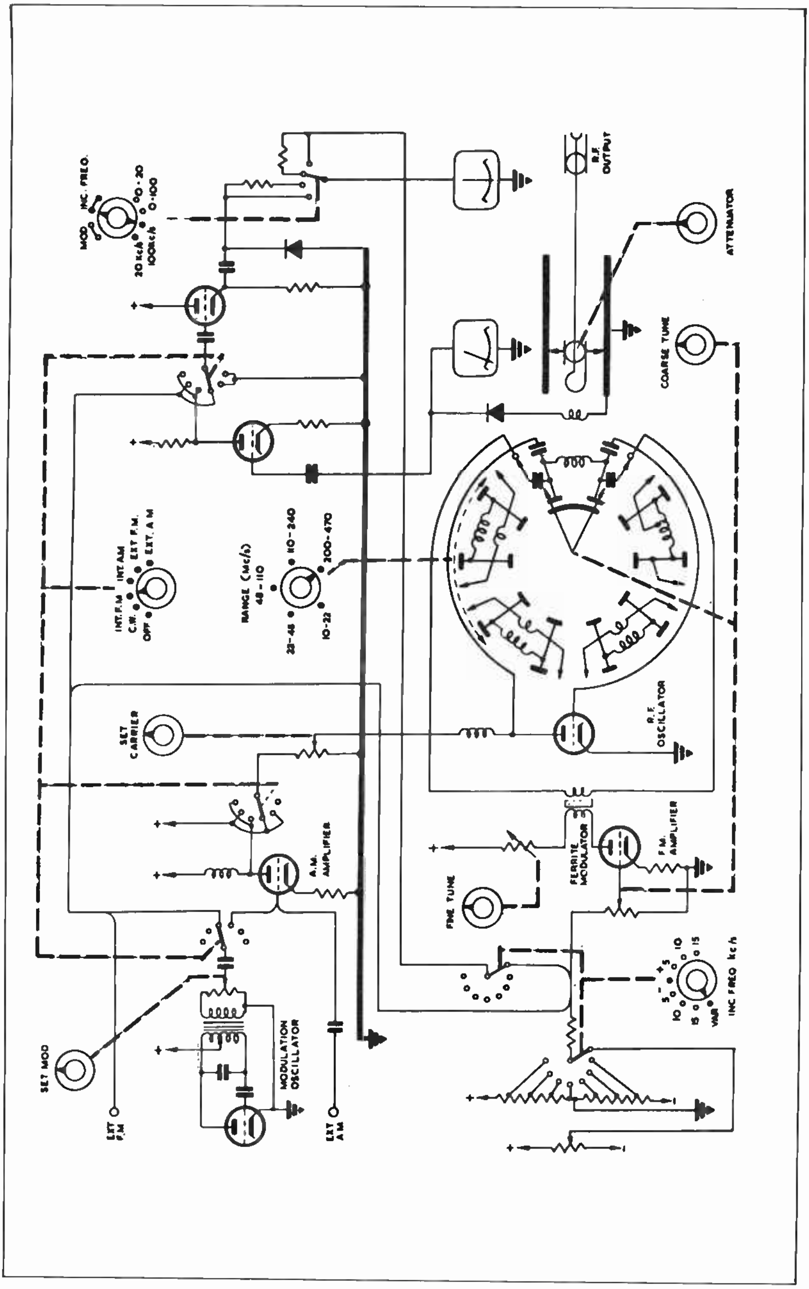


Fig. 10-39. Functional diagram of the signal generator in Fig. 10-38. (Courtesy of Marconi Instruments, Ltd.)

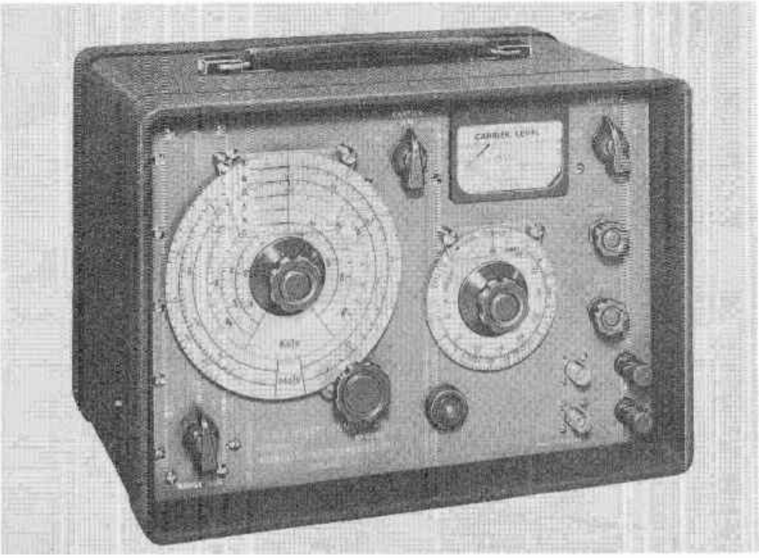


Fig. 10-40. The Model 1064 signal generator is designed for mobile radio servicing. (Courtesy of Marconi Instruments, Ltd.)

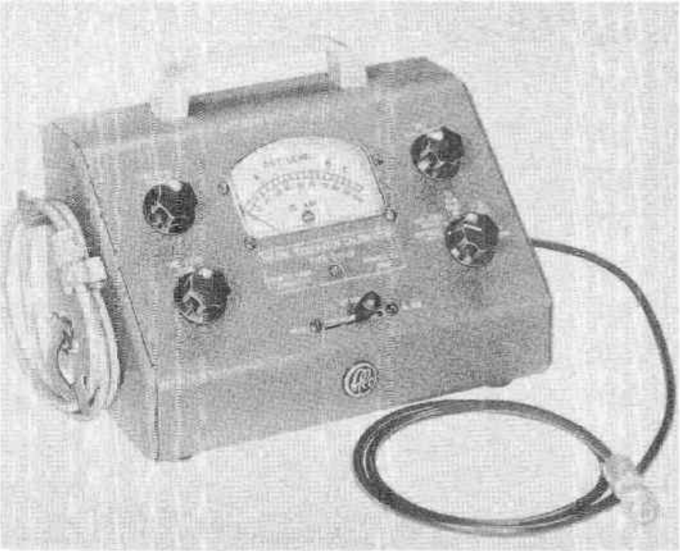


Fig. 10-41 Signal-generator calibrator. (Courtesy of Boonton Radio Corp.)

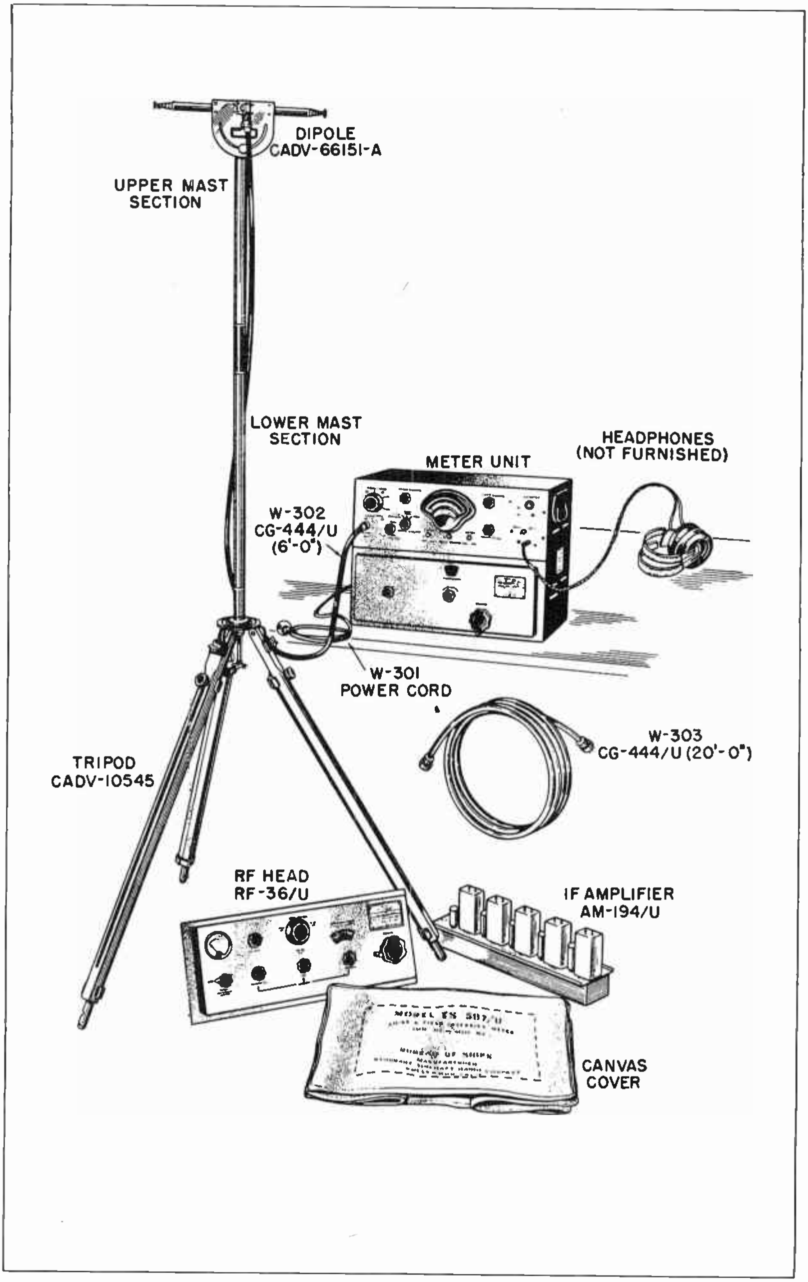


Fig. 10-42. Stoddart TS-587/U field-strength meter for the 15-400 mc range. (Courtesy of Avionic Associates.)

The signal generator is frequency modulated (FM) at 1,000 cps, the signal deviation being adjustable from 0 to 16 kc peak. FM can be obtained at other modulating frequencies by using an external audio oscillator.

The Marconi TF 1066A signal generator (Fig. 10-38) covers from 10-470 mc in five bands, providing a CW (unmodulated), FM, or AM signal with an open-circuit output voltage adjustable from 0.2 to 200,000 microvolts. The output impedance is the standard 50 ohms. The signal can be modulated at 1,000 or 5,000 cps by the internal oscillator, with a frequency deviation up to 100 kc, or AM up to 40 per cent. When an external audio oscillator is used, an FM signal modulated at any frequency between 30 to 15,000 cps can be obtained.

Two tuning knobs are provided, one for coarse tuning (below the tuning dial at the left in Fig. 10-38), and the other for fine tuning (above and to the right of the dial). Fig. 10-39 is a functional diagram showing the band-selector circuitry and the shunt-fed Colpitts oscillator circuit.

Another Marconi signal generator is shown in Fig. 10-40. Especially designed for mobile radio servicing, it provides CW, AM, or FM signals at the most popular RF and IF frequencies.

Signal generators are generally recalibrated by the manufacturer or at a specialized instrument service depot. However, spot calibrations can be made against signals from WWV on 2.5, 5, and 10 mc. Fig. 10-41 shows a typical calibrator. It provides direct, calibrated measurements of the RF voltage at 25,000, 50,000 and 100,000 microvolts, plus serving as a calibrated source of RF voltage at 0.5, 1, and 2 microvolts. Another model delivers 5, 10, and 20 microvolts. The calibrator also measures the modulation percentage of the signal generator, between 500 kc and 1,000 mc.

FIELD-STRENGTH METERS

The transmitter output can be gauged and the radiation pattern of an antenna determined with a field-strength meter. This can be a very simple device, or as elaborate as the one in Fig. 10-42. The meter illustrated will indicate the signal strength between 15 and 125 mc, down to 5 microvolts per meter, and between 100 and 400 mc, down to 20 microvolts per meter.

Far more simple, but less sensitive, is the instrument in Fig. 10-43. It consists of a 0-50 or 0-100 DC microammeter shunted by a crystal diode. For the 152-174 mc band, an 18-inch piece of wire can be extended from each of the two meter terminals to serve as a dipole antenna. For the 450-470 mc band, the elements need be only six inches long. For the 25-50 mc band, the antenna elements should be eight to nine feet long, although shorter lengths will suffice.

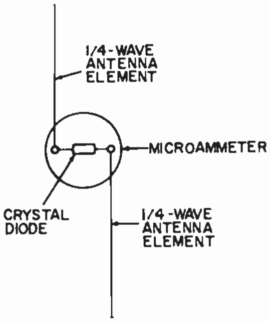


Fig. 10-43. A simpler (but less sensitive) field-strength meter than that in Fig. 10-42.

Another way to determine transmitter output and field strength is to measure the limiter voltage at a distant receiver and note any increase or decrease as the transmitter adjustments are made.

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