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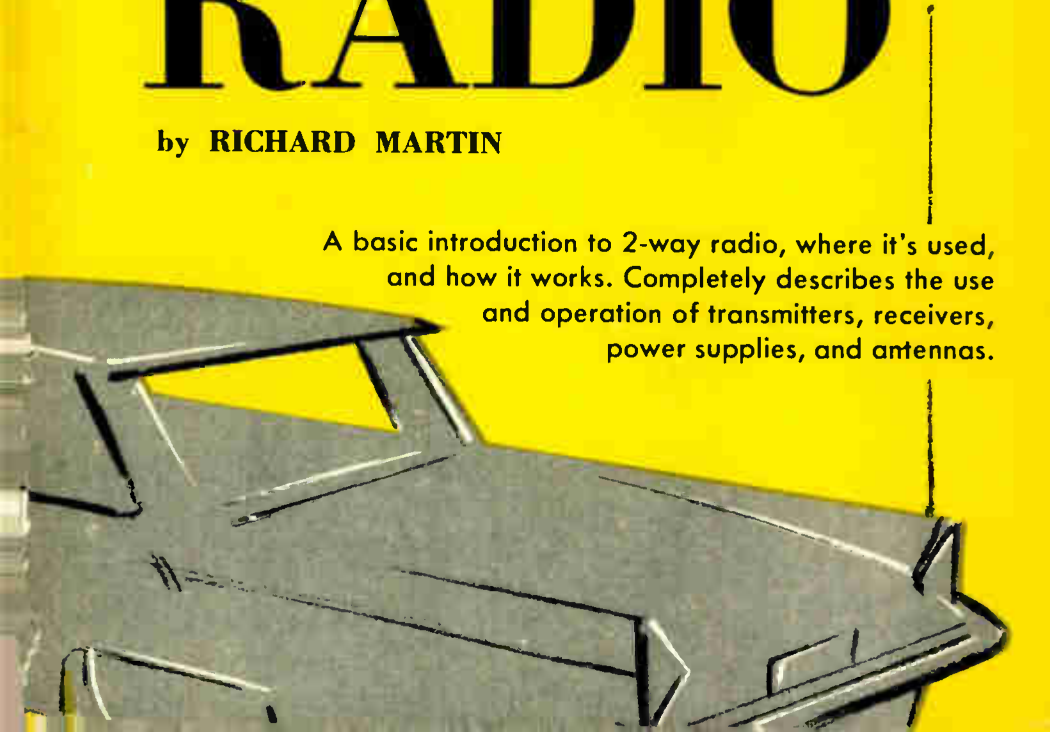
abc's of MOBILE RADIO

by **RICHARD MARTIN**

A basic introduction to 2-way radio, where it's used, and how it works. Completely describes the use and operation of transmitters, receivers, power supplies, and antennas.



$1.95
Cat. No. AMR-1

ABC's of
MOBILE RADIO

by RICHARD MARTIN

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

FIRST EDITION
FIRST PRINTING — APRIL, 1962

ABC's OF MOBILE RADIO

Library of Congress Catalog Card Number: 62-15010

Preface

While the telephone provides quick, convenient communications between two stationary points, it is still stationary. You cannot pick it up and take it with you.

Progress has thus created a strong demand for a more versatile means of communications. People in service businesses, government activities, professional work, and many other fields need some means of keeping in touch with their offices and with each other. This need has been met by the use of radio.

Radio waves need no wires to travel through; therefore, anywhere a radio wave can go, communications can be maintained. With the use of radio, police cars cruising streets, roads, and highways can be alerted at a moment's notice; a taxicab can be dispatched to a location within seconds; and a businessman need never lose contact with his office, not even while in his car.

ABC's of Mobile Radio was written for the benefit of users or potential users of two-way radio equipment, and technicians and students who need an introductory text on the subject. In addition to a complete explanation of mobile-radio communications systems and their applications, the content includes basic but comprehensive discussions of transmitter and receiver operation. Power supplies and antennas are also discussed.

My special thanks to the manufacturers who so willingly submitted some of the photographs and diagrams included herein, thereby making it possible to prepare a modern, up-to-date publication.

RICHARD MARTIN

March, 1962

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Chapter 1

Two-Way Radio Communications

Recent technical advances in the field of two-way radio have resulted in vastly improved equipment design. Modern two-way radios are much smaller and consume less primary power than their predecessors. For example, a mobile two-way radio now takes up less space than a small overnight case and consumes less battery power than the headlights of the automobile. Moreover, it is quite easy to install and remove for servicing.

Since only one two-way radio is no better than a disconnected telephone, a second radio is required on the same operating frequency to establish communications. Usually there is a main two-way radio centrally located in the desired area of coverage. It is a stationary type and is aptly referred to as the "base station," since it is generally the one from which most communications originate.

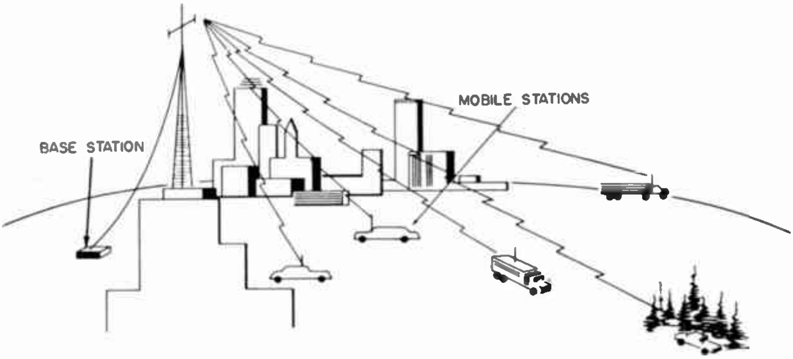


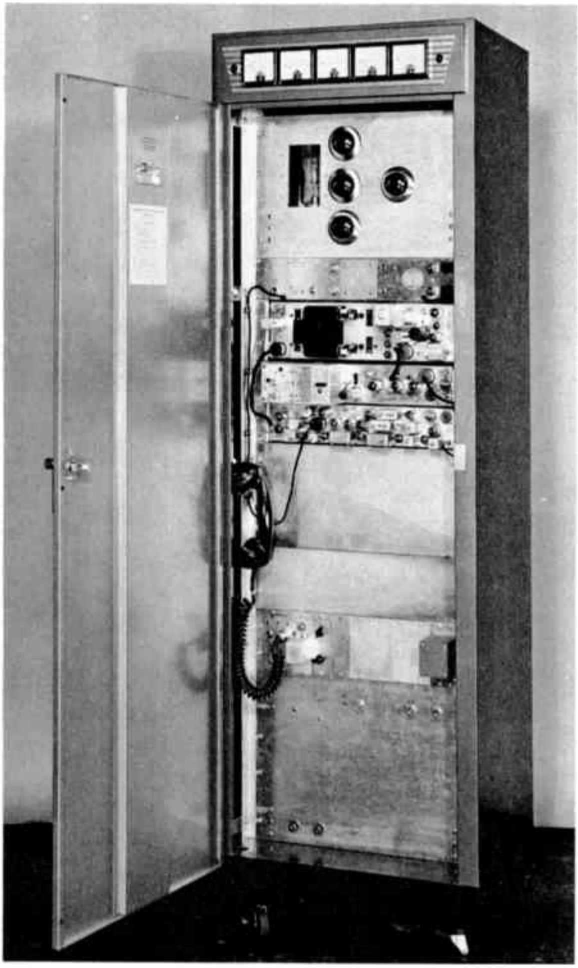
Fig. 1-1. Relationship between base and mobile stations.

Courtesy Bendix Radio Corporation.

Fig. 1-2. Typical 60-watt base station.

A two-way system may consist of any number of base or mobile units. Most are comprised of one base, and several mobile stations. Fig. 1-1 shows that the mobile units are free to move about the centrally located base station without losing radio contact. The farther apart the base and mobile stations are, the weaker the received radio signal becomes. Moreover, weak signals are sometimes blocked completely by intervening buildings, terrain, etc., thus resulting in complete loss of communications.

Figs. 1-2 and 1-3 show typical 60- and 250-watt base stations, respectively. In contrast, a mobile two-way radio appears in Fig. 1-4. Notice how conveniently this small mobile unit fits into the trunk. It can also be removed from the trunk



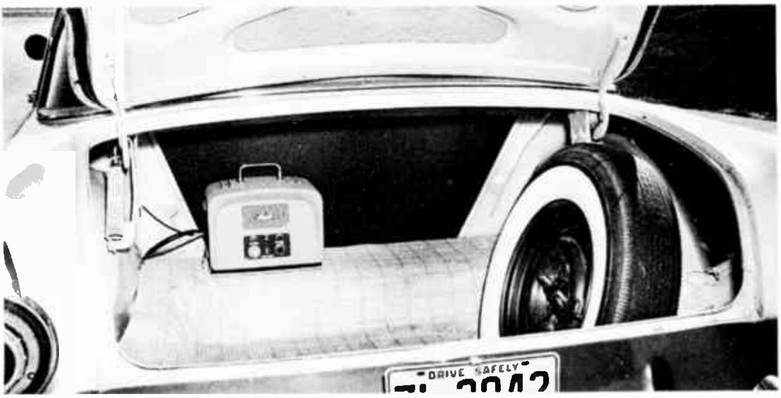
Courtesy Bendix Radio Corporation.

Fig. 1-3. Typical 250-watt base station.

and used for portable operation (Fig. 1-5). Both the base and the mobile units are capable of receiving as well as transmitting a signal.

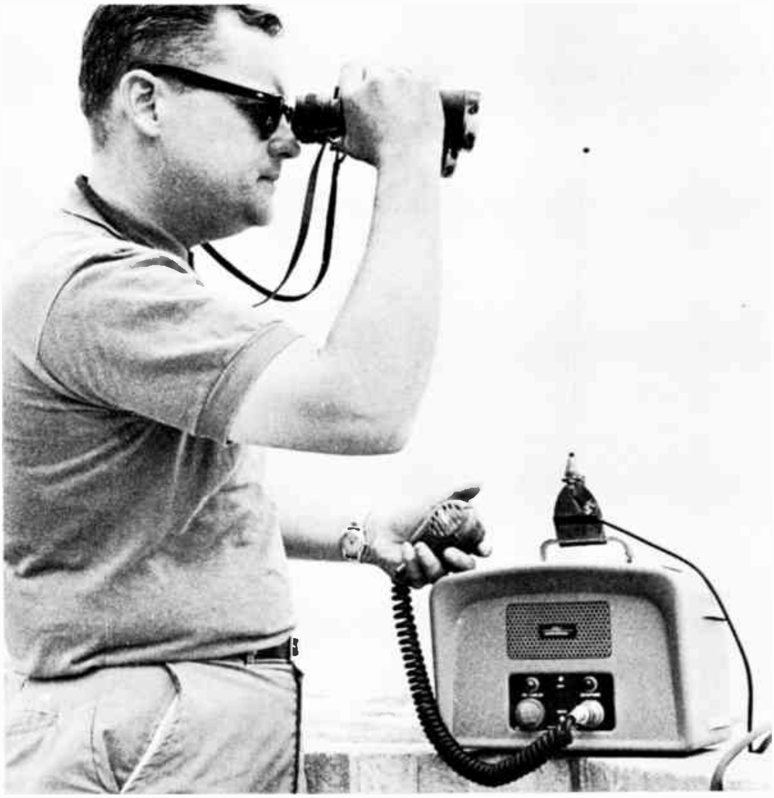
HOW FM TWO-WAY RADIO OPERATES

Two-way radio is comparable to a telephone system except there are no interconnecting wires. In fact, two-way radio is often called radiotelephone. A telephone mouthpiece and a microphone are practically the same, and in many cases, elec-



Courtesy Aerotron Company.

Fig. 1-4. A trunk-mounted two-way radio.



Courtesy Aerotron Company.

Fig. 1-5. The two-way radio of Fig. 1-4 can also be used as a portable station.

trically they are directly interchangeable. The microphone converts the voice into small electrical impulses, which are amplified and used to vary (modulate) the frequency of a carrier signal generated by the transmitter oscillator. It is the amplified latter signal that carries the electrical equivalent of the voice through the air to the receiving station. Here the transmitted wave is picked up by an antenna and fed into the receiver, where it is amplified and the voice signal recovered from it much as in a conventional radio. Ultimately the message is heard through the speaker.

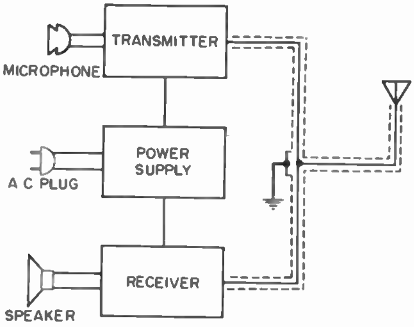


Fig. 1-6. Block diagram of a two-way radio system.

Fig. 1-6 shows the three basic sections to the complete two-way radio. These are a transmitter, receiver, and power supply. The only basic difference between a base and mobile station is that a base station operates from the standard 110-volt AC line, whereas the power supply of a mobile station relies on energy from the automobile battery. In either case, the radio power supply is designed to supply the necessary operating voltages. The transmitter and receiver sections of the base and mobile units are directly interchangeable. The only section not interchangeable is the power supply. In present-day two-way radio equipment, a *single* power supply provides the proper operating voltages for both the transmitter and receiver.

The transmitter to which this voltage is supplied amplifies the voice signal from the microphone and provides it with a radio-frequency (RF) carrier signal capable of being radiated from the antenna. The receiver, on the other hand, selects and amplifies the correct RF carrier (out of the countless number existing in space). Then it separates and amplifies the audio (voice) signal originally produced by the microphone. Finally, the receiver converts the audio signal, by mechanical means, back into sound waves that can be heard and understood. Notice that both the transmitter and receiver use the same antenna (Fig. 1-6). A relay arrangement automatically switches the antenna from the receiver to the transmitter circuitry whenever the push-to-talk button on the microphone is depressed. This will be covered later in another chapter.

REMOTE CONTROL AND POWER CABLING

Two-way radio equipment is generally mounted as near the antenna as possible, especially in the case of base stations. Usually this places the radio equipment some distance from the control point, so that some form of remote control is required. There are two basic reasons for remoting base-station equipment. First of all, seldom is there adequate space for a cumbersome radio cabinet in the room where the operator sits. Secondly, by locating the base equipment close to the antenna, a shorter length of transmission line is required. This is important because the RF signal loss incurred in the line increases with the length of the line. Therefore, the shorter the over-all distance between the transmitter and antenna, the lower the line losses, and thus the more radio-frequency energy radiated from the antenna.

Remote-Control Amplifier

When the radio equipment is to be remote controlled, an amplifier must be employed to boost the strength of the audio signals going to the transmitter and coming from the receiver. This amplification is necessary because the electrical signal produced by the microphone is weak to begin with, and in most remote systems there is enough loss in the lines between the microphone and the transmitter to effectively "dissipate" a weak signal. An insufficient microphone signal will result in poor reproduction of the voice at the receiving station, and if too weak, could permit noise to be amplified and transmitted along with what little audio voltage did get through. The received message then would be so weak and scratchy that communications would be very poor. To overcome this condition, the microphone is directly connected to a remote-control amplifier (Fig. 1-7), which boosts the microphone voltage more than enough to offset any losses incurred in the control lines feeding the transmitter. With more than sufficient audio signal being applied to the transmitter, the voice heard at the receiving station will be loud and clear.

In addition to amplifying the signals from the microphone, the remote-control unit also amplifies the audio signals en route from the receiver to the speaker (located at the control point), and is even used in conjunction with similar units as an intercom system. In many models, "alert" tones (to indicate that a message will follow) can be generated and transmitted over the air by pushing a single button. The remote-control unit also has provision for activating the transmitter to put messages on the air. The transmitter is normally in a standby condition, allowing incoming signals to be received. When it is activated to make a transmission, the receiver is automatically disabled.

Courtesy Communications Company, Inc.

Fig. 1-7. A typical remote-control amplifier.

Fig. 1-8 shows an intercabling diagram of a remote base-station system. Only two wires are used to perform the functions just described. This is made possible by applying the amplified microphone signal (AC) to the same wires that carry DC from the remote amplifier to the remote-control chassis to operate the transmitter relays. A schematic of a

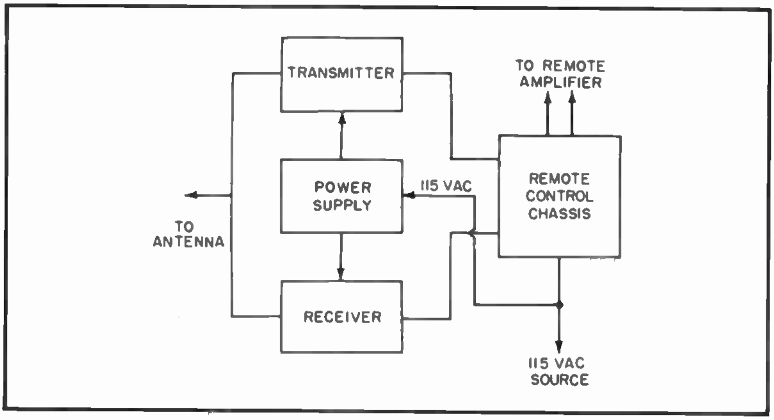


Fig. 1-8. Base-station intercabling.

remote-control amplifier is shown in Fig. 1-9. When the microphone "push-to-talk" button is depressed, relay M1 is energized and switches the amplifier circuit from the "receive" to the "transmit" mode.

The microphone signal is coupled from the mike plug, through mike gain control R1, to the first audio amplifier (V1A). Here the signal is amplified and passed along (M1 contact 6 is shown in the "receive" position), to be further amplified by V1B and V2. The now strong audio signal is coupled to the L2 secondary winding of transformer T1. From here the signal is fed, via M1 contacts 7 and 9, to the L4 portion of the T2 primary, and then appears at the L5 and L6 secondaries of this transformer. L5 and L6 are directly connected to the control lines at an appropriate terminal board.

At the time relay M1 was energized and all its contacts (shown by dotted lines) were transferred, DC voltage was then taken off the cathode of V4A through contacts 2 and 3 and applied to the control lines at L5 and L6 of T2. This voltage is impressed on the lines connected to the transmitter. In the transmitter, a relay is energized by this DC voltage. Its contacts actually control the operation of the remote transmitter.

When the microphone "push-to-talk" button is released, relay M1 drops out and the amplifier circuit returns to the normal "standby," or receive position. At this time, any incoming audio signal on lines 1 and 2 (from the base receiver or another remote unit) is transferred to the amplifier circuit through the L4 and L5 secondaries to the primary of T2. From here the audio signal is fed to the volume control by way of M1 contact 8. The signal developed across this control is amplified in V1B and V2, and then coupled into T1. The M1 contacts are now in the receive (R) position as shown, so the amplified audio is heard through the speaker.

The power-supply section is straightforward. Full-wave rectifier V3 supplies more than enough voltage to power the amplifier, and a very efficient filtering system keeps AC ripple practically non-existent. If ripple were to be introduced into this unit, it could cause hum in the transmitted signal. Tubes V4A and V4B adjust the DC control voltage to the desired value, according to the transmitter used.

Base-Station Relay Control

By using a system of relays, the transmitter and receiver of a base station can be controlled directly from the remote-control amplifier. When the DC voltage from this amplifier is impressed across a relay in the "remote-control chassis," the relay is activated and transmitter operation is initiated. The

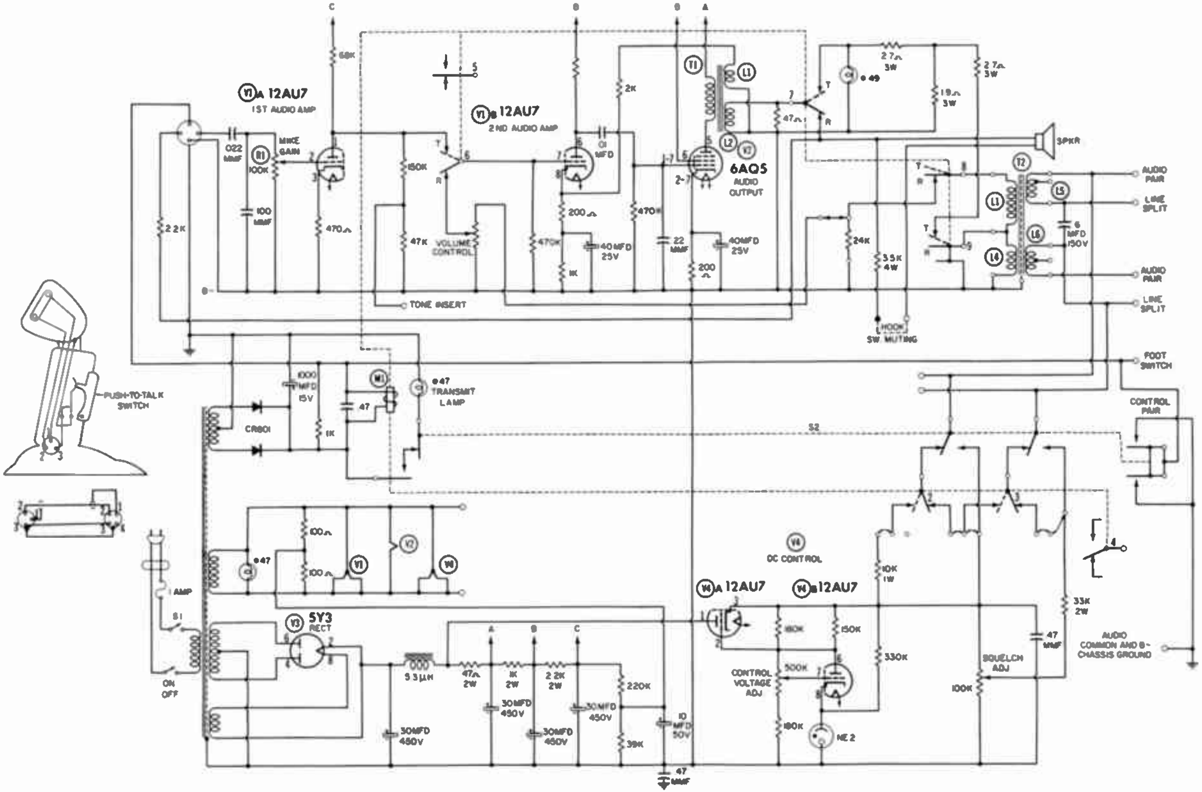


Fig. 1-9. Schematic of a GE remote-control amplifier.

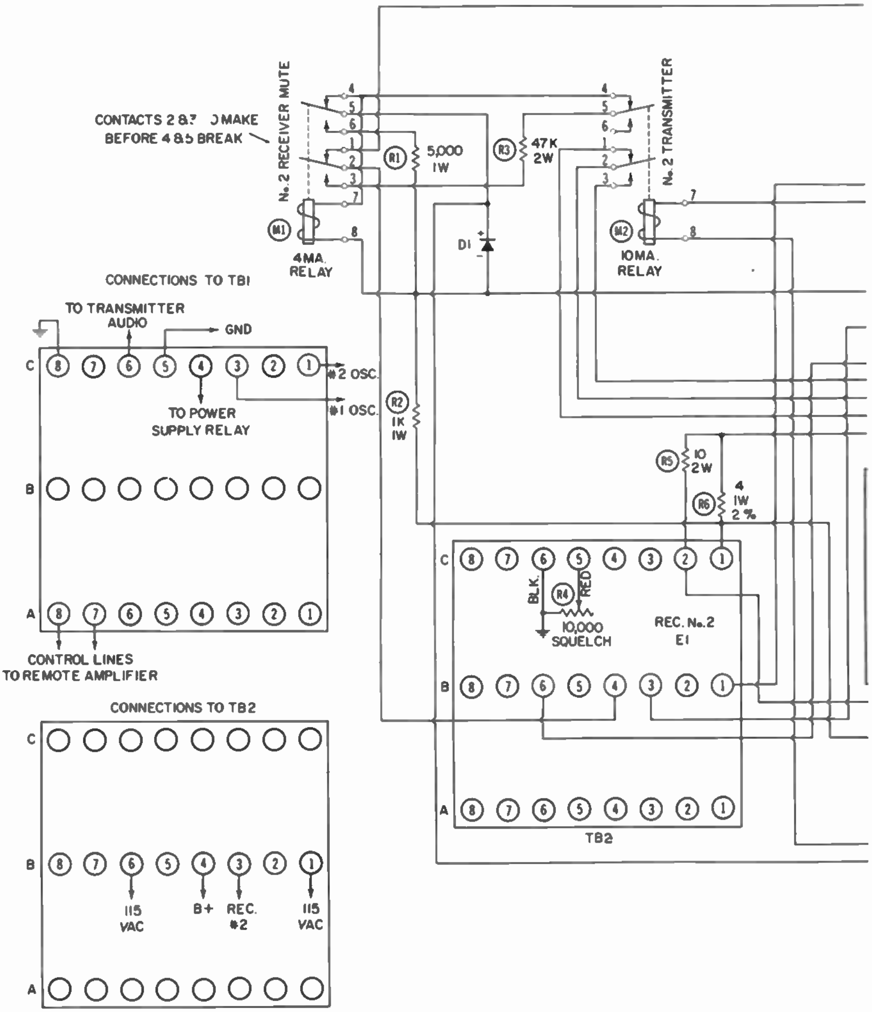
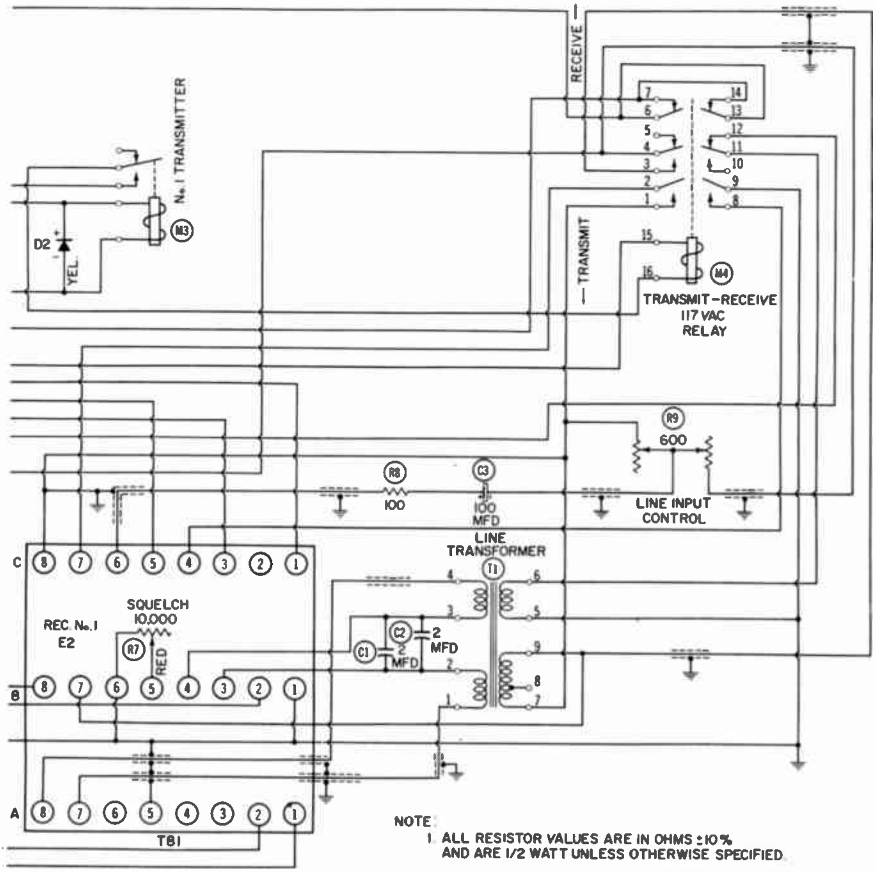


Fig. 1-10. Schematic of a



NOTE:
1. ALL RESISTOR VALUES ARE IN OHMS ±10% AND ARE 1/2 WATT UNLESS OTHERWISE SPECIFIED.

remote-control chassis.

remote amplifier and the transmitter are now directly connected, and the amplified microphone signal is as strong as, or stronger than, if the microphone output were fed directly into the transmitter. When the DC voltage is removed from the line ("push-to-talk" button released), the control relay returns to its normal resting condition. This disconnects the transmitter input and connects the audio output of the receiver to the control lines. The audio signal is then fed into the remote-control amplifier, where it is boosted in strength and then converted into sound energy to enable the dispatcher to hear the incoming message.

The heart of the base station is the remote-control chassis itself; it controls the transmitter, receiver, and power supply. For the sake of illustration, the transmitter output and the receiver input were shown as being connected together in the block diagram of Fig. 1-8. In reality, a relay connects the antenna to either the transmitter or receiver circuit, depending on the operation desired. In other words, when the microphone button is depressed, the relay is automatically energized and switches the antenna into the transmitter circuitry. Conversely, releasing the mike button returns the relay to its normal resting position, whereby the antenna is connected to the receiver circuit.

In Fig. 1-10 the lines coming from the remote amplifier are connected to terminals 7 and 8 of TB1-A. Transformer T1 has one end of each primary winding connected to terminals 7 and 8; therefore, the incoming voltage through these windings appears at TB1-A1 and 2. From terminal A1 the voltage (negative) causes current to flow through diode D1, relays M3 and M2, and then back to TB1-A2, which is positive. This current flow is sufficient to energize only relay M3 but not M2 (unless the No. 2 frequency is selected at the remote amplifier). It takes only 45 volts DC to produce enough current to activate 4-ma relay M3, while M2 (the 10-ma relay) requires 100 volts DC or more. However, when there is sufficient current to energize M2, M3 is also energized. Where only M3 is activated, contacts 5 and 6 complete the 117-volt AC circuit through transmit-receive relay M4. M2 contacts 1 and 2 are in series between ground and the transmitter No. 1 oscillator cathode. When M4 is then energized, the relay in the base-station power supply transfers its contacts and the transmitter is put on the air on frequency No. 1.

Notice the shielded wire connected to terminal 9 of the T1 secondary winding. The incoming audio-modulation signal is fed to this winding and is sent into the transmitter through the M4 contacts, line input control R9, C3, R8, and TB1-C6. The audio return path is through common ground. In this remote chassis, the line input control is of the pad type. As the control is adjusted in either direction, the amount of audio across it is changed correspondingly. However, the impedance of the circuit is not upset by this adjustment, as it would be if an ordinary potentiometer were used. Any such impedance change would cause distorted audio to be delivered to the transmitter, and the result would be indistinct modulation.

If the radio operator (at the remote amplifier) desires to transmit on frequency 2, he merely flips the frequency switch on the amplifier case itself. (This switch determines whether 45 or 100 volts DC is impressed on the control lines.) Now, when he depresses the push-to-talk microphone switch, relays M2 and M3 (in the remote-control chassis) will both be energized. Relay M3, of course, will pick up M4 and in turn place the transmitter on the air. Relay M2, however, now transfers its contacts 2 from 1 to 3. This removes the ground from the No. 1 oscillator in the transmitter, and connects the cathode of oscillator No. 2 to ground. Thus, the operating frequency of the transmitter is changed, and the operator is talking on a different channel.

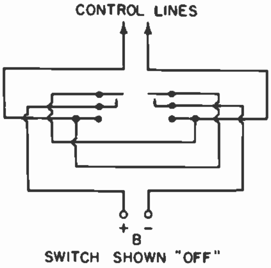


Fig. 1-11. Polarity-reversing switch connections.

In base stations equipped to receive two channels at the same time, Channel 1 almost always takes precedence over Channel 2; therefore, sometimes it is necessary to quiet Channel 2 in order to hear Channel 1. This is done by depressing the Channel 2 Mute switch located on the remote amplifier. The switch reverses the polarity of the voltage on the control lines. This feature is not included on the model in Fig. 1-10; however, Fig. 1-11 shows a simulated circuit for voltage polarity reversal. With the polarity of the control voltage reversed on the control lines, the voltage at TB1-A1 will now be positive and TB1-A2 negative. This means that D1 will block the positive voltage on TB1-A1, and relay M1 will be energized. As the M1 contacts are switching, contacts 2 and 3 make before 4 and 5 (pickup circuit) break. This establishes a constant voltage path from TB2-B4 through M1 via contacts 2 and 3 of M1 and 4 and 5 of M2. The return path from M1 is through D2 (this prevents relay M3 from being activated) and M2. M2 will not be activated because it requires 10 ma of current to do so, and only 4 ma is flowing. When M1 contacts 1 and 2 open, the B+ path to receiver No. 2 is broken. This, of course, "kills" the second receiver, leaving only receiver No. 1 operating. Since the holding path from M1 (receiver No. 2 mute) is through M2 (transmitter No. 2), after M2 has been energized, receiver No. 2 is again active.

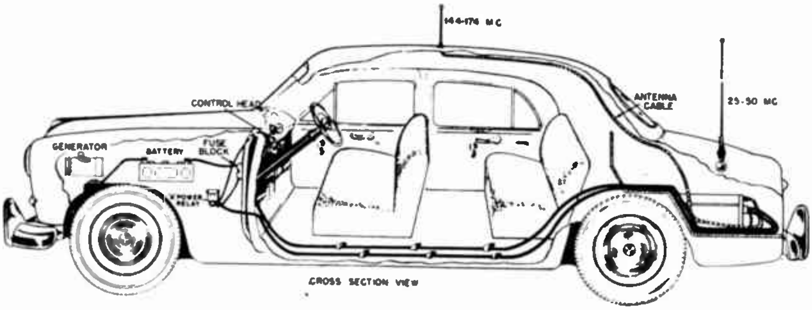
This completes the discussion on the remote-control amplifier and remote chassis. You can see that any necessary transmitter or receiver operation can be conveniently performed from the remote amplifier. Not covered in this discussion is the added feature of "tone alert," which is simply a one-tube low-frequency oscillator incorporated in the remote amplifier. Through an appropriate switching arrangement, this tone (approximately 100 cps) is fed into the control lines just like the microphone audio. This alert is generally used to call attention to a forthcoming message to be transmitted.

Mobile-Station Control

Basically, there is no difference between the operation of a base and a mobile station. Some mobile radios are designed to be mounted in the trunk, as shown previously, while others are mounted under the dashboard of the car (Fig. 1-12). The

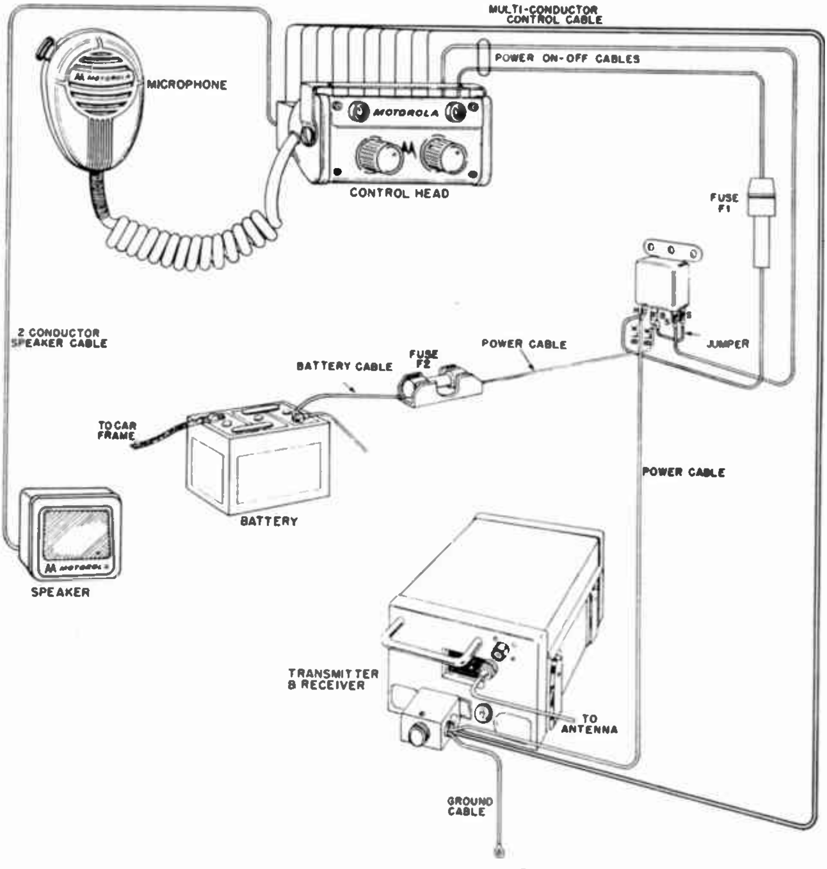
Courtesy General Electric Company.

Fig. 1-12. A transistorized GE dash-mounted two-way radio.



Courtesy Motorola C and E, Inc.

Fig. 1-13. Cutaway view of automobile, showing trunk-mount installation.



Courtesy Motorola C and E, Inc.

Fig. 1-14. Detailed intercabling arrangement for a typical mobile two-way radio installation.

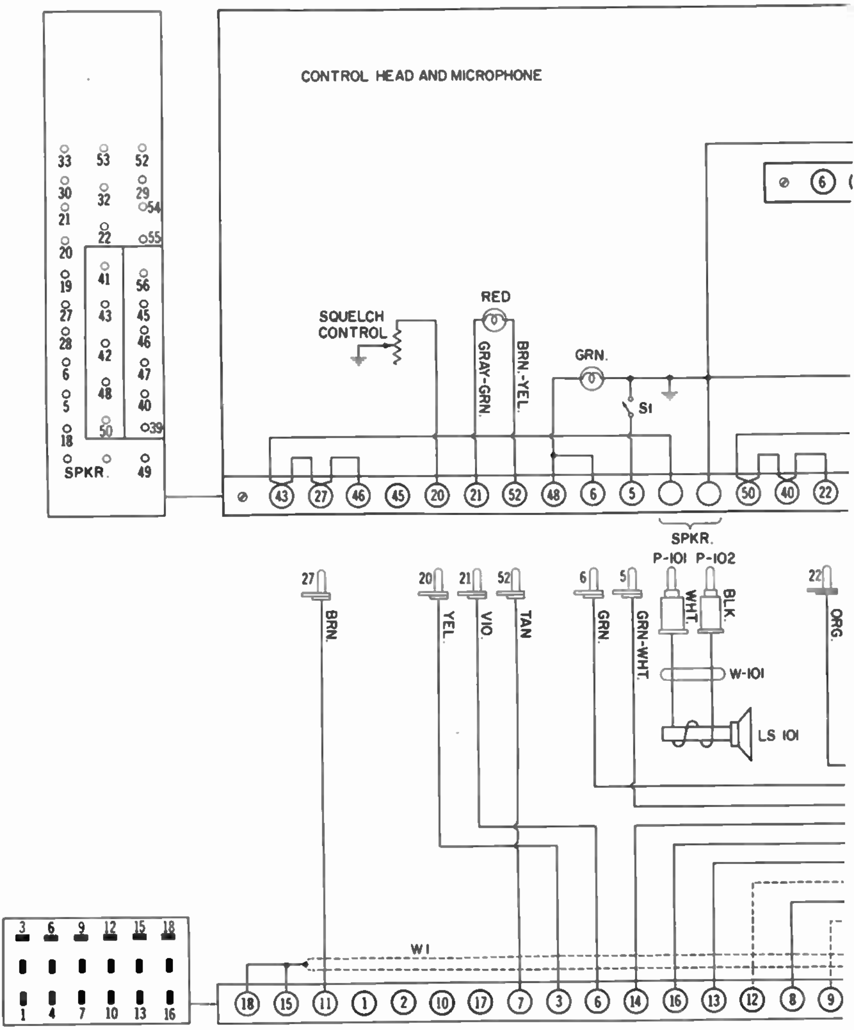
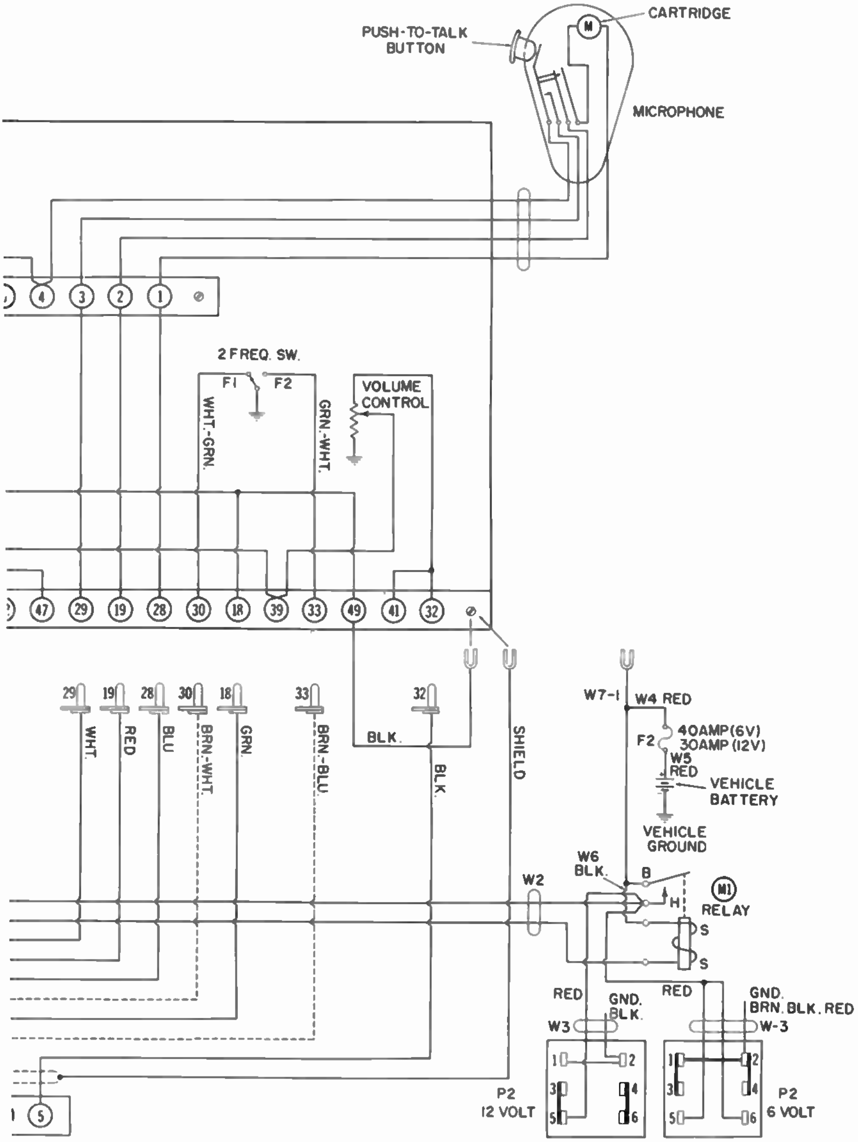


Fig. 1-15. Schematic of a



Motorola control head.

front-mount (dash-mount) type has the controls right on its cover. Fig. 1-13 is a cutaway view of an automobile, showing a trunk-mounted two-way mobile-radio installation; and Fig. 1-14 shows a more detailed view of the system. Notice the arrangement of the control head and radio. Since the radio and the operator are only a few feet apart, there is very little loss in the cabling and therefore no need for a remote amplifier.

A typical schematic of a mobile control head is shown in Fig. 1-15. When S1 (on-off switch) is turned on, the circuit is completed from one side of the car battery to the other side (ground) through power relay M1. The resulting current flow through M1 energizes it, causing its contacts to transfer and thereby completing the circuit from the battery to the power supply. The purpose of the power relay is to handle the heavy current flow (as high as 30 to 40 amps during transmitting) in the power cable. If this current were to be passed through the on-off switch itself, the switch would soon burn out. So, in order to present a small control head (instead of using a large switch to turn on the radio directly), this method is employed. Now, on-off switch S1 need pass less than 1 amp of current, for that is all the relay pulls.

A green lamp on the control-head panel indicates when the power is on, and a red one indicates when the transmitter is on the air. Notice the two-frequency switch, squelch, and volume controls. Every control necessary for 100% two-way operation is included in this one control box. All wiring from the control head to the radio is through a cable approximately 15 feet long terminated in a plug (P1) connected to the front of the radio itself, as shown in Fig. 1-14.

Chapter 2

The Transmitter

By themselves, the audio signals produced at the microphone cannot be radiated through space as radio waves. A radio transmitter, however, is designed to amplify these audio signals and provide for them an RF carrier signal that *is* capable of such radiation. The audio signals are then made to vary, or modulate, this carrier in such a way that it will contain the audio intelligence. One method of doing this is for the audio signal to vary the *amplitude* of the RF carrier in accordance with it, and the other involves varying the *frequency* of the carrier. Hence, the methods are termed amplitude modulation (AM) and frequency modulation (FM), respectively.

FREQUENCY AND PHASE MODULATION

Within the classification of FM is still another method of modulating the RF carrier known as phase modulation (PM). It is important that this method be understood in order to fully comprehend two-way radio, because it is used almost exclusively in commercial two-way radio.

The block diagram of a basic phase-modulated (PM) transmitter in Fig. 2-1 is similar to the frequency-modulated transmitter in Fig. 2-2 except for one major difference. This is the method by which the audio signal is introduced into the RF circuit. In the FM system of Fig. 2-3 the audio from the modulator is applied directly to the oscillator. This system, called "direct FM" because the oscillator is driven directly by the audio, differs from the PM system shown in Fig. 2-1. In Fig. 2-1, the audio is applied to the stage following the oscillator. This system is aptly called "indirect FM" because the oscillator output, rather than the oscillator itself, is driven by the audio.

As stated earlier, except for the method of modulation, the two systems are identical. In both systems, the oscillator operates at much lower than the assigned channel frequency.

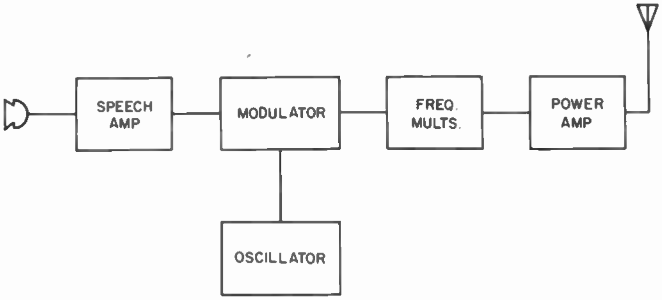


Fig. 2-1. Block diagram of a phase-modulated transmitter.

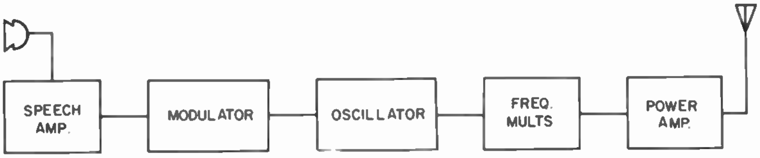


Fig. 2-2. Block diagram of a frequency-modulated transmitter.

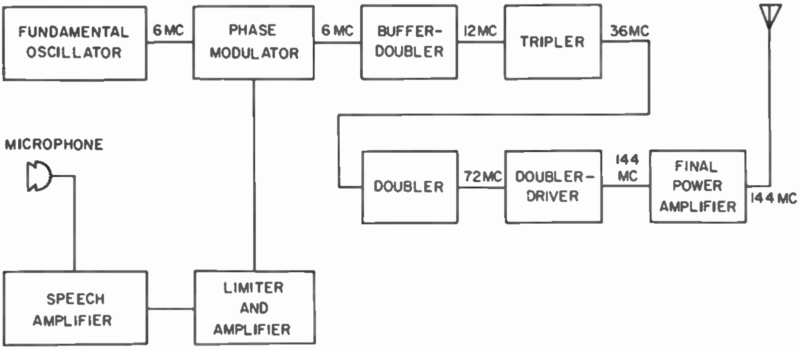


Fig. 2-3. Detailed block diagram of phase-modulated transmitter.

Therefore, a series of frequency multipliers must be used between the oscillator and power amplifier. They not only multiply the frequency, but also increase the deviation of the modulation. In addition, each multiplier stage successively increases the power of the RF signal. After the oscillator signal has been modulated and amplified, it is then applied to the power amplifier, or final, for one last tremendous boost in power. The signal is then fed into the antenna, where it is radiated into space.

BLOCK-DIAGRAM ANALYSIS

Since the phase-modulation (PM) system is used almost exclusively in commercial two-way radio, the function of each stage will be studied briefly. Later in the chapter a detailed study of the action of each stage will be presented. It is unnecessary here to discuss "direct FM," because this system is practically nonexistent in commercial two-way radio.

The Oscillator

In analyzing the stages of the transmitter in Fig. 2-3, we will begin with the oscillator. Its primary funtion is to generate the fundamental RF signal necessary to drive the transmitter into production of an amplified RF signal suitable for transmission. As might be expected, since the oscillator is the source of this energy, any changes here will show up in the transmitted wave. Therefore, good frequency stability is essential in maintaining good-quality communications. If the oscillator were to drift off frequency, it might cause not only poor (or even complete loss of) communications, but interference on an adjacent channel as well. To provide this needed stability the oscillator is crystal controlled. Many manufacturers go even one step further and enclose the crystal in a heated, thermostatically controlled oven to prevent any frequency drift caused by temperature variations.

Transmitters operating at 144 to 170 mc generally use crystals that will oscillate at 6 to 7 mc. This signal is amplified to some degree by the oscillator tube and then coupled into the phase-modulator stage.

The Audio Amplifier

The audio signal produced by the microphone is relatively weak and must, therefore be amplified (by a conventional audio amplifier). From the speech amplifier the signal is fed into a limiter stage. The purpose of the limiter is to prevent any sharp peaks (like noise) from getting into the modulator and causing overdeviation of the RF carrier. If the signal from the speech amplifier is weak—due to an extremely weak microphone signal—the limiter will act like a conventional amplifier. However, if the signal is abnormally strong, the limiter ceases to amplify anything over a predetermined amplitude. Without the limiter, the RF carrier might be overmodulated and thus cause very poor communications. From the limiter the audio signal is again amplified in another conventional amplifier, after which it is fed into the phase modulator.

The Phase Modulator

In the phase-modulator stage the RF signal from the oscillator and the AF signal from the audio amplifier are combined. Although the modulator here might look like a mixer or a low-level modulation stage of an AM transmitter, it is actually designed to hold the amplitude modulation of the RF to the minimum. The modulator is included at this point in the transmitter to simplify the design and to reduce the audio power required to drive the modulator. Actually, the modulator can be considered a mixer of frequencies, in which two different signals are intermingled to create one composite output ready to be multiplied.

The Buffer-Doubler

The oscillator and modulator have a buffer circuit in their output to isolate them from the multipliers. Because frequency multipliers present a variable load to the preceding stage, nonlinear modulation could occur if the modulator were that preceding stage. A good buffer requires very little driving power for efficient operation. Also, the fact that its driving requirements are constant enables the modulator output to remain linear. If the modulator and oscillator worked into a changing load (like an RF amplifier or frequency multiplier), their output requirements would likewise change and thus reflect a changing impedance into their circuits.

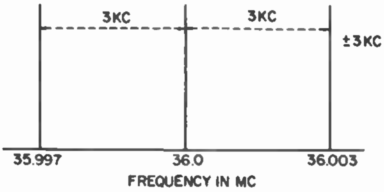
While the buffer input allows the modulator load to remain constant, the output circuit passes only the second-harmonic frequency of the grid signal to the next stage, thereby providing a doubling action. For example, if a 6-mc oscillator signal were fed to the grid of the buffer-doubler, the output circuit of this stage would be designed to recognize only the second-harmonic frequency of the input (6.0-mc) signal. In this case the output would be 2 × 6.0 mc, or 12 mc. Furthermore, not only would the frequency be doubled, but also its deviation. If the 6.0-mc oscillator signal were modulated by a 1,000-cycle tone, the signal appearing at the buffer input would be 6.0 mc plus 500 cycles, and 6.0 mc minus 500 cycles, as shown in Fig. 2-4A. However, at the output circuit both the frequency and the deviation are doubled, as shown in Fig. 2-4B. Hence, 2 × 6 mc equals 12 mc, 2 × 5.9995 mc equals 11.999 mc, and 2 × 6.0005 mc equals 12.001 mc.

The Tripler

The buffer with its doubling action is only the first in a series of multiplier amplifiers. FM transmitters usually use doublers, triplers, quadruplers, or any combination of these to increase the frequency and power in steps toward the final transmitted frequency. The reason for using several stages to obtain the final frequency and power is obvious. The oscillator signal is a weak 0.2 watt or so, and there is no feasible tube that will put out a signal of 15 or 20 watts with only a 0.2 watt input. Therefore, one multiplier amplifier drives a second, the second a third,and so on. In this way the power, frequency, and deviation are gradually increased more stably and efficiently than by using only one tube (if this were possible).

(A) ±500 cycles.

(B) ±1 kc.



(C) ±3 kc.

Fig. 2-4. Frequency deviation.

Following the buffer-doubler is the tripler (Fig. 2-3). Because less power output is available from any multiplier-amplifier for the higher-order harmonic frequencies, low ones (usually no higher than the fourth) are utilized in multipliers. The frequency tripler operates essentially like the preceding buffer-doubler, except that its grid and plate circuits require more input power because of the greater output power needed. By operating the tripler (and all multipliers) in Class-C, maximum efficiency can be realized from the stage(s). Remember that the 6.0-mc oscillator signal was multiplied to 12 mc in the doubler. At the tripler output, the 12-mc input signal will appear as a 36-mc signal. This is three times the input, or six times the oscillator, signal. (The combination of the doubler times the tripler equals an increase of six.) The 36-mc signal will now have a multiplied deviation of ±3 kc, as shown in Fig. 2-4C.

The Second Doubler

As stated previously, the frequency and power in a transmitter are gradually increased in steps. Because the power is higher from one stage to the next, the design of each stage must be different. The larger the power, the higher the current-carrying capabilities of the tube need be. As an example, the oscillator in most transmitters is a miniature sharp-cutoff pentode, and the second doubler is usually a miniature *power* pentode. Except for the increased power requirements and capabilities, the second doubler in a power-pentode arrangement operates exactly like preceding multipliers. This Class-C amplifier has its plate circuit tuned to recognize the second-harmonic frequency of the grid input signal of 36 mc ± 3 kc. Therefore the output is 2 × 36 mc ± 3 kc, or 72 mc ± 6 kc.

The Double-Driver

The doubler-driver performs two important functions. First, it multiplies the signal frequency one last time before the latter is amplified by the final stage and transmitted. Secondly, the power delivered to it by the second doubler must be amplified high enough to "drive" the final RF amplifier. The twenty-fourth harmonic frequency of the original oscillator signal appears in the output circuit of this stage. By multiplying the order of multipliers we see that the buffer-doubler, tripler, second doubler, and finally the doubler-driver multiply the frequency a total of 24 times ($2 \times 3 \times 2 \times 2$ equals 24; and 24×6 mc equals 144 mc). Likewise, the original ±500-cycle deviation now becomes ±12 kc. At this time the signal is now at its final frequency, ready to be transmitted; however, the RF power is not sufficient to carry the signal very far. Different classes of power amplifiers will be encountered after the doubler-driver, depending on the type of service for which the transmitter is licensed, and also on its design.

The Final Power Amplifier

As shown in Fig. 2-3, the last stage of the transmitter is the power amplifier. Here the RF signal is boosted to the desired level for transmitting. The output power of this stage, however, is not the same in all frequency ranges, even if the same types of tubes are used. As the frequency increases, the power output capability of a tube decreases.

The efficiency of the final stage is usually 50% or better. This figure is computed by dividing the plate power consumed from the power supply (P = IE), by the measured output power in watts as read on an RF wattmeter. As an example, if a 6146 were used as a final with plate conditions of 600 VDC at 200 ma, the input power would be 600 × 0.2 equals 120 watts. At 50% efficiency, then, this stage would have an RF power output of approximately 60 watts (120 × ½ = 60). The output of the power amplifier is fed to the antenna, where the RF energy is radiated into space. However, the antenna and amplifiers cannot merely be connected together, because there would be a serious impedance mismatch between them. Instead, a coupling network is needed to properly match the impedance of the RF output stage to that of the antenna system. Only then can maximum power be transferred to the antenna. (Coupling networks will be discussed in detail when the transmitter is analyzed.)

OPERATIONAL ANALYSIS

Up to this point you have studied how the over-all transmitter works, what each stage does, and why. Now let's further analyze each function in order of its importance.

The Crystal Oscillator

A crystal (quartz) has the property of oscillating at many frequencies, depending on how it is cut and how it is used in an appropriate circuit. Quartz in its natural state is a relatively hard crystalline mineral. For use in radio it is first cut into thin slabs, which are then dressed down still further to a precise thickness. (The finished product is as thin as a page of this book.) When a small voltage is placed across it, the crystal will oscillate at a definite frequency. Normally this oscillation is so weak that it must be amplified before it can be of any use. Fig 2-5 shows a typical crystal-controlled oscillator used in two-way radio transmitters. Because the crystal is merely a source of oscillations, it is not a developer of any appreciable amount of power. To subsequently amplify the signal (oscillations), an amplifier that requires little input power must be used. This requirement can easily be met, by operating a suitable voltage amplifier in a Class-AB_1 mode. Class-AB_1 operation means the plate current of the tube flows for more than half but less than the full cycle of input-grid signal voltage. However, at no time during normal operation will the control grid be driven positive enough to draw grid current. The circuit in Fig. 2-5 is used with a 6AK6 tube in typical Class-AB_1 operation. Normal grid voltage is −10 volts DC, and normal cathode voltage is 0.2 volt. From Fig. 2-6 we see that with −10 volts on the grid

(E_{C1}) and the plate at 200 volts, only 13 ma of plate current flows. However, when crystal M1 in Fig. 2-5 oscillates, it will drive the grid with a signal of approximately 10 volts AC

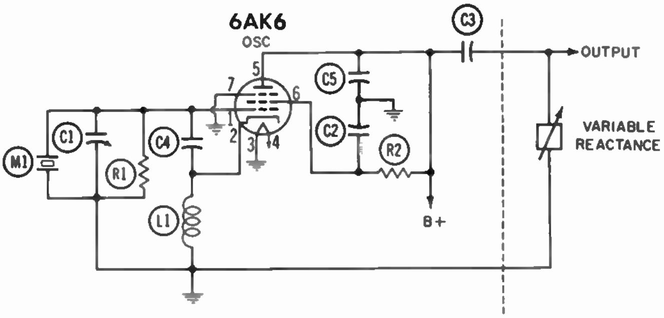


Fig. 2-5. Typical crystal-oscillator circuit.

peak-to-peak. Yet only about four-fifths of this 10-volt signal will cause the plate current to increase. An E_{C1} of -2 volts DC will cause approximaetly 34 ma of DC plate current to flow, because the 8-volt AC signal counteracted the -10 volts DC and thereby caused a net potential (during oscillation) of -2 volts to appear on the grid. This apparent -2 volts is still well below the value at which grid current will flow, so the

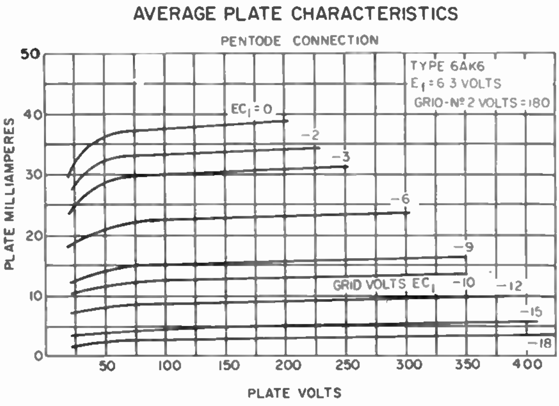
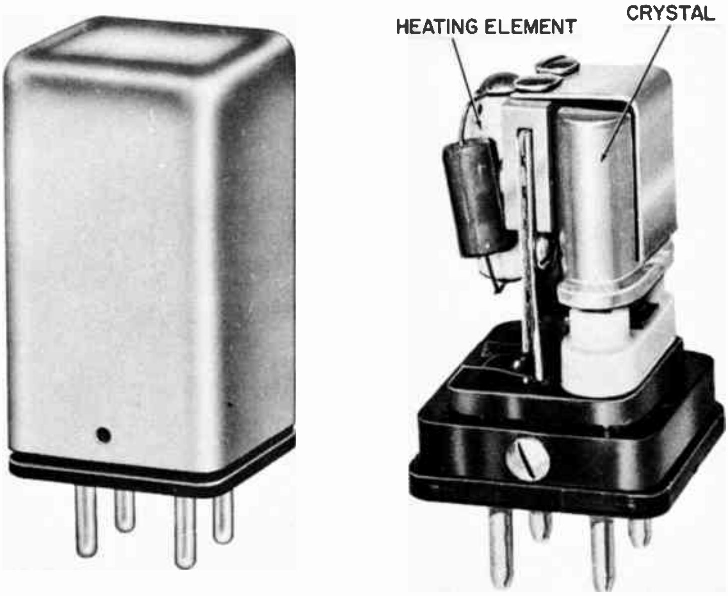


Fig. 2-6. Class-AB$_1$ operating characteristics.

input of the oscillator circuit takes no power from the crystal. The actual circuit operation is as follows.

In the oscillator circuit of Fig. 2-5 a resonant circuit is formed by crystal M1, C1 and R1 being in parallel with C4 and L1. Normally the potential is slightly less on the grid than on the cathode because of the IR drop across R1. However, as M1 oscillates, the IR drop will alternately be opposed and aided (according to each cycle of oscillation.) This means the tube conduction will increase when the grid signal is going positive; therefore, the plate current will appear as strong pulses. The frequency of these pulses appearing across C3 in Fig. 2-5 is determined by the frequency of the grid signal, which in turn is determined by the crystal oscillations.

Although the frequency of an oscillator is stabilized by using a crystal, a change in the reactance of this circuit will shift the frequency one way or the other. Notice in Fig. 2-5 that the capacitive reactance of the circuit is made variable by C1. As C1 is adjusted from 4 to 22 mmf, the operating frequency will decrease, but will increase as C1 is adjusted from 22 to 4 mmf. Thus the final transmitted frequency can be adjusted slightly in either direction, as required. The reactances of the circuit aren't all that will shift the frequency, though. The crystal itself (like other materials) exhibits a temperature coefficient—that is, as its temperature increases, the crystal expands, causing a corresponding change in the rate of oscillations (i.e., frequency). For this reason the crystal itself is enclosed in



Courtesy International Crystal Mfg. Co.

(A) External view. (B) Internal view.

Fig. 2-7. A crystal oven.

an oven, which maintains the crystal at a constant temperature and thereby keeps it from changing in shape. Fig. 2-7A shows a typical crystal oven. An internal view of this oven appears in Fig. 2-7B.

In a circuit where good oscillator stability is important, the load presented to the oscillator must be kept constant. Likewise, the power taken from the oscillator must be constant and not too large if maximum oscillator stability is to be realized. Any amount of power taken from the oscillator reflects a low resistance into the oscillator. Therefore, the greater the power requirements, the less stable the oscillator. Most generally, the output of the transmitter is fed to the modulator and then to a buffer stage. As you know, this buffer and modulator require very little driving power, because a heavy load at the buffer input will result in nonlinear modulation. Therefore, good oscillator design is all-important if maximum efficiency is to be obtained from the unit.

The Reactance-Tube Modulator

Commercial FM two-way radio transmitters employ the reactance-tube method of modulating the oscillator frequency. Although called FM (meaning frequency-modulated), the transmitters are actually PM or phase-modulated. However, the two are closely related because, whenever the frequency of a wave is changed, its phase (time relationship) is likewise changed and vice versa.

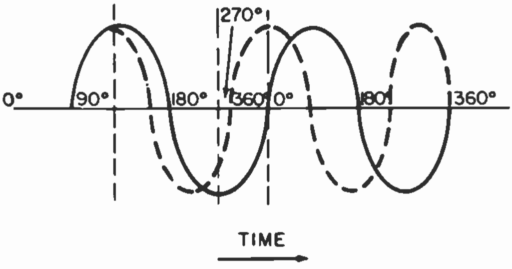


Fig. 2-8. Phase shift of a sine wave.

Notice in Fig. 2-8 that the sine wave represented by the solid line is of a certain frequency. Now if its frequency were increased by one-fourth cycle in one full cycle, you can see from the dotted line that the time displacement would be changed, and that at the end of two full cycles the new frequency would lead by almost half a cycle. It makes no difference whether the phase or frequency of the wave is changed; when one is affected the other is, too. Therefore, what is phase-modulated is really frequency-modulated; and what is frequency-modulated is actually phase-modulated. For the sake of standardization, however, the two are referred to indiscriminately as FM (frequency modulation.)

Recall, in the discussion of the crystal oscillator, that any change in the reactance of the circuit parallel to the crystal will also change the frequency. This is the main principle behind the reactance-tube method of modulation. Notice in Fig. 2-5 that there is a variable reactance across the output side of the oscillator tube. The frequency from the output side of C3 to ground will in part be determined by reactance X—as it increases the frequency decreases and vice versa.

By inserting a vacuum tube in place of variable reactance X, as shown in Fig. 2-9, and by controlling its reactance to the oscillator frequency with an audio signal applied to the control grid, the frequency across C5 can be changed. The ability of a tube to vary in reactance is due primarily to its transconductance.

As you know from amplifier fundamentals, when an alternating signal is applied to the control grid of a tube, this signal controls the flow of electrons between the plate and cathode, and thus the transconductance. In Fig. 2-9, audio from a speech-amplifier network is applied to the control grid of V2A through a 150K resistor, while RF from the oscillator is fed to the plate through C3, and to the grid through C4. This means the two RF signals will appear out of phase at the plate. A predistorter network (C6 and R3) is provided to shift the phase of the applied audio voltage from the speech amplifier by 90°. This is

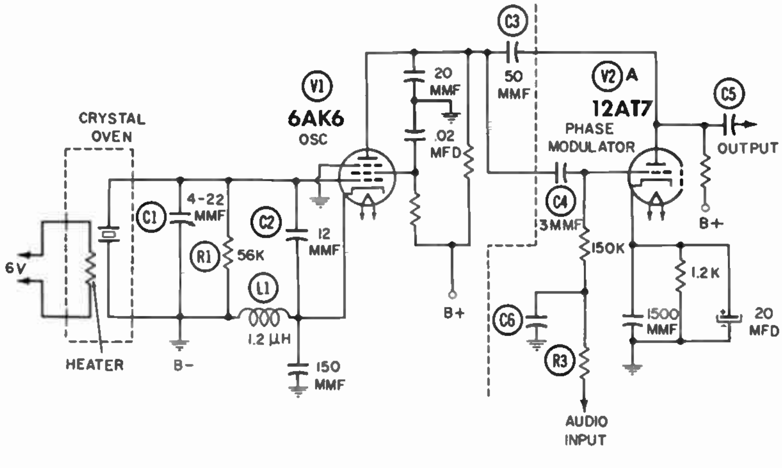
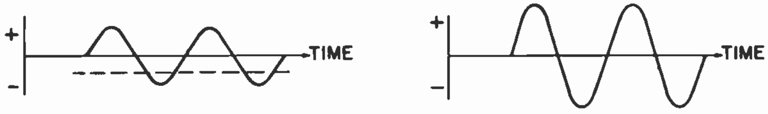


Fig. 2-9. Oscillator-modulator circuit.

accomplished by impressing the audio through R3 and across C6. The reason for shifting the phase of the grid signal is that the frequency deviation in PM is directly proportional to the AF signal frequency; and in a phase modulator the deviation must depend only on the audio amplitude, not on its frequency. Therefore, with this network, the audio applied to the modulator changes the response so that indirect FM (which is desired) is produced, rather than direct FM.

Fig. 2-10 shows the two sine waves that are fed to the circuit of Fig. 2-9. The audio signal (A) is applied to the grid, and RF (B) is applied across the reactance tube, from plate to cathode and grid to cathode. In Fig. 2-10C the effects, in the output circuit, of the signal on the grid are shown. As the amplitude of the audio signal increases in the positive direction, the RF signal increases in frequency above its unmodulated value; and as the AF signal increases in the negative direction the RF signal decreases below the normal resting frequency. Study the phase relationship of the RF signal in Figs. 2-10B and C. Notice in C that at the end of two AF cycles, the RF is out of phase with B. Figs. 2-10D, E, and F show the effects of a stronger AF signal on the output frequency. Fig. 2-11 shows the frequency excursion plus and minus from the carrier (resting) frequency according to the grid signal. In this



(A) Audio sine wave.

(D) Increased-amplitude audio sine wave.

(B) RF sine wave.

(E) Normal RF sine wave.

(C) Resultant modulation.

(F) Resultant modulation.

Fig. 2-10. Modulation of FM waves.

manner, then, is the frequency of the transmitter modulated with the application of an audio signal to the reactance-tube modulator.

The amount of deviation of the carrier frequency from its resting to its maximum plus and minus values is termed "modulation deviation"—more clearly, this is the amount of frequency change (in kc) the carrier undergoes during 100% modulation. This 100% modulation deviation is the frequency swing ±15 kc from the carrier in wide-band communications, and ±5 kc in the new narrow-channel systems. As an example, in Fig. 2-11 a center frequency of 48 mc is modulated with a

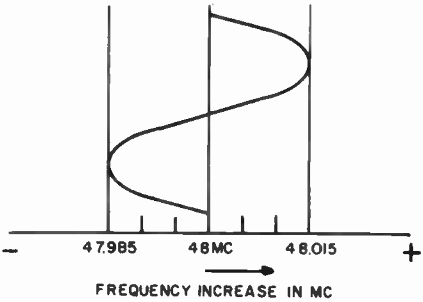
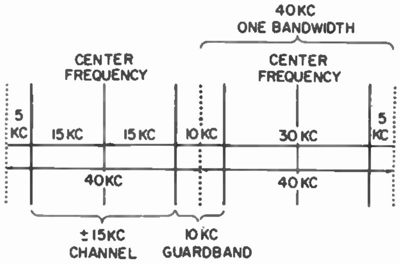
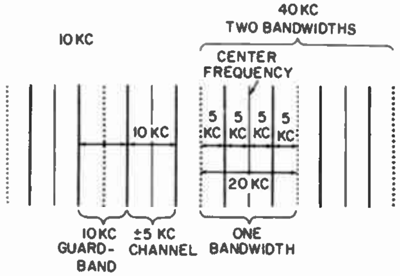


Fig. 2-11. Carrier-wave deviation.



(A) Wide channel.



(B) Narrow channel.

Fig. 2-12. Guard bands between channels.

tone sufficient to produce a final deviation of ±15 kc. With the modulator being driven into full conduction, the actual transmitter output frequency will be varied in accordance with the audio frequency. In this case, the carrier will deviate from center (48 mc) to 47.985 mc (−15 kc) and back to 48 mc. Then it will go from 48 mc to 48.015 mc (+15 kc) With a swing of −15 and +15 kc, the transmitter is said to be 100% frequency-modulated (±15 kc).

In radiocommunications there are portions of the frequency spectrum known as "guard bands." A guard band lies between all radio channels and is 5 kc in width on either side of the ±15-kc carrier. This means there is a total bandwidth of 40 kc for a ±15-kc system. Fig. 2-12 shows the bandwidth for both the "wide" (Fig. 2-12A) and "narrow" (Fig. 2-12B) channels. Notice that by reducing the amount of deviation in the wide channel from ±15 to ±5 kc in the narrow channel, twice the number of radio channels can be put on the air in the existing allotted frequency spectrum.

Frequency Multiplication

As has been stated, the common method of multiplying a frequency is to operate a tube in Class-C condition and tune the output circuit to the desired harmonic frequency. A Class-C–operated tube is one in which the grid bias is arranged to hold the plate current well into cutoff. In this manner, it takes a strong grid signal to cause tube conduction. As you can see in Fig. 2-13, an alternating grid signal allows plate current to flow only on the positive peaks of the signal. On the negative swing of the grid, the tube is driven further into cutoff. Therefore, the plate current only flows in short pulses.

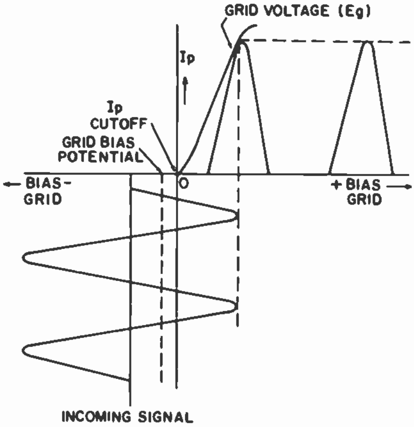


Fig. 2-13. Class-C operating characteristics.

A typical frequency-multiplier stage is shown in Fig. 2-14. A series-resonant circuit (C1-L1) at the input is tuned to the frequency of the incoming signal. Another series-resonant circuit (C2-L2) is present at the output, and by selecting the proper values of inductance and capacitance in this circuit, any harmonic frequency of the input signal can be chosen. For example, a 10-mc signal fed to the grid of a multiplier will appear as 20 mc at the output when the latter is tuned to the second-harmonic frequency of the input signal. Frequency doublers are the most commonly used, and then triplers and quadruplers. Recall that as the order of harmonic frequencies increases, the power decreases. Therefore, usually no higher than the third or fourth harmonic frequency is utilized, because what is gained in frequency is lost in power. If higher frequencies are desired, additional multiplier stages are employed.

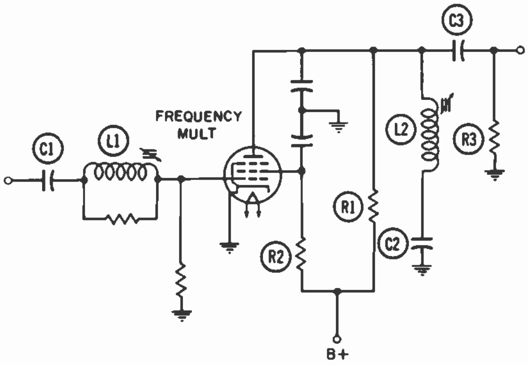


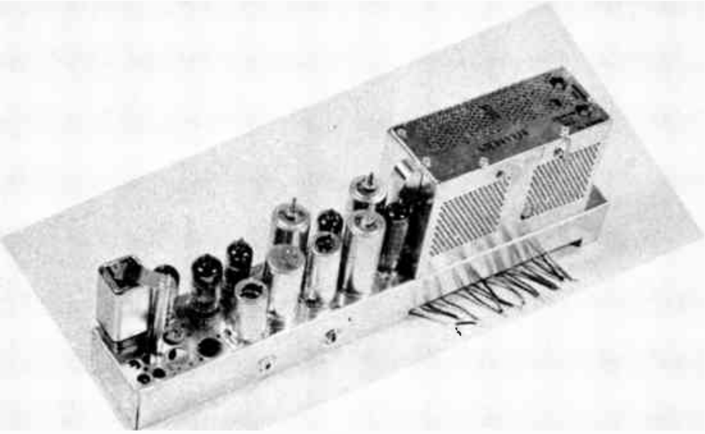
Fig. 2-14. Frequency-multiplier stage.

From the pulses of plate current in Fig. 2-13 one might believe that this is the actual signal appearing in the grid circuit of the next stage. Actually, the transferred signal must be a sine wave like that of the incoming signal in order to provide efficient Class-C operation of the next stage. As the pulses of plate current appear in the resonant plate circuit, the signal is transformed into a sine wave. Let's study this more closely to get a clearer understanding of how it is brought about.

When a pulse of plate current appears in the series-resonant circuit (L2-C2) of Fig. 2-14, C2 charges through L2. This causes a negative-going pulse to appear across C3. When the plate cuts off, the signal across C3 starts to swing positive (B+ rising). Since C2 can no longer continue to charge, it now starts to discharge through L2 and R1, causing C3 to continue in its positive direction, even though the plate is out of the circuit. The reason is that the current of C2, in discharging through L2, builds up a counter field that bucks the discharge path of C2 and thereby keeps the current flowing after plate-current cutoff. Before C2 completely discharges, however, plate current again flows and thus causes the waveform across C3 to swing negative again. So you can see how the plate pulses will appear as a sine wave at the input of the succeeding stage.

ANALYSIS OF A TYPICAL FM TRANSMITTER

The preceding sections of this chapter have explained the basic functions of the different parts of an FM transmitter.



Courtesy Motorola C and E, Inc.

Fig. 2-15. A typical phase-modulated transmitter.

(Fig. 2-15 shows a typical mobile unit.) It is best to keep these fundamentals in mind when following this analysis. For the sake of clarity, the transmitter stages are presented individually.

The Speech Amplifier

Fig. 2-16 shows the audio-amplifier portion of a transmitter. With the exception of the limiting action provided by V8A and the addition of a pre-emphasis network, this speech amplifier is as simple and straightforward as any ordinary PA amplifier.

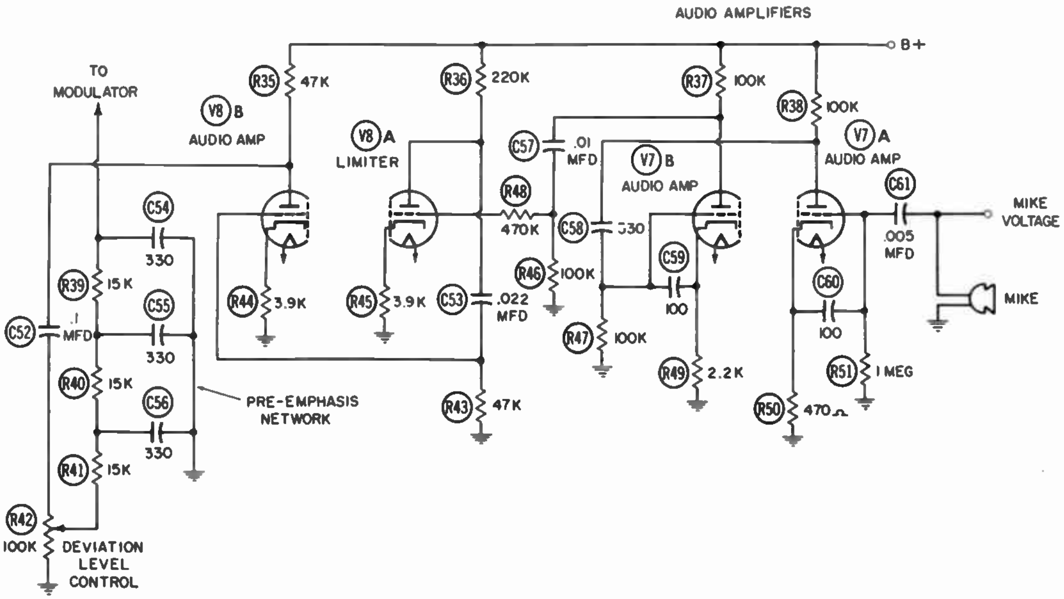


Fig. 2-16. Speech amplifier.

A limiter is used in transmitter audio amplifiers to prevent the carrier frequency from being overdeviated (overmodulated). The limiter amplifies and passes on to the next stage all audio signals below a preset amplitude, or strength. If loud noises picked up by the microphone were allowed to overdrive the modulator, this overmodulation would distort the transmitted wave and could even cause interference on adjacent channels; so you can see the important role the limiter plays in good-quality communications.

Since the higher voice frequencies lack the intensity of the lower ones, they must be raised to the latter's level of intensity by means of a "pre-emphasis" network. When the higher frequencies are not emphasized, the audio quality will be impaired because these weak high frequencies make the greatest contribution to speech intelligibility. It is the spoken consonants rather than the vowels that are more accented, and these sounds have their energy among the higher audio frequencies.

To avoid degrading these upper frequencies, a certain amount of emphasis is placed on them in the transmitter audio circuit. To keep the recovered audio in the receiver from sounding unnatural, the reverse procedure (called "de-emphasis") is added in the receiver audio circuit. It might be thought that pre-emphasis would overdeviate the transmitter, but this is not true because the original high frequencies are merely brought up to the strength of the lower frequencies to make the audio frequencies equally strong over the entire range. The characteristics of the pre-emphasis network are shown in Fig. 2-17. Notice that the plotted curve remains relatively constant from 50 to 400 cps, and then rises abruptly to 15,000 cps. Since this rise is specified in decibels, a change of 6 db means the signal amplitude has doubled. From this curve, then, we see that the output of the pre-emphasis network at 15 kc is almost eight times that at 1 kc.

The combination of R41-C56, R40-C55, and R39-C54 in Fig. 2-16 is the pre-emphasis network. The audio is impressed across each capacitor in turn, through the series resistors. The output is taken off across one capacitor and applied to the next. Since the capacitive reactance falls as the frequency increases, the network output voltage rises. Actually the higher the frequency, the less reactance the circuit offers to it. Therefore, the lower and higher frequencies applied to the modulator will have approximately the same signal strength.

The input from the microphone in Fig. 2-16 is developed across the 1-meg grid biasing resistor (R51) of V7A through coupling capacitor C61. This causes the grid of V7A to fluctuate at an audio rate, thus controlling the plate current. Capacitor C60 provides a certain amount of feedback from cathode to grid to stabilize the amplifier. R50 is the cathode bias for V7A, and R49 is the bias resistor for V7B. The plate load of V7A is R38, and the plate load of V7B is R37. Coupling capacitor C58 injects the amplified audio from the V7A plate into the V7B grid. C59 is the cathode-to-grid feedback stabilizing capacitor, and R47 is the grid-bias developing resistor. The output of amplifier V7B is coupled into the input of limiter V8A through C57. R46 is the limiter grid-bias resistor, and R48 keeps the grid from drawing too much current. R45 and R44 are the cathode bias resistors, and R36 and R35 the plate load resistors. The limited audio signal is coupled from amplifier V8A to V8B through C53. R43 is the grid bias resistor for V8B. From the V8B plate the signal goes through C52 into deviation-level control R42, which permits periodic adjustment of the deviating audio signal to compensate for aging tubes and components. After going through the pre-emphasis network, the audio signal is then fed into the phase-modulator circuit.

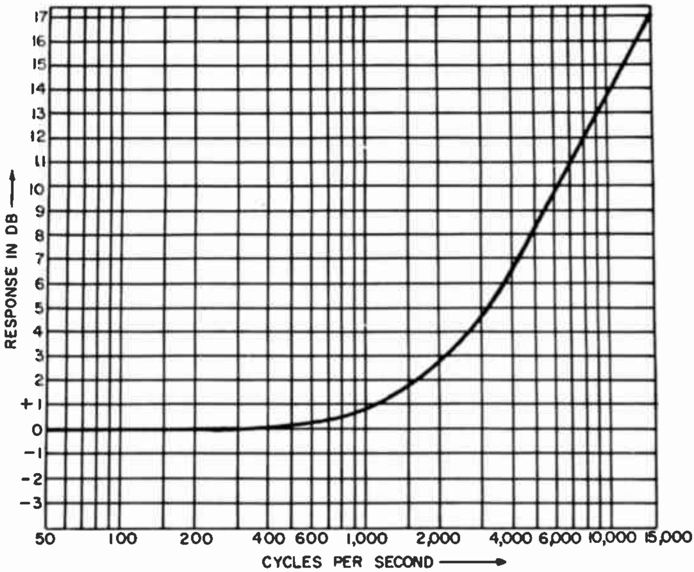


Fig. 2-17. Pre-emphasis curve.

The Crystal Oscillator

Fig. 2-18 shows that section of the transmitter making up the oscillator modulator and buffer. The crystal oven in this oscillator has a thermostat (pin 7) in series with the 12-volt

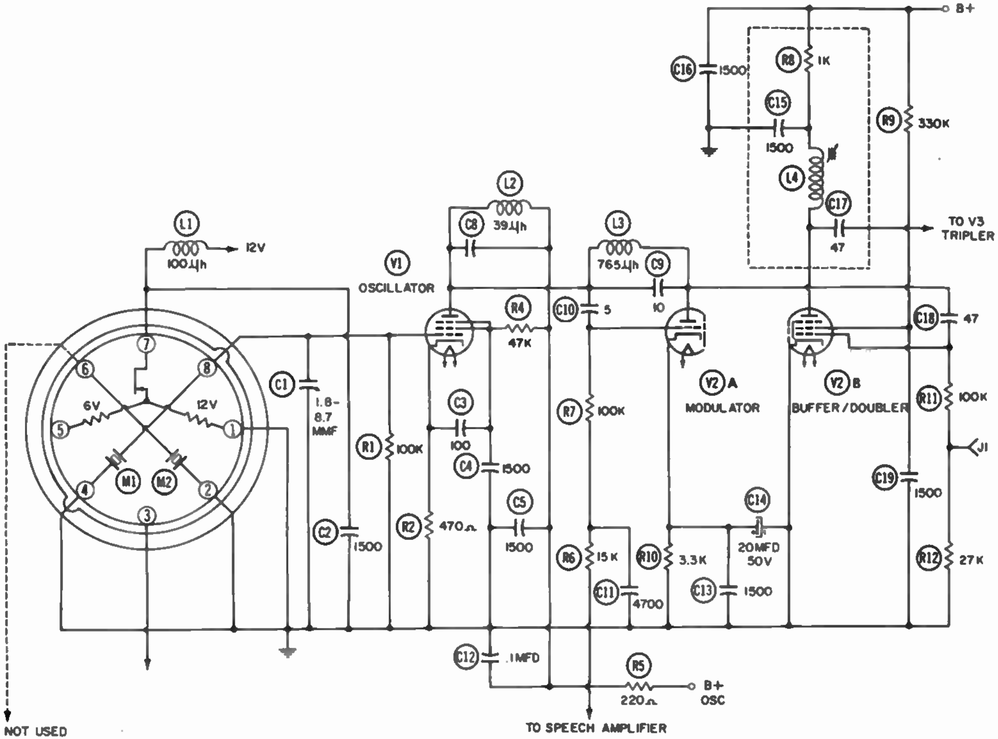


Fig. 2-18. Crystal oscillator and modulator buffer-doubler.

dropping heater and 12-volt filament supply. When the thermostat contacts are closed, the heater maintains the interior of the oven at a constant temperature; no heat is developed when the contacts are open. Crystal M1 is used for oscillator V1, and M2 is in a second oscillator circuit (not shown) for use as a two-frequency transmitter. M1 and frequency-adjusting capacitor C1 in parallel form the resonating oscillator circuit. RF choke L1 and capacitor C2 keep the RF (from the crystal) out of the filament circuit. Otherwise, it would cause the cathode emission to fluctuate at an RF rate and cause any number of troubles. R1 is the grid biasing resistor, and R2 is used for cathode bias. The cathode is bypassed for RF by the combination of C3 and C4 in series. C4 is the RF bypass for the screen, and C5 and C12 are the plate RF bypass capacitors. R4 is the voltage-dropping resistor in the screen-grid circuit. The combination of L2 and C8 provides enough damping action on the RF, between the screen and plate, to prevent undesired oscillations. Capacitor C10 couples the amplified oscillator signal to the phase-modulator grid, and C9 couples the same signal to the plate.

The Phase Modulator

In Fig. 2-18 the signal from the speech amplifier is fed, through predistorter network R6 and C11, to signal-voltage stabilizing resistor R7. At the grid of V2A, the RF from V1 and the AF from the speech amplifier are joined. The B+ for the plate comes from the oscillator circuit, and L3 blocks the modulated RF from the B+ circuit. The high cathode bias needed to operate the tube in a region of low transconductance is provided by R10. The cathode is bypassed for RF and AF by both C13 and C14.

The Frequency Multipliers

Up to this point we have dealt primarily with generating the AF and RF signals and combining them in the modulator. From now on, however, we will be concerned with increasing the frequency, deviation, and power of the output from the modulator. The sections of the transmitter where this is done are known as the frequency multipliers.

The Buffer-Doubler

From the plate of modulator V2A in Fig. 2-18, the phase-modulated signal is coupled, through C18, to the grid of the buffer/doubler. This stage not only isolates the modulator from the multiplier, but is actually a multiplier itself. The signal across grid biasing resistors R11 and R12 is rectified between

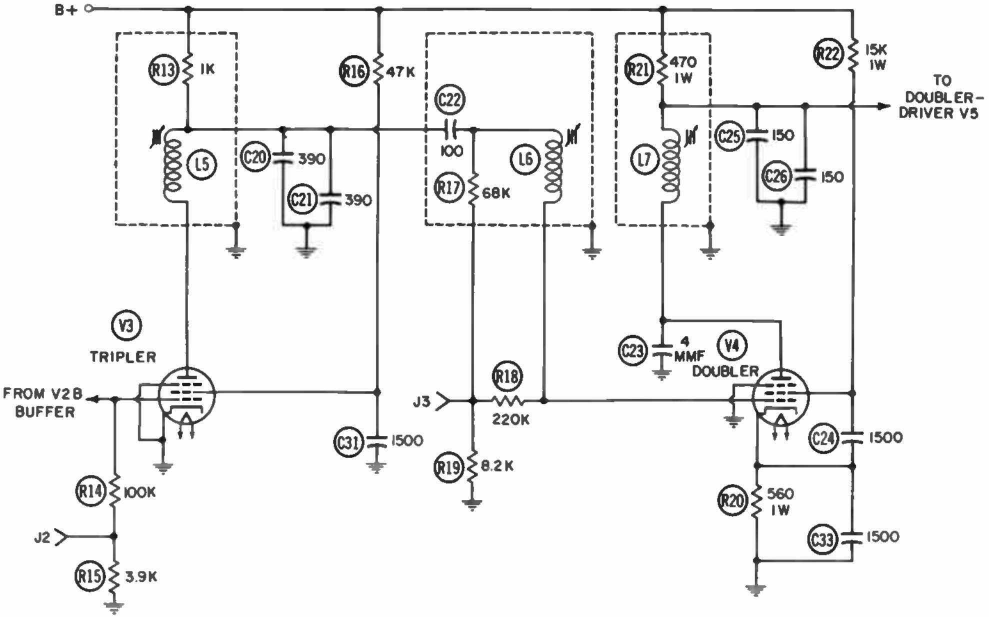


Fig. 2-19. Tripler and second doubler.

the cathode and grid. Since the signal swings positive enough to draw grid current, enough bias is developed across R11 and R12 to operate the tube in Class C. (J1 is a test jack for measuring the effective amount of signal present.) L4 and C15 make up the tuned plate circuit that recognizes the second-harmonic frequency of the grid signal. R8 and R9 are the plate and screen load resistors, respectively. C16 and C19, the RF bypass capacitors for the plate and screen, present a relatively low reactance to the RF and thus effectively short it to ground in these circuits. Otherwise, RF could be coupled through B+ to other circuits and thereby cause intrastage oscillations.

The Tripler and Second Doubler

The buffer-doubler output signal, which is twice the oscillator frequency, is coupled into the tripler in Fig. 2-19. The signal is rectified across the grid and cathode via R14 and R15, and the circuit output is tuned to the third harmonic of the grid signal. Hence, the signal at the output will be six times the oscillator frequency. The LC series-resonant circuit consists of L5 and the parallel C20 and C21. The output is taken across C22, R17, and R19. To provide maximum transfer of power, the input circuit of the doubler is tunable (by L6) to the exact frequency of the incoming signal. R17 and R19 are the grid bias resistors, and R18 limits the grid current. R20 is the cathode bias resistor being bypassed for RF by C33. R21 and R22 are the plate and screen load resistors, the series combination of C24 and C33 makes up the screen-grid RF bypass, and C23 is the plate RF bypass. The output of this doubler is tuned to twelve times the frequency of the oscillator signal. As you can see, the circuit arrangement is practically the same for all multipliers. Notice that doubler V4 handles much more plate current than V3 or V2, as seen by the use of 1-watt resistors in the cathode, screen-grid, and plate circuits.

The Doubler-Driver

Final multiplication takes place in the doubler-driver stage. The tube used here must be capable of delivering 2 to 4 watts of RF power to the final amplifier. Unless such high-power tubes are protected by fixed grid bias from the power supply, they may be damaged should the driving signal on the grid be lost. With a loss of signal no bias would be developed, and as a result the tube would "run away" (plate current would become excessive).

The circuit operation of V5 in Fig. 2-20 is the same as for the preceding stages except for the fixed bias arrangement on

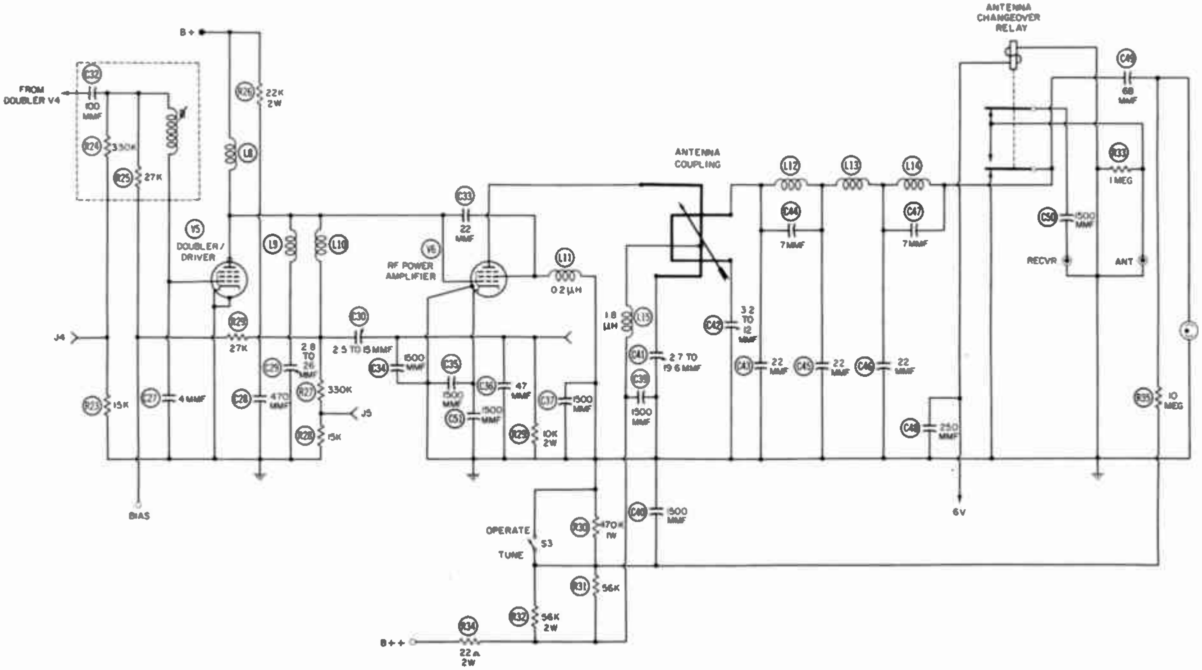


Fig. 2-20. Doubler-driver and final power amplifier.

the grid. In addition, the output resonant circuit has a tunable capacitor instead of inductor. The reason for this is that the combination of L9 and L10 provides a fixed impedance match for the signal; hence any adjustment of these coils seriously impair the transfer of power between stages.

The RF Power Amplifier

In the RF power amplifier, the signal is boosted to the desired transmitting power. Being the last stage of amplification it is often called simply the "final." Obviously, in order to transmit as strong a signal as possible, the final not only must develop a large amount of power, but must also be capable of delivering the power efficiently to the antenna. This calls for careful circuit design and a wise choice of transmitting tubes.

The disadvantages of using ordinary triode amplifiers for finals are many: Because triodes require neutralization, additional adjustments must be incorporated which make the circuit design more critical. Moreover, since triodes have a low power sensitivity, a large amount of input power is required to produce a given output. Also, the high output capacitance of triodes reduces the tank-circuit inductance, resulting in too high a Q and thus a very narrow bandpass. At higher frequencies, tetrodes or pentodes are more useful because they provide more amplification than triodes and generally require no neutralization. With tetrode and pentode tubes, grid bias is set with reference to screen-grid, rather than plate-current, cutoff. The angle of plate current therefore depends largely on control-grid bias and screen-grid voltage. The grid voltage must never exceed the screen voltage; and during the operating cycle, the minimum plate voltages must never drop lower than the screen voltages. The presence of the screen and suppressor grids decreases the interelectrode capacitance of the tube, generally making external neutralization unnecessary. This, of course, simplifies the circuit design considerably.

The power developed in the final amplifier must be transferred to an antenna instead of another amplifier, and this antenna system has a "loading" effect on the operating Q of the plate-circuit coil. Since the antenna circuit consumes a large amount of power, the resistance presented to the output circuit of the final is extremely low; thus the Q of the coil must be low. As you can see, the Q depends on more than just the LC resonant network. For efficient operation it should be on the order of 10.

The power amplifier in Fig. 2-20 is operated as a Class-C amplifier. The input signal is taken between the grid and cathode of V6, and stable feedback is obtained from screen to control grid through C33. "Tune-operate" switch S3 is used to reduce the plate voltage (B++) to the final during alignment of the final and/or antenna circuits. The coils couple RF power from the resonant circuit to the antenna. The plate coil acts like the primary of a transformer, and the antenna is coupled in by a movable secondary which loads the antenna and thus changes the mutual inductance. You can see that a high inductance is needed here, to provide the most efficient transfer of power. For proper "loading" the antenna must be resonant at the operating frequency, and there must be a good impedance match between it and the final. If not resonant, the antenna will present a high resistance to the amplifier and thus reflect much of the output power back into the final. A bad impedance mismatch will also present a high impedance to the final. With a good antenna, adjustments C41 and C42 (along with the antenna coupling itself) will provide a high degree of power transfer.

As stated previously, a good Class-C–operated stage generates an output signal rich in harmonics. The final is a very good harmonic generator; and a suitable network suppresses these harmonics before they are radiated. The combination of C43, C44, L12, C45, L13, C46, C47, and L14 suppresses all but the operating frequency. This circuit also helps to match the output impedance of the plate circuit to the input impedance of the antenna. The antenna changeover relay permits connecting the antenna to either the transmitter or receiver. In Fig. 2-20 it is shown in the "receive" position. Notice that one of its contacts shorts the harmonic-suppressor output to ground when the transmitter (and thus the relay) is not in use. The relay is operated by depressing the push-to-talk button on the microphone. In the position shown, the antenna input to C50 and thus to the receiver is developed across 1-megohm resistor R33. When the transmitter is activated, the relay changes the antenna to the harmonic-suppressor output and opens the circuit between the suppressor and ground.

Chapter 3

The FM Communications Receiver

A good-quality FM communications receiver must be capable of reproducing the transmitted information as intelligible audio, with little noise, at the speaker. For this reason, amplitude modulation was mainly given up as a faithful means of two-way radiocommunications. AM suffers from all kinds of noise, both natural and man-made. The transmitted wave is subject to so many kinds of interference that, before it is received, it quite frequently has picked up enough extraneous noise signal to make reproduction unintelligible. Noise pulses produce variations in the amplitude radio signals and are therefore very troublesome in AM operation. The hum of power lines, spark of the ignition system in an automobile, running of a motor, and even atmospheric disturbance are but a few of the sources of interference to these signals. However, the noises that bother AM do not cause interference in FM reception because they affect only the amplitude of the signal, not the frequency. In an FM transmitter, as previously explained, the audio modulation causes excursions of the frequency—not amplitude, as in AM. Therefore, any amplitude variations of the FM wave (and there are many, due to the same noise sources as for AM interference) are not reproduced in the receiver. Instead they are removed from the signal by the limiter stages. As a result, only frequency variations are converted into audio.

Even within the FM class, some types of equipment perform better than others. For example, a single-conversion FM superheterodyne has poorer combined overall image-frequency and adjacent-channel rejection than one having dual conversion.

To achieve good adjacent-channel rejection with a single-conversion receiver, a low IF value is necessary. This, however, does not provide good image rejection. On the other hand, if good image rejection is needed, the high IF required impairs the rejection of adjacent-channel signals. By combining both a high and low IF in one receiver, both good image and adjacent-channel rejection are obtained; such a receiver (Fig. 3-1) is known as a double superheterodyne. The action of producing two IF's is basically that of generating first one IF, amplifying it, and then using it to generate a second IF. This is accomplished by mixing the received RF signal with a high-frequency oscillator signal, as shown in the block diagram of Fig. 3-2. This combination of RF and oscillator signals produces the high-frequency IF necessary for good image-frequency rejection, which is obtained in the tuned selective circuits of the IF amplifier. After one or two stages of amplification, the high-frequency IF signal is injected into a second mixer stage and combined with a low-frequency oscillator signal. This mixing action produces the low-frequency IF necessary for good adjacent-channel rejection. Actually, most of the adjacent-channel interference is removed from the low IF by the selective filter which comprises several LC resonant circuits very sharply tuned to the exact bandwidth of the low IF. This means that practically no adjacent-channel or even

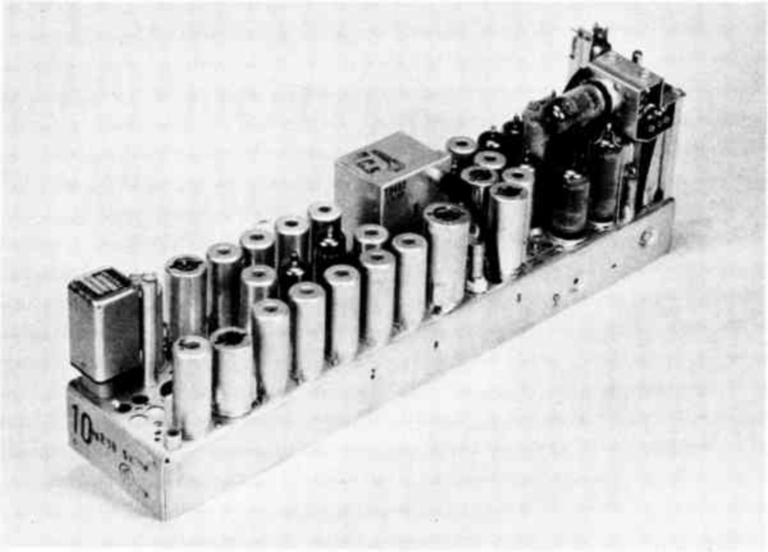


Fig. 3-1. A double superheterodyne receiver.

image-frequency interference gets into the low IF's; therefore, the signal at this point is fairly clean. However, there is still the problem of amplitude variations (noise) in the IF signal; if these were to get into the discriminator, they would be partially reproduced and heard as noise in the speaker. To get rid of this noise, the FM receiver uses a limiter which works just like the one described in the audio section of the transmitter; that is, an incoming grid signal will increase the plate current up to a certain point. Beyond that point a larger (higher-amplitude) grid signal will cause no further increase in plate current. Therefore, the noise pulses (because they produce the excessive amplitude excursions) are not passed by the limiter.

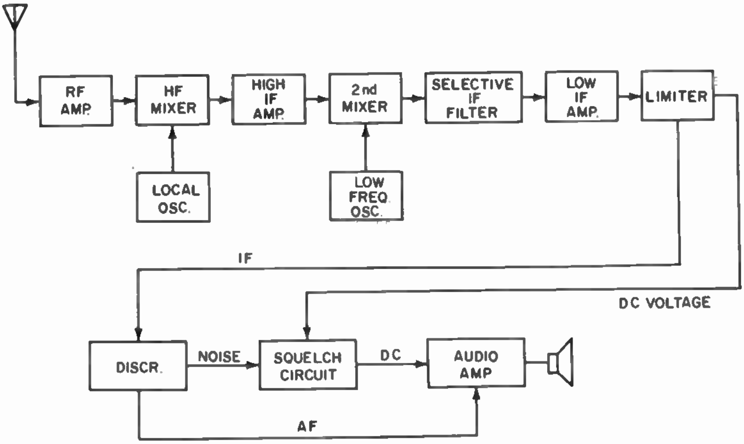
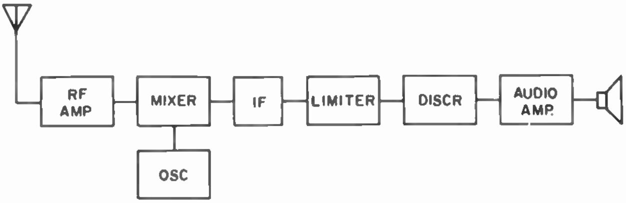


Fig. 3-2. Block diagram of a typical FM communications receiver.

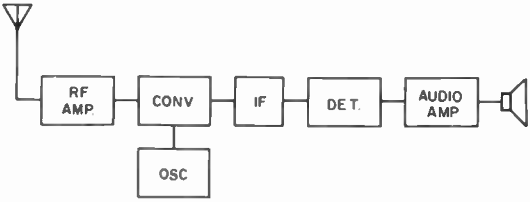
You can see that the combination of the high and low IF's and the limiter literally wipes away all interference and noise from the transmitted signal. This "clean" signal is then changed back into audio by the discriminator, boosted in strength by an audio amplifier, and then fed to the speaker where it is converted into sound energy. While no interference may be heard in the speaker when a signal is present, there certainly will be noise while no signal is being received. A certain amount of noise is produced in each stage by electrons as they flow through tubes and other components. Tubes in particular generate considerable noise due to thermal effects, mechanical vibrations, etc. The noise produced in each stage is amplified and passed along to the next stage, where it is treated like a weak radio signal. Every tube produces some noise; in a 15- or 20-tube receiver, considerable noise builds up. As an example, the noise produced in the first RF amplifier is amplified by this stage and then injected into the following. Here it is further amplified and so on right down the line, picking up and amplifying the additional noise contributed by succeeding stages and finally being heard from the speaker. By now it is so unbearably loud that the radio listener has to turn the volume down to keep from becoming fatigued. To prevent this, a built-in squelch circuit blocks the audio stage until a signal is received. Notice in Fig. 3-2 that the squelch circuit is between the discriminator and audio amplifier. Because there is no limiter action with no signal present, the squelch circuit effectively cuts off the audio amplifier, and the speaker is silenced. When a signal causes the limiter to go into heavy conduction, this squelch action is killed and the audio amplifier once again performs its normal function.

RF AMPLIFIERS

The receiver of a typical two-way radio is shown in Fig. 3-1. Each coil can has a tunable slug inside it to permit periodic adjustment. Fig. 3-3A shows the block diagram of a basic FM receiver. In spite of the apparent similarity to the standard AM receiver in Fig. 3-3B, the FM receiver is actually quite different, as you will see in this chapter. The requirements of FM are the same as for AM, only more stringent. Perhaps the most important is high sensitivity, which is determined by the minimum RF signal-voltage input required to produce a specified



(A) FM.



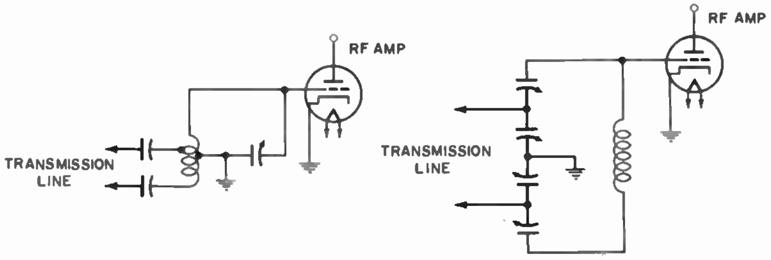
(B) AM.

Fig. 3-3. Block diagrams of FM and AM receivers.

output at the speaker. The most sensitive receiver is one that will faithfully reproduce the greatest output with the smallest input signal.

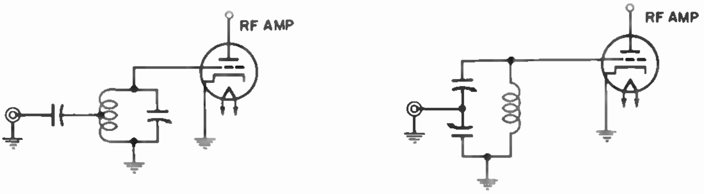
The next major requirement of a receiver is its ability to select a desired station and to reject all others. Unwanted adjacent-channel signals are rejected by the bandpass characteristics of the IF amplifiers, while most of the incoming image frequencies are lost in the RF amplifiers and mixer. The combination of sensitivity and selectivity makes for a very efficient receiver.

The signal is brought from the antenna to the RF amplifier by either a two-wire or coaxial transmission line. In an open-insulator, two-wire line, the two signal voltages are equal in strength but opposite in polarity; therefore, a balanced input (Figs. 3-4A and B) is required at the RF amplifier input. However, since a coaxial line has its outside conductor at ground potential, an unbalanced circuit (Figs. 3-4C and D) is required. With its inside conductor shielded, the coaxial line does not act like an antenna and pick up stray noise, as the two-wire line does. Since the noise voltages on both sides of the two-wire line are in phase with each other (each line being 90° out of phase with ground), and since these noise voltages are 180° out of phase with ground, the balanced input circuits will



(A) Balanced tapped inductance.

(B) Balanced capacitance.



(C) Unbalanced tapped inductance.

(D) Unbalanced capacitance.

Fig. 3-4. RF-amplifier input circuits.

cancel them out. (The balanced input recognizes only signals out of phase with each other and 90° out of phase with ground.)

The input circuit of an RF amplifier, whether balanced or unbalanced, usually consists of an input LC network. The part of the circuit "facing" the antenna is built to match the impedance (usually 50 ohms) of the antenna and transmission line, and the part "facing" the tube matches the high impedance of the grid-to-cathode input circuit to the antenna. The tuned circuit allows peaking of the resonant circuit to the incoming signal in order to effect maximum transfer of signal power. The actual amplifier circuit must be capable of greatly improving the signal-to-noise ratio, suppressing the image frequencies, and preventing the local-oscillator signal from traveling back into the antenna and being radiated. These circuit requirements constitute a wide varity of design for RF amplifiers. Naturally the better-designed circuits found in many of the more expensive receivers will give a more satisfactory overall performance than one of poorer design.

RF Amplifier Problems

The RF amplifier, being the first stage of the receiver, naturally affects all following stages. In today's modern narrowband communications receivers, the RF section must be critical in accepting the required signal and still reject all others. This is hard to do, since the resonant antenna circuit must be broad enough to be tuned over a complete band. Because so many stations operate on the same or on adjacent frequencies, the problems of intermodulation and desensitization are more acute than they were in the earlier days of FM. These two conditions occur during reception of undesired RF signals in the RF amplifier circuit. *Desensitization* is the condition whereby an off-channel signal causes the amplifier grid to draw current on the positive peaks. This increases the grid bias and thus reduces the stage gain. Desensitization means the receiver has become "desensitive" and requires a much stronger signal to operate. This can happen if a strong adjacent-channel signal gets into the RF circuit and is amplified. The signal will not pass all the way through the IF's because of their bandpass response; therefore the operator will probably be unaware that another station is interfering. However, if an "on-channel" signal is received, it now must overcome the interfering signal or the set will be effectively dead.

Intermodulation is also caused by undesired signals entering the RF stage, but does not kill the receiver. Rather, it is reproduced and heard as audio in the speaker. Providing it is strong enough, an "on-channel" signal will usually overcome this condition, and then only the desired information will be heard. Unlike desensitization, intermodulation occurs only when *two* signals of the proper frequency are present at the antenna at the same time. As an example, if a 52-mc receiver has two signals—one at 52.12 and the other at 52.24 mc—entering its antenna circuit, they will produce a resultant at 52 mc. Since the second harmonic of 52.12 mc created in the mixer stage is 104.24 mc, the difference between it and 52.24 mc is 52 mc—the center frequency of the RF circuits. Any modulation on either original signal will be recognized by and heard in the speaker.

Desensitization and intermodulation are strictly problems of selectivity; therefore, good RF amplifier design is important. In normal use the amplifier seldom develops trouble. When a component does need replacing, however, the exact replacement should be used if possible, or the one closest to it. What a different value of component will do to help or hinder intermodulation and/or desensitization in a receiver is impossible to accurately predict. Just keep in mind that the original component was put there for a specific purpose, and you should not try to work around RF amplifier problems by trying to rebuild the circuits. They have been designed at the factory for optimum performance, and seldom if ever need reworking.

RECEIVER OSCILLATORS

Most communications receivers are double superheterodynes, which require two oscillators, each operating at a different frequency. The first, or high-frequency, oscillator output is mixed with the incoming RF signal to produce the high-IF frequency. This IF is then amplified and mixed with a signal from the second, or low-frequency, oscillator to produce the low-IF frequency. Since the local oscillator controls the front-end of the receiver, any change here will be noticed in the following stages as it is amplified. The frequency stability of the first oscillator is much more stringent than that of the second (low-frequency oscillator). The local oscillator must be able to maintain the IF at the center of the bandpass for a given incoming signal frequency. If it should drift even slightly, the IF center frequency would shift to one side of the bandpass response and a poor signal would be reproduced.

Frequency Drift

Other than a bad crystal in an oscillator circuit, perhaps the most common cause of frequency drift is mechanical. Over a period of time, vibration changes the adjustment settings of inductors and capacitors, altering the circuit constants which control the oscillator frequency. Generally, this problem is overcome by securely mounting all components and by shock-mounting the receiver to protect it from vibrations. Frequency drift also arises from voltage variations on the tube electrodes—a fluctuating B+ on the plate or screen, or an erratic cathode voltage. Any of these conditions can seriously affect the oscillator output; however, these are generally no problem with a good-quality power supply. Most B+ supplies have good voltage regulation, so electrical frequency drift is seldom encountered. Power supplies do go bad at times, however, and the trouble might show up first as frequency stability at the high-frequency end of the receiver.

Still another cause of frequency instability in an oscillator is thermal drift. Temperature variations cause coils and capacitors in the circuit to expand and contract, thus changing their circuit constants. This problem may be greatly lessened by using quality components having low-temperature coefficients. Air-dielectric trimmer capacitors depend on air for insulation. Since dry and moist air have different dielectric constants, the trimmer capacitance will undergo variations as the humidity fluctuates. This is easily amended by inserting the trimmer into a hermetically sealed chamber (leaving provision for adjustment, of course). Another method is to use a heating device near the trimmer to keep the air dry. In some circuits the trimmer can be mounted on top of the chassis, near the crystal oven (which becomes quite warm); or a small filament lamp bulb can be placed next to the trimmer.

High-Frequency Oscillator

In a high-frequency oscillator, the crystal doesn't oscillate at the desired frequency. Instead the oscillator operates on a crystal harmonic, and the desired working frequency is obtained by means of a multiplier stage similar to those employed in the transmitter. Fig. 3-5 illustrates the pentode crystal oscillator used in many communications receivers. This stage works like the one in the transmitter oscillator except it develops much less power. If excessive, power might leak through the RF amplifier stage and into the antenna, where it would be radiated and cause interference with other stations. The power requirement of the receiver oscillator is small because it only mixes with the incoming RF to produce the IF. In the transmitter, however, the oscillator must develop more power because it drives frequency multiplier–amplifiers.

In the VHF range of frequencies where most two-way radios operate, the local oscillator must operate at a very high frequency. An overtone or a harmonic crystal oscillator is therefore necessary. The harmonic oscillator is the lesser used because of the very high harmonic content in its output circuit. If these harmonics are allowed into the mixer, serious difficulty from spurious responses may arise. Therefore, a special crystal is used which is made to oscillate on other frequencies very close to odd harmonics of their fundamental. The main advantage of this crystal oscillator is its relative freedom from harmonics below its oscillating frequency. To realize this feature, special circuitry must be employed that has some means of feeding back part of the output signal into the input circuit. This feedback is not used for oscillating purposes, but rather to hold the rate of oscillations steady at the desired overtone. The necessary energy is generally developed in the output resonant circuit and fed back either inductively or capacitively.

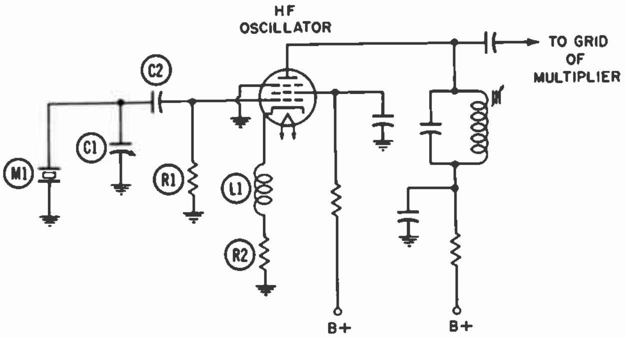


Fig. 3-5. Receiver high-frequency oscillator.

Notice in Fig. 3-5 that the combination of M1 and C1 forms the input parallel-resonant circuit. Oscillations will occur between the grid and cathode through cathode RF choke L1 and resistor R2, ground, the input resonant circuit, and C2. The resultant flow of RF plate current is taken off through C3 and injected into the multiplier stage. Feedback is obtained in the grid circuit through L1, R2, and grid resistor R1 (which develops the required operating grid bias). This type of feedback should be small enough not to cause oscillations, but merely serve as a synchronizing signal for the overtone.

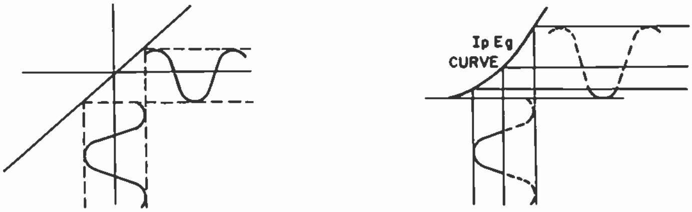
Like the transmitter oscillator, this type of receiver oscillator suffers from crystal frequency drift. This is the reason the high-frequency crystals are enclosed in a thermostatically controlled oven. If normal temperature variations were allowed to affect the expansions and contractions of the crystal, the subsequent frequency drift would distort the received signal. In actual use the crystal oscillator requires only occasional adjustment as normal aging of the crystal and components gradually lowers the frequency (this normally will not happen for several years). The crystal should be replaced when the oscillator frequency becomes so low that the frequency-adjusting capacitor is no longer able to compensate. However most communications receivers are so well built that it is not uncommon for them to stay in service 10 or 15 years. Since the oscillator is the heart of the radio, it should be kept in top working efficiency by replacing the crystal if at all needed.

THE MIXER

The mixer stage in an FM receiver beats the applied RF amplifier signal against the injected RF oscillator signal in order to produce the intermediate frequency (IF). This mixing action in the electron stream of the mixer tube produces sidebands at the sum and difference frequencies of the two applied signals. Generally the difference signal (lower sideband) is used as the IF, and since the local-oscillator signal is stronger than the RF amplifier signal, development of spurious sidebands is kept to a minimum. However, if the oscillator signal happens to contain harmonics, they will also beat against the incoming RF signal and produce sidebands. To prevent these unwanted sidebands from feeding into the following stage, the output circuit of the mixer is designed to discriminate against all but the desired sideband. Generally this discrimination is accomplished by two or three very critically tuned (high-Q) resonant circuits following the mixer.

The low percentage of modulation required for frequency conversion can be produced in one of several ways; however, the most common method in communications receivers is dependent on the transfer characteristic of the mixing device (the relationship of the input- to output-signal characteristic of the device). With a purely resistive device, any signal at its input may be lowered in amplitude at its output. Otherwise, the two signals will look exactly alike. In Fig. 3-6A the diagonal line represents the transfer characteristic of pure resistance plotted against the input voltage. Notice that the output is practically identical to the input. However, in a device such as a vacuum tube, the output is dependent on the familiar I_p-E_g (plate-current–grid-voltage) curve shown in Fig. 3-6B. The vacuum tube is a nonlinear device, and as you can see in Fig. 3-6B, only part of the grid signal is faithfully reproduced.

Any nonlinear device like a vacuum tube or a solid-state diode can be used as a mixer. In the vacuum tube, the RF signal is usually applied to the control or screen grid, whereas the oscillator signal is usually applied to the cathode or control grid. Both signals modulate the plate current. The output of the diode mixer is likewise modulated. When a diode is used as a mixer, whether vacuum tube or solid-state, the incoming RF signal is applied to the input circuit and the oscillator signal is coupled to the output of the mixer. Modulation then takes place because the incoming RF signal is impressed on the oscillator signal and causes the latter to vary in accordance. This mixing then causes sidebands, just as in the vacuum-tube mixer.



(A) Linear. (B) Nonlinear.

Fig. 3-6. Transfer characteristics.

Since a mixer is nothing more than a low-level modulator, it can produce many different IF frequencies according to the incoming RF signal and its sidebands, and the sidebands of the oscillator signal. If all frequencies but the desired RF are attenuated before arriving at the mixer, and if the oscillator is operating with low harmonic content, the mixer output will be very low in spurious responses. The most bothersome spurious response is the image frequency, which combines with the oscillator signal to produce a spurious sideband. As an example, if the oscillator is operated 1 megacycle higher than the RF signal, the image will appear 2 megacycles above the RF signal. If a strong carrier happened to appear at this image frequency (and it does quite often in two-way radio) it would interfere with reception of the desired station signal. A station does not necessarily have to be operating on the receiver image to create trouble. If the receiver is near a high-powered transmitter, any number of spurious responses are possible.

As previously stated, the mixer and RF amplifier circuits must be well designed, to keep the oscillator signal from leaking back into the antenna and being radiated. If this were to happen, it could cause interference in nearby receivers. In poorly designed mixers the weak oscillator signal is loosely coupled through the stray capacitance of the wiring. Even in well-designed circuits, however, stray capacitance is a problem. Another way the oscillator signal can get back to the antenna is via the capacitance of the mixer tube. If the incoming RF signal is injected at the control grid and the oscillator signal is impressed on the cathode, the capacitance between the two electrodes will effectively couple the oscillator signal back into the RF input circuit. Still another way the signal can get back into the input circuit is through the electron stream of the tube itself.

Typical Circuits

Diode mixers are used at the extreme upper end of the VHF range, where ordinary tubes are unsatisfactory. The diodes (whether vacuum-tube or solid-state) must have extremely small internal dimensions, and their anode and cathode must be close together. Since diode mixers function very efficiently with not only the oscillator fundamental but also the harmonics, oscillators operating at lower frequencies can be used.

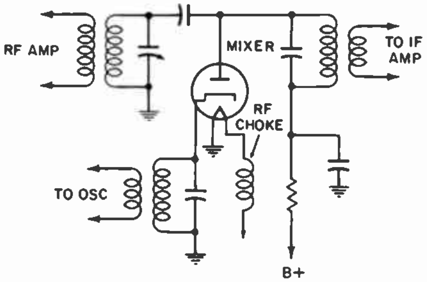
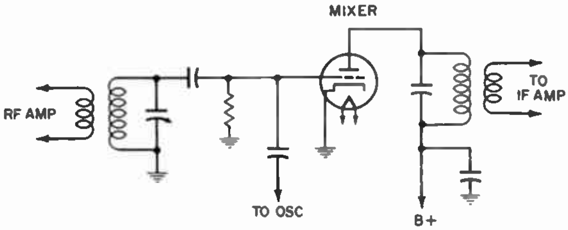


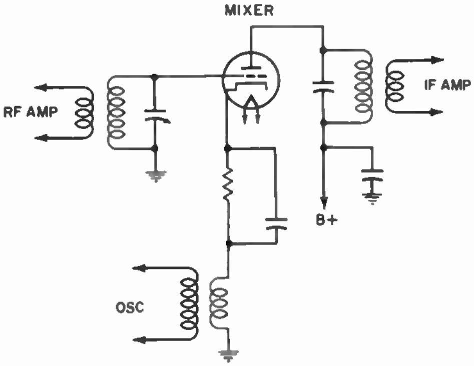
Fig. 3-7. Diode mixer.

Fig. 3-7 shows a typical diode mixer circuit. The parallel-resonant circuit of the cathode is resonant at the oscillator signal voltage, and the capacitor is also used at the cathode RF bypass. The capacitance between the heater and cathode in most vacuum tubes is sufficient to kill the oscillator injection circuit if not isolated. This is one reason for using an RF choke in the heater circuit of the diode. Another reason is to keep RF from being coupled to other stages through the filament circuit.

Fig. 3-8 shows two triode mixer circuits commonly used in FM receivers. In Fig. 3-8A the oscillator as well as the incoming signal is injected at the control grid; in Fig. 3-8B, however, the incoming signal is coupled to the grid, but the oscillator signal is injected into the cathode circuit. As far as performance is concerned, there is little difference between the two circuits. With cathode injection, the grid loading effect is slightly higher than with grid injection; however, cathode in-



(A) Oscillator injection at grid.



(B) Oscillator injection at cathode.

Fig. 3-8. Triode mixers.

jection gives better oscillator stability, since a low-impedance load is presented to the oscillator.

THE IF AMPLIFIER

Considerable IF selectivity is required in communications receivers in order to prevent adjacent-channel interference. However, the IF gain must also be increased when higher IF selectivity is desired. Because of difficulties arising from instability and feedback in an IF system, there is a limit to the amplification—and therefore, the selectivity—obtainable. Besides this, a high-frequency IF is needed in order to provide for good image rejection, but the high IF further lowers the selectivity obtainable. Therefore, the problem is met by using two IF frequencies to help reduce instability. The high IF provides the necessary image rejection, and the low IF the necessary selectivity.

In the conventional FM IF circuit shown in Fig. 3-9, the operation of the LC resonant interstage coupling transformer

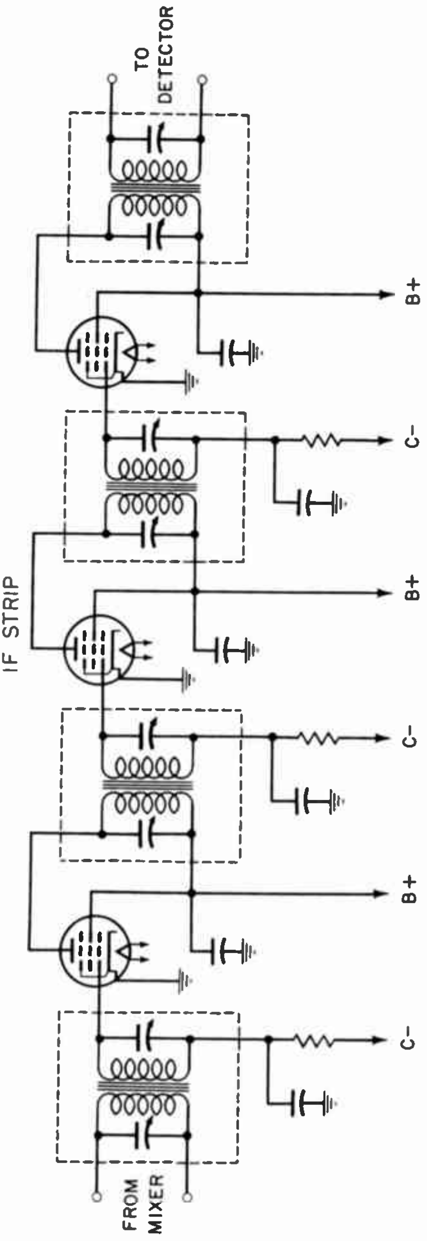


Fig. 3-9. A typical 3-stage IF-amplifier circuit.

determines the gain and selectivity of the stage. In general, these transformers must be made adjustable so that the set performance can be controlled. The transformation coupling is determined in the design stage, and the transformer is built to these specifications. Since the efficiency of the resonant circuit must be kept up to par, however, either the capacitor or inductor is made adjustable.

To gain the full advantages of FM reception, the IF system must have a selectable response that does not introduce objectionable distortion into the sideband system. At the same time, it must have sufficient adjacent-channel rejection. If the selectivity curve shown in Fig. 3-10 is not symmetrical about the center frequency, considerable distortion will appear in the receiver output because some sidebands are amplified more than others. To correct such distortion, the response curve must be made as flat-topped as possible. Notice in Fig. 3-10 that the curve showing the widest response has a dip in its center. Although the circuit showing this characteristic has sufficient bandwidth, it introduces distortion. However, if a single tuned circuit is added to this double-humped curve, the dip in the center can be raised, to eliminate the distortion, without affecting the response. In the typical amplifier, alternate circuits are used with either single tuned circuits or undercoupled transformers to fill in the dips left by the other overcoupled stages. If two stages are overcoupled and two others are coupled by the right amount, an almost ideal curve can be achieved. Overcoupled circuits are difficult to align because the tuning of the primary and secondary interact on each other, making the desired curve hard to obtain.

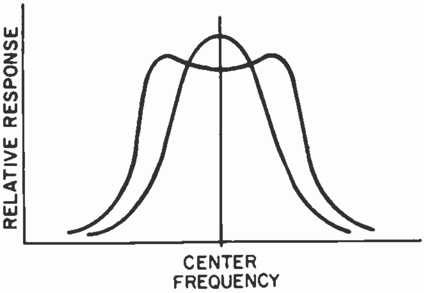


Fig. 3-10. IF response curve.

Another and perhaps the best way to obtain the optimum response curve in IF transformers is to *stagger-tune* them in succession—that is, to tune one circuit slightly above the center frequency and the other slightly below it. In this manner, each successive stage provides a portion of the desired flat-topped curve. Since no two successive stages are tuned to exactly the same frequency, they are less prone to become unstable. If an IF stage were unstable, the selectivity characteristic would not be symmetrical and distortion would be high. Instability can be caused by signal feedback from the output to the input, either in a single stage or over several. An unstable, or regenerative, amplifier not only has poor selectivity characteristics, but is affected more readily by variations in supply voltage, tube characteristics, or signal-voltage input. For best operation of IF amplifiers, all signal-voltage feedback must be reduced to an absolute minimum, so that interchanging tubes and components during repair work does not produce undesirable results. It is possible to reduce the feedback by lowering the gain of the stage, but this will impair the sensitivity of the receiver; therefore it is best to use the proper components and design in order to forestall trouble.

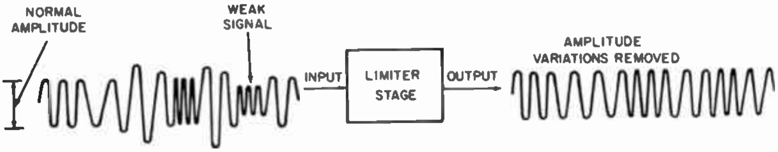
The High-Gain Low-IF Amplifier

Since maximum over-all gain in the IF amplifier permits the discriminator to operate at the high level required, the amplifier gain must be increased. One way is to decrease the ratio of capacitance to inductance in the IF transformers. Yet whenever the grid-circuit capacitance is reduced to too low a value, the varying transconductance of the amplifier changes the effective input capacitance sufficiently to detune the stage and cause distortion. When sharp impulse noise bursts increase the signal at the grid of the last IF stage, these bursts momentarily swing the signal far into the cutoff region. This detunes the IF transformer because the input capacitance can change as much as 2 mmf. The sudden detuning spoils the symmetry of the amplifier response curve and thus produces distortion. Most of the amplitude variation produced by this type of distortion is removed in the limiter, but phase distortion remains.

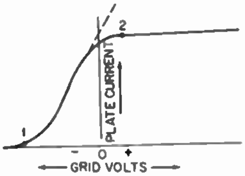
Since the gain of an IF amplifier increases as the product of the transformer capacitance decreases, it is possible to overcome this distortion. This is done by using the stray capacitance to tune the output circuit (and thereby increase the ratio of inductance to capacitance) while employing a fairly high input capacitance.

THE LIMITER

A limiter is in reality an IF amplifier so arranged that, beyond a certain point, a further increase in grid signal will produce no corresponding increase in plate-current signal. If the gains in the low-IF amplifiers are such that a strong signal is delivered to the limiter, amplitude variations in the signal will be removed. Since the discriminator responds to frequency variations only, the removal of these excessive amplitude variations does not adversely affect the signal reproduction. Notice in Fig. 3-11A that the input signal to the limiter varies in amplitude as well as frequency, but that the output varies in frequency only. Also notice that weak portions of the input are amplified to the desired level. The plate and screen voltages of a limiter stage are generally lower than in a regular amplifier, and a relatively small bias is applied to the control grid. Therefore, a highly positive grid-signal voltage drives the tube quickly into saturation; conversely, a highly negative signal drives it into cutoff. Fig. 3-11B shows the transfer characteristic of the ideal limiter. Any portion of grid signal below point 1 of the curve will cut off the plate current,



(A) Input versus output.



(B) Characteristic curve.

Fig. 3-11. Ideal limiter performance.

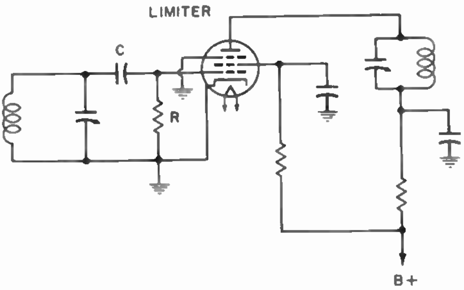
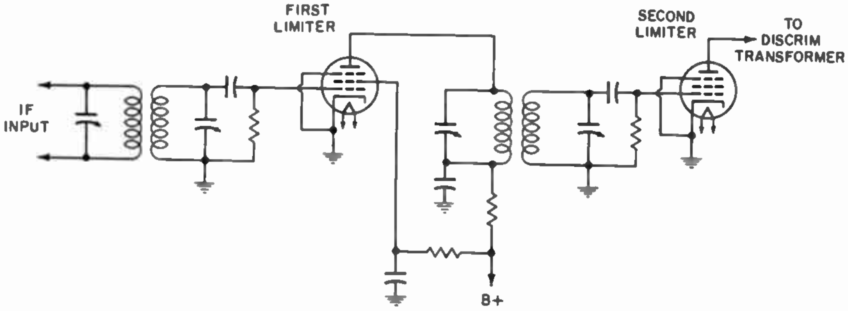
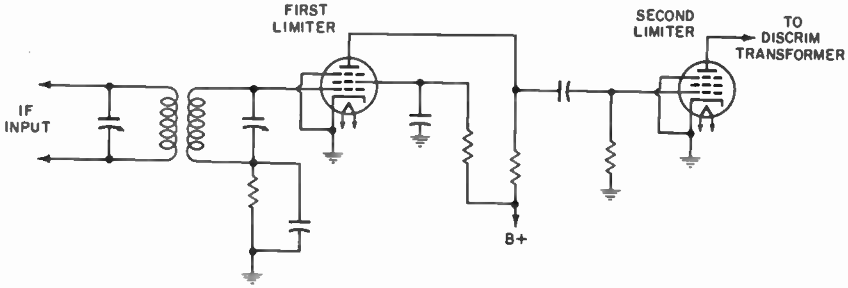


Fig. 3-12. Typical limiter stage.

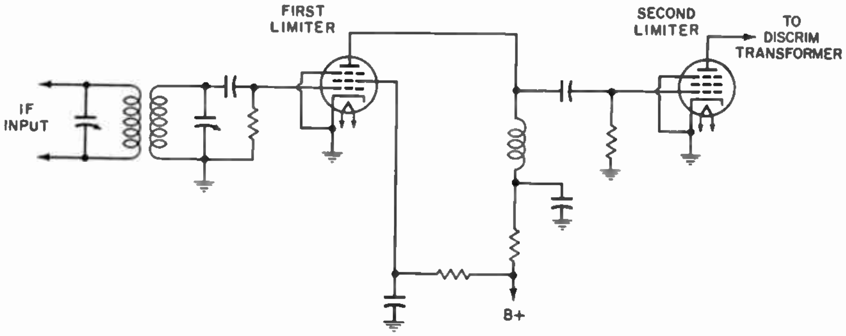
any any portion beyond point 2 will fail to increase the plate current any further. However, any signal that does not quite swing from points 1 to 2 will be amplified. For good limiter action, the input to the limiter should therefore be between the two points.



(A) Transformer-coupled.



(B) Resistance-coupled.



(C) Impedance-coupled.

Fig. 3-13. Cascade limiters.

Fig. 3-12 shows a limiter circuit that looks just like a typical IF amplifier except for the RC network in the grid circuit; this network provides the input clipping action on excessive noise peaks, and also furnishes the grid operating bias. This RC combination produces a voltage as a result of the peak DC rectified voltage between cathode and grid. Any noise pulses in the input signal that are longer than the time constant of the RC network are clipped off, but the longer variations caused by signal fading actually appear in the limiter output. To overcome this fading, the normal design procedure is to follow the first limiter with a second having an input network with a longer time-constant.

Notice in Fig. 3-13A that the limiters are transformer-coupled; this method provides greater gain for the second limiter, but is disadvantageous when there is sufficient signal to saturate the first limiter. The resistance-coupling method in Fig. 3-13B is more widely used because of its simplicity and ease of adjustment. The impedance coupling in Fig. 3-13C is a compromise between the two.

Any over-all gain in the limiters is undesirable because it will increase the problem of high-gain intrastage feedback. Amplification in the limiter takes place only when there is insufficient signal to drive it into saturation. Since about 2 volts of signal is required to saturate the limiter, an over-all gain of 2,000,000 must be realized ahead of it with an input of 1 microvolt in the antenna.

THE FM DISCRIMINATOR

In FM receivers the discriminator converts the IF signal into audio. Fig. 3-14 shows the signals before and after passing through the discriminator. Notice that as the input to the discriminator varies only in frequency, the voltage (amplitude) in its output likewise varies. When the frequency reaches a peak value on either side of the center frequency, the output (audio) voltage also reaches a peak value.

Fig. 3-15 shows a circuit of a typical double-tuned discriminator used in communications receivers. T1 is tuned to the

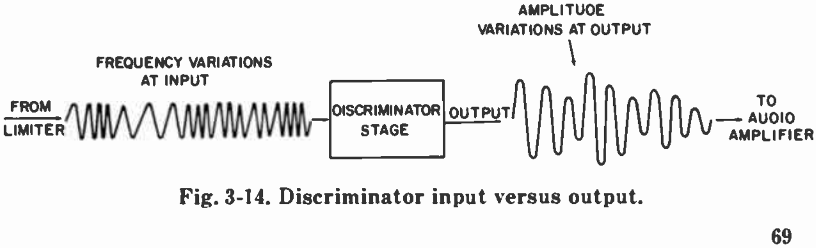


Fig. 3-14. Discriminator input versus output.

IF (center) frequency, and T2 and T3 are tuned above and below the carrier frequency (Fig. 3-16). With a constant-amplitude center-frequency carrier applied across T1 in Fig. 3-15, the voltages developed across T2 and T3 will be 180° out of phase, and alternate polarities will appear at the anodes

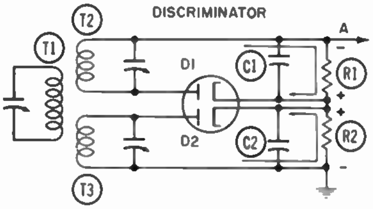


Fig. 3-15. Double-tuned discriminator circuit.

of D1 and D2. These voltages will increase and decrease in amplitude with the changing frequency; for èxample, assume that T2 is higher in frequency than the incoming IF signal. As the induced voltage approaches the resonant frequency of T2, its amplitude increases in a positive direction. If T3 is now tuned the same amount lower than the incoming IF, as the induced voltage approaches the resonant frequency of T3, its amplitude will increase in a negative direction. When the anode of D1 goes positive, the conduction is from the cathode, through the tube to the anode, through T2, and back through R1 to the cathode. Therefore, the resultant IR drop across R1 will be equal to the signal in T2; likewise, as the signal goes positive at the anode of D2, current will flow in the same manner. Capacitors C1 and C2 filter out any AC variations and thus permit a pure DC voltage to be developed across R1 and R2. In this manner the voltages across the individual load resistors, R1 and R2, oppose each other because both cathodes are at the same potential. Therefore, the total IR drop between the top of R1 and ground depends on the IR drops across the individual resistors. Since the voltages across the individual resistors depend on the polarity of the applied signal, if the incoming signal is higher in frequency than the reso-

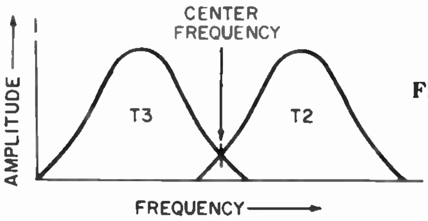
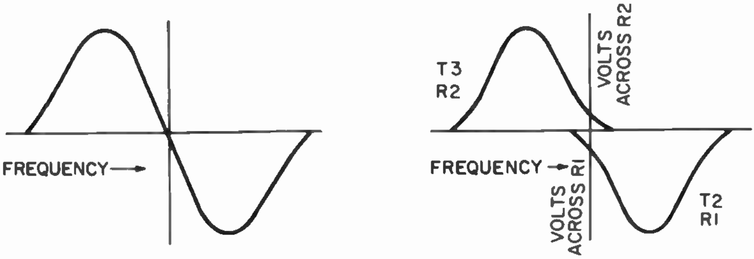


Fig. 3-16. Response of discriminator.

nant circuit of T1, D1 will conduct more heavily than D2 (because T2 is tuned higher than the carrier). On the other hand, if the incoming signal is lower than the resonant circuit of T1, D2 will conduct more heavily (because T3 is tuned lower than the carrier). Depending on which half of the discriminator conducts more heavily, one of the resistors will have a larger IR drop across it. However, if the incoming carrier is exactly at the resonance bandpass of T1 (center frequency), the IR drops across both resistors will be equal and thus the total output voltage of the discriminator will be zero. As an example, when the incoming signal increases in frequency, more voltage is developed across T2. As a result, a greater IR drop appears across R1, thus making point *A* more negative. When the signal drops below the center frequency, more voltage is developed in T3 than T2. Hence, there is a larger IR drop across R2, and point *A* now becomes more positive with respect to ground. As the applied frequency swings from above to below the center frequency, point *A* therefore goes from negative to positive; this results in the output-voltage-versus-frequency curve in Fig. 3-17A. The voltage across the individual resistors, with respect to frequency, is shown in Fig. 3-17B.



(A) Across discriminator. (B) Across resistors.

Fig. 3-17. Output voltage of discriminator.

COMCO 400-R-E RECEIVER

The receiver in Fig. 3-18 is a fixed-frequency, crystal-controlled, dual-conversion superheterodyne type for use in mobile or fixed FM station equipment in the 144-174–mc band. Each frequency conversion is controlled by a separate crystal. The receiver is designed for either wide- or narrow-band operation and can be easily changed from one to the other.

The Comco 400-R-E provides good sensitivity and has sufficient front-end selectivity to minimize the possibility of over-

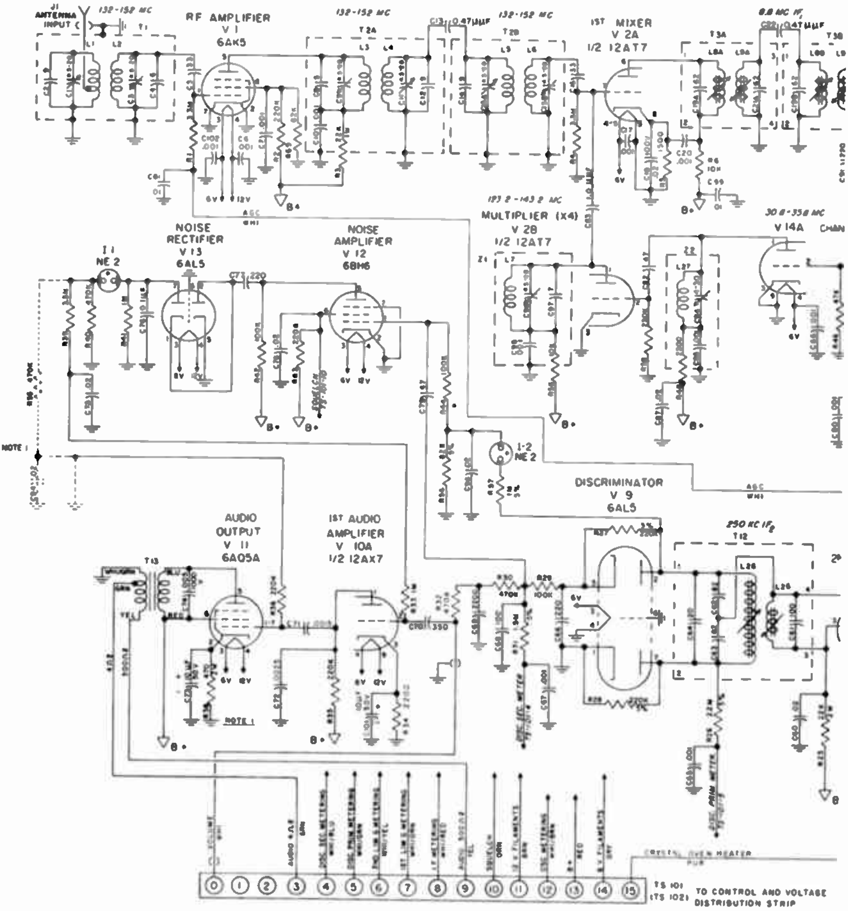
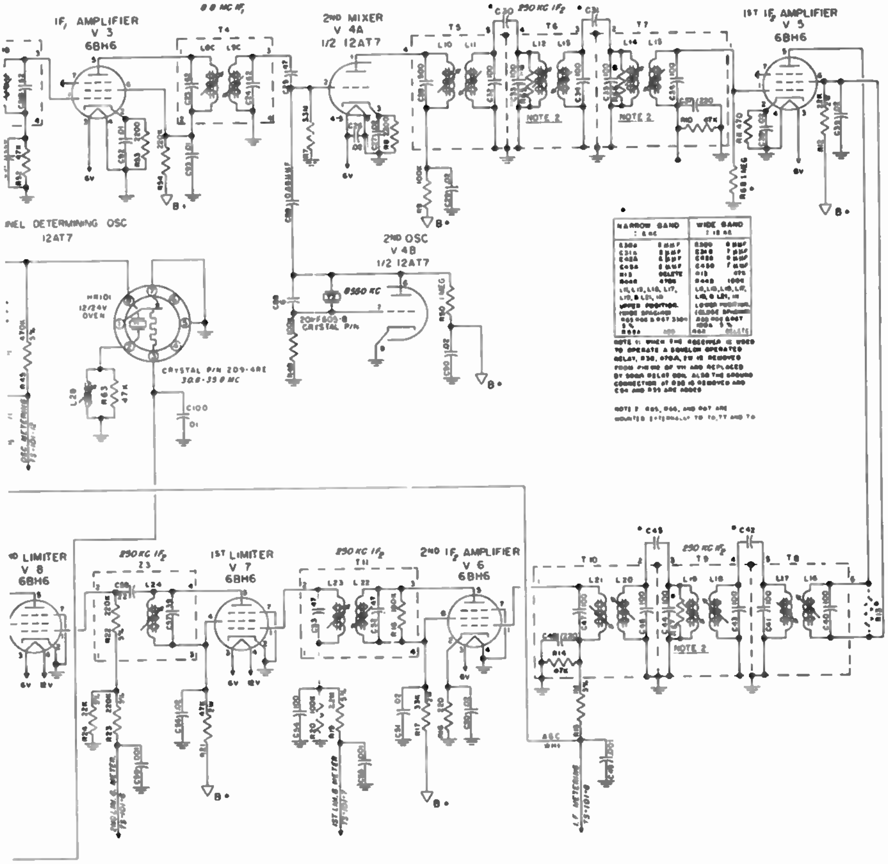


Fig. 3-18. Schematic of the



Comco 400-R-E receiver.

load, desensitization, intermodulation, mixing, and other undesirable conditions caused by a strong adjacent or off-channel signal. High-Q dual tuned circuits (filters) are provided between the antenna, RF stage, and first mixer.

An overtone crystal is used in the channel-determining oscillator for the first conversion. This, of course, minimizes the possibility of spurious responses. Provision is made for controlling the temperature of the channel-determining crystal. A temperature-controlled crystal is essential for split-channel operation.

High-Q multituned circuits follow the first mixer. Operating as a filter at the first IF frequency, they reject the second IF image and thus further minimize spurious responses. These circuits are followed by the second mixer/second oscillator, which uses a crystal similar to the military CR-18/U. The output of the second conversion is 250 kc. The second mixer is followed by two extremely high-Q tuned circuits, which provide the desired selectivity for the receiver. Two types are available, depending on whether the receiver is for use in wide-band (60-kc channel system with ±15-kc deviation) or narrow-band (20- to 30-kc channel system with ±5-kc deviation) operation. The change from broad to sharp selectivity can be accomplished by either (1) changing the filters, or (2) changing component values and/or removing several resistors and capacitors and retuning by the peaking method. The latter can be performed by the average technician with a standard signal generator. However, both broad- and narrow-band pretuned filters are offered for the customer's convenience.

The front-end gain of the receiver is purposely kept low to reduce mixing, overloading, and other undesirable conditions. The major portion of the gain is in the two 250-kc IF_2 stages (V5 and V6) following the high-Q filters. These are followed by two limiters, the discriminator, the de-emphasis network, and a conventional AF system with a speaker output of approximately 2 watts. A voltage-compensated squelch circuit, associated with the limiter and audio circuit, eliminates noise during standby.

RF Amplifier

Radio-frequency signals picked up by the antenna are coupled to antenna jack J1 and then to the grid of RF amplifier V1 through a high-Q double-tuned circuit. This circuit presents the proper load impedance to match a 50-ohm antenna input. The RF amplifier (V1) obtains grid bias from contact potential developed across the grid resistor. When the grid voltage of the second IF amplifier exceeds a certain level, AGC voltage is fed to the RF-amplifier grid circuit. This voltage reduces the gain of the RF amplifier and thereby prevents intermodulation by adjacent- or alternate-channel signals. RF signals which have been amplified in V1 are then coupled, through four additional high-Q capacitor tuned RF circuits, to the grid of the first mixer (V2A). These tuned circuits consist of two capacitively coupled, double-tuned transformers, T2A and T2B.

First Oscillator

The first oscillator (V14A) utilizes an overtone crystal which oscillates at one-fourth the first-mixer injection frequency. (The injection frequency is always equal to the channel frequency minus 8.8 mc.) The crystal is ground to a tolerance of ±.0015%. It plugs into an octal-socket crystal oven using pins 2 and 8. This oscillator circuit operates the crystal on its third mode when the plate circuit (Z2) is resonated according to the tuning instructions. The use of mode-type crystals greatly reduces the possibility of spurious responses. Crystal trimmer coil L28 is provided in series with the channel-determining crystal so that the latter can be set on the exact frequency. The trimmer can vary the injection frequency approximately ±.006% or more. This is sufficient to compensate for the crystal-grinding tolerances, and also to permit netting into systems which are permitted channel-frequency tolerances such as ±.005%. Oscillator grid voltage is developed across resistor R46 and metered through R45. The oscillator output is coupled through capacitor C82 to the grid of V2B, where the frequency is quadrupled. The plate circuit of this stage is resonated to the multiplied frequency, and coupling capacitor C83 is used for injection to the first mixer grid. Grid bias is developed across multiplier grid resistor R59.

First Mixer of the IF_1 Amplifier

The first mixer (V2A) receives the amplified RF signal and the first-oscillator multiplier output on its control grid. These are combined in the first mixer type, and the resulting difference frequency is the first IF of 8.8 mc. This signal is then passed through four tuned circuits before being applied to the grid of 8.8-mc IF_1 amplifier V3. The tuned circuits consist of transformers T3A and T3B, which utilize high-Q slug-tuned coils. Both transformers are coupled by capacitor C22.

The amplified 8.8-mc signal in the plate circuit of IF_1 amplifier V3 is coupled, by T4, to the grid of second mixer V4A, which is half of a 12AT7 tube.

Second Oscillator

The second crystal oscillator is operated at 8,550 kc. Its plate circuit is coupled to the second-mixer control grid through injection capacitor C89.

Second Mixer

The 8.8-mc IF signal and the second-oscillator output of 8,550 kc are coupled to the control grid of second mixer V4A, and are combined in the tube to form the desired difference frequency of 250 kc. The second mixer and second oscillator are both in the same tube (V4), a dual triode 12AT7.

First IF_2 Amplifier

The second-mixer output of 250 kc is coupled through the high-*Q* tuned-circuit transformers, which provide the basic selectivity for the receiver. Each transformer utilizes different amounts of coupling to obtain the desired selectivity. However, the coupling of these coils can be changed (as outlined in the tuning procedure) in order to convert the receiver selectivity from broad- to narrow-band.

After passing through T5, T6, and T7, the 250-kc IF_2 frequency is amplified by the first IF_2 amplifier (V5). It then passes through T8, T9, and T10, to the grid of second IF_2 amplifier V6. Drive to the grid of the second IF_2 amplifier is metered through resistor R15. The signal is amplified in the second IF amplifier. It then passes through another double-tuned IF transformer (T11) which, because of its very high impedance, gives extremely high gain from the second IF_2 amplifier.

Discriminator

The output of second limiter V8 is fed to a Foster-Seeley type of discriminator which has a high output and good linearity. The discriminator transformer has temperature compensation (provided by capacitor C64), and has been impregnated with a high-temperature wax to protect it from moisture. The discriminator is therefore extremely stable with temperature and humidity changes (and is also unaffected by shock and vibration). Its output (pin 5, V9) contains the audio (or noise, in the absence of a signal).

Noise Amplifier and Squelch Circuit

The discriminator output, in the absence of a signal, consists of amplified thermal or shot noise (among other things), which originates in the early stages of the receiver. This noise then passes through RF filter network R29-C68 and is impressed on the noise-amplifier grid through coupling capacitor C79. It is then amplified through noise-amplifier tube V12, the gain of which is controlled by turning the Squelch control (on the control panel) to raise or lower the screen voltage. The amplified noise in the plate circuit is coupled, through capacitor C77, to the plate of noise rectifier V13, which functions as a voltage doubler.

This voltage is filtered by C76, which has sufficient capacitance to remove most noise fluctuations. The rectified noise voltage is then applied to the NE-2 neon bulb I1. With no input signal to the receiver and with the Squelch control advanced to the point where the V12 screen voltage has increased so that approximately −70VDC is across capacitor C76, bulb I1 will have sufficient voltage to ionize (and hence conduct). A negative DC voltage will then pass through RF filter R39, and C75 will have sufficient amplitude to completely bias first audio amplifier V10A beyond cutoff. When the latter occurs, there will be no audio output from the receiver. A negative DC voltage may also pass through R55 and R36 to the grid of audio-output tube V11, depending on the wiring of the receiver. From the schematic you can see that C94, R36, and R55 may be connected to the neon-bulb output or that R36 may be connected to ground. If the screen voltage on noise amplifier V12 is reduced with the Squelch control, the voltage across C76 will be reduced below the ionization (conduction) point of the neon bulb. When this occurs, the bias voltage—measured from the control grid of first audio amplifier V10A to ground—will disappear. The neon bulb provides a positive and very fast-acting squelch action. As a signal is received, the bias increases on the limiter control grids, thereby reducing their gain. In turn, less "thermal" or "shot" noise is applied to the noise amplifier. When the noise amplifier and rectifier receive less noise, the voltage presented to the neon bulb (I1) will be too low to cause conduction. As a result, no negative voltage will be applied to first audio amplifier V10A. Being unbiased, the tube will therefore amplify the signal.

If R55, C94, and R36 are connected to I1, the negative squelch voltage will be applied to the grid of audio-output tube V11 and partially cut it off while the squelch is operating. This bias reduces the battery drain and also permits inserting a 300- to 500-ohm squelch relay in place of the cathode resistor. This relay, which must have suitable sensitivity in order to operate, can be used for signaling or for operating other devices. If resistor R36 is connected to ground, the audio-output tube will not receive the extra bias while the receiver is "squelched off." The squelch operation is slightly better when the audio-output stage is not receiving this extra bias; therefore, it is suggested that resistor R36 be connected to ground except when a squelch-operated relay is desired. The squelch circuit in this receiver has a means of compensation, to prevent power-source voltage variations from opening or tightening the squelch.

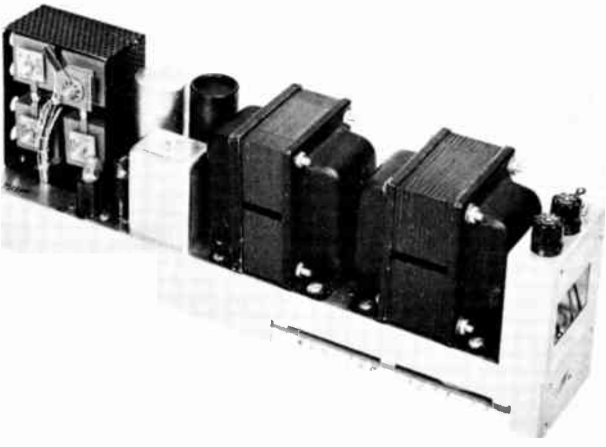
Compensation is obtained by coupling the negative voltage from the discriminator plate, through a neon bulb and a resistive voltage divider, to the grid return of the noise amplifier. The neon bulb, having a constant voltage drop, will supply to the noise amplifier a bias with a greater percentage change than the voltage present at the discriminator plate. The bias voltage changes the gain of the noise amplifier so that its output is held constant. Of course, the noise-amplifier voltage output can still be adjusted with the Squelch control. When set at its most sensitive point, the squelch will operate with signals that provide approximately 2 db of noise quieting in the receiver audio output. The Squelch control should be adjusted to a point just beyond where slight pulses of noise are heard in the speaker. If advanced any further, the squelch will require stronger signals in order to operate.

After going through RF filters R29 and C68, the discriminator output is passed through de-emphasis network R30-C69. This network—in combination with other tone-compensating capacitors such as C70, C72, and C74—results in an audio response which has a decreasing 6-db-per-octave slope from 300 to 3,000 cycles without deviating from a tube 6-db-per-octave de-emphasis slope by more than +2 to −8 db. From the de-emphasis network the audio signal is applied through capacitor C70 to first audio amplifier V10A, which derives its operating grid bias from cathode resistor R34. Here the audio signal is amplified and then applied, through coupling capacitor C71, to the grid of audio-output stage V11. Correct operating grid bias is obtained for V11 by means of its cathode resistor, R38, which is bypassed by electrolytic capacitor C73. The audio output from the plate of V11 is coupled to transformer T13 (which has two secondary output impedances, 4 ohms and 500 ohms). Capacitor C74, across its primary, controls the audio-frequency response and also protects transformer T13 from high-voltage audio surges.

Chapter 4

Power Supplies and Intercabling

Unlike a regular radio receiver, a two-way radio presents two separate power requirements to its power supply. In the normal standby (receive) position, the only drain on the power supply is the filament and plate power required by the receiver. In the "transmit" position, however, the power supply (Fig. 4-1) must deliver not only filament and normal plate power, but also a negative bias (in some sets) to the final-amplifier grid as well as high B+ to the plates of the driver and final. These conditions require specially designed power supplies. Moreover,



Courtesy Motorola C and E, Inc.

Fig. 4-1. AC power supply.

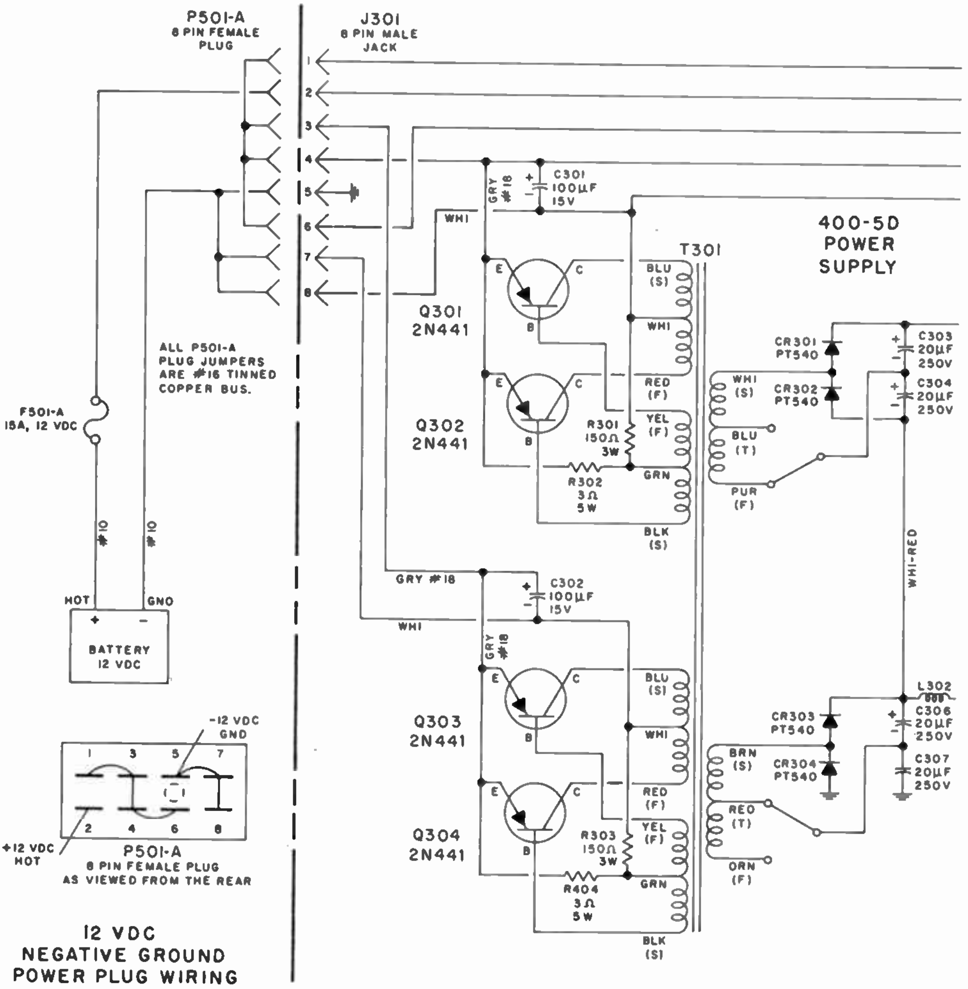
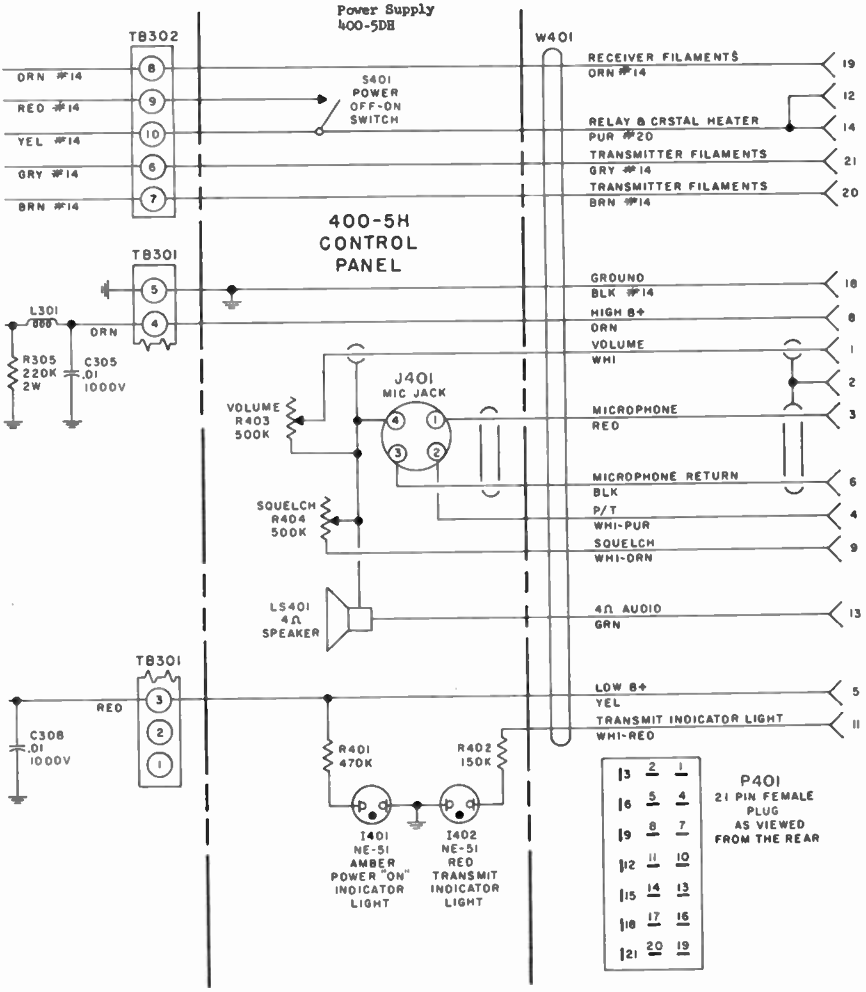


Fig. 4-2. Comco 400-5DH



power supply and control head.

each manufacturer has his own design, thus the service technician in the field has to contend with an array of designs.

The different voltage conditions for "transmit" and "receive" are easily managed through the use of switching relays. When the push-to-talk switch on the microphone is activated, these relays transfer their contacts from the "receive" to the "transmit" mode. In some power supplies the antenna relay is on the chassis and it switches the coaxial antenna input from the receiver to the transmitter when the push-to-talk switch is activated.

THE COMCO 400-5DH POWER SUPPLY

The Comco 400-5DH (Fig. 4-2) is a combination transistor power-supply control box and speaker designed to supply the proper operating voltages and control functions for the Comco AN/VRC-51 series of equipment. The design and choice of components permit operation in the ambient temperature range from −30° to +60° C. Four quality transistors, type 2N441, in an electronic self-excited switching circuit provide AC voltages, which are stepped up by a toroidal transformer. (Important: This is really two 12-volt supplies connected in series or parallel.) After being rectified by silicon rectifiers, the voltages are filtered and then supplied to a receiver-transmitter unit. An automatic safety feature reduces the battery drain if the B+ lead is shorted, effectively protecting the components from damage. The power supply can be readily removed as a unit for servicing or replacement. All power leads are properly filtered to prevent radiation of the switching-frequency harmonics and both voltage regulation and operating efficiency are extremely good.

The power supply is designed to accept a DC input of either +13.6 volts (negative ground return), −13.6 volts (positive ground return), +24.6 volts (negative ground return), or −24.6 volts (positive ground return) from a battery-generator supply, in accordance with EIA standards. (These voltages are more commonly referred to as "12VDC" or "24VDC.") The tube filaments will accept either polarity—*but the polarity of the voltage fed to the transistors must be observed.* Polarity may be reversed by using jumpers in the primary input plug. This unit normally is wired at the factory for a 12-volt DC, negatively grounded battery system.

Oscillator (Switching) Circuit

This oscillator (or switching) circuit closely resembles that of a push-pull vacuum-tube oscillator. When power is applied, more current will flow through one of the collector circuits (because of the minor dissymmetry of the two transistors) than the other. This current will induce a proportional current in the base winding, on the same transformer core. The winding connections are phased so that the polarity of the current biases the conducting transistor in the direction that increases its conduction, while biasing the other transistor in a direction which cuts off its collector current.

This process continues, with the collector current of one transistor rising (driving it further into conduction until transformer saturation occurs), and the collector current of the other decreasing. When transformer saturation occurs, the rising collector current can no longer induce a current in the base winding. As a result, the bases of both transistors return to their normal bias. Because its collector is at a high negative bias, the nonconducting transistor will start to conduct and the conducting transistor will be cut off. The oscillator output is essentially a square wave, but appears as a sine wave at the secondary of T301. From here the signal is rectified and filtered in the usual manner.

Automatic Safety Features

The 400-5DH power supply contains an automatic safety feature which prevents excessive current from damaging power-supply components in case any B+ leads become shorted. In such an event, the B+ lead will present a low impedance in parallel with the power-transformer output and, by changing the level of feedback, cause the transistors to go out of oscillation. As a result, the current drain will drop to about 0.25 amp. On the other hand, if a short causes excessive current drain, fuse F501 will blow and thereby protect the transistors.

Transformer Outputs

There are two transformer outputs. One (low B+) of approximately 220 to 245 volts DC supplies both the receiver and transmitter, except for the power-amplifier plate circuit. It is fed by another output (high B+) of approximately 485 volts DC.

The low B+ is developed across one secondary winding of T301 and fed to a half-wave rectifier circuit, the output of which is filtered by C306 and C307 in series. It is then fed through RF choke L302 (which removes the switching-circuit harmonics) and is further filtered by C308. R305 acts as a bleeder resistor for both the high-and low-B+ circuits. Taps are provided for switching the number of turns on the secondaries of the toroidal power transformer and thereby boosting the low B+ if required (such as to compensate for power-supply regulation as components age). To make this change, it is necessary to reconnect the wires. This is not recommended unless absolutely necessary.

The higher B+ is also developed by feeding the output of one of the T301 secondary windings to a half-wave rectifier circuit. The positive output is filtered by C303 and C304, and L301 and C305, R305 is the bleeder resistor. The negative leg is connected to the lower B+ circuit so that the two act in series when the transmitter is in operation. The high B+ circuit also has taps for changing the output voltage.

Push-to-Talk Relays

The push-to-talk relays are mounted on the interconnecting chassis, between the two receiver-transmitter chassis. When the push-to-talk switch on the microphone is energized, one relay switches the antenna from the receiver input to the transmitter output and the other has contacts which transfer the low B+ from the receiver to the transmitter circuits.

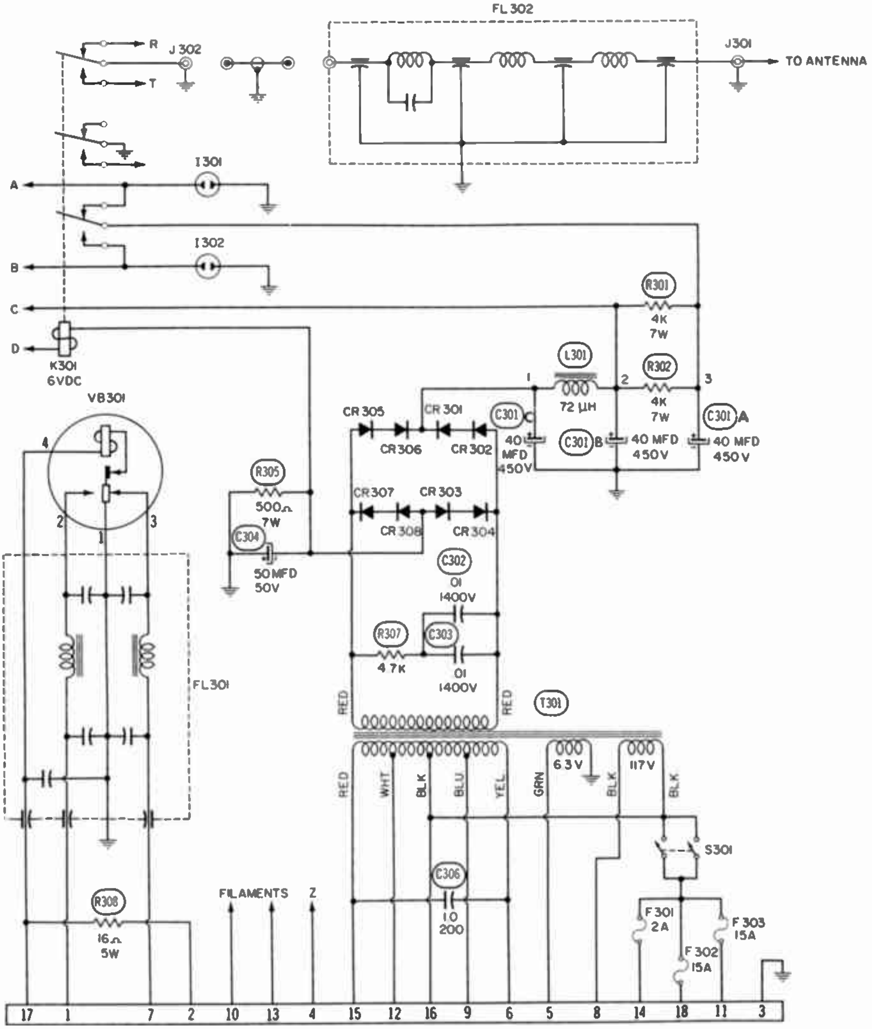
AEROTRON "600" SERIES POWER SUPPLY

The Aerotron "600" series equipment has a compact, integral three-way power supply. All sets can be operated from either 6 or 12 volts DC or 115 volts, 50 to 400 cycles AC. When operated from a DC source, a series-driven vibrator converts the direct current into square-waves, which can then be stepped up to the high voltage required by the set.

In Fig. 4-3 a special power transformer, T301, has primary windings for three standard input-voltage sources. These in turn are automatically and properly connected by jumpers in an external power-cable plug. A separate fuse is provided for each input voltage. Heavy-duty switch S301, attached to the back of the volume control, turns the set on within the first few degrees of clockwise rotation.

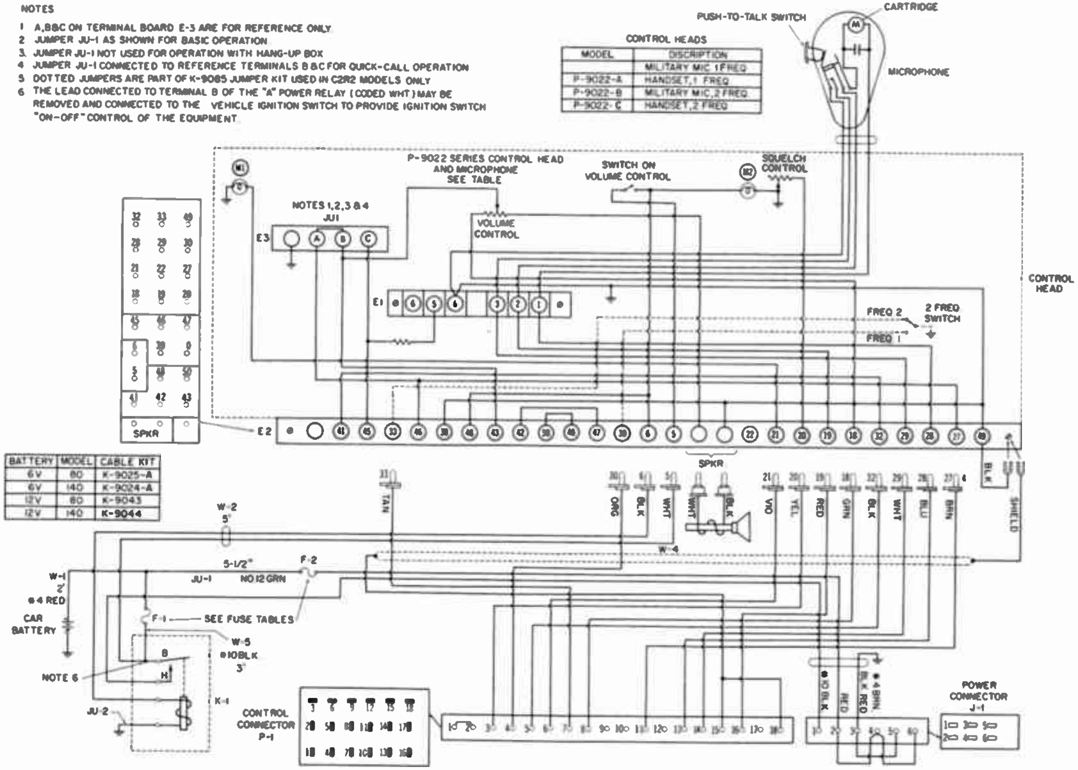
On AC operation, the filaments and crystal-oven heater are supplied with 6.3 volts from a low-voltage winding on the power transformer. AC from the high-voltage winding of T301 is applied to a conventional full-wave bridge consisting of the eight silicon rectifiers CR301 through CR308. The negative side of the bridge rectifier is returned to ground through R305, which is a convenient source of low-voltage DC for operation of transmit-receive relay K301. Capacitor C304 provides a low-impedance return from the bridge to ground.

The high-voltage DC output is applied to a filter network consisting of C301A, B, and C, L301, and R301 and 2. Unkeyed



NOTES
1. UNLESS OTHERWISE SPECIFIED; RESISTORS ARE 1/2W 10%
CAPACITORS ARE U UF

Fig. 4-3. Aerotron "600" series power supply.



NOTES

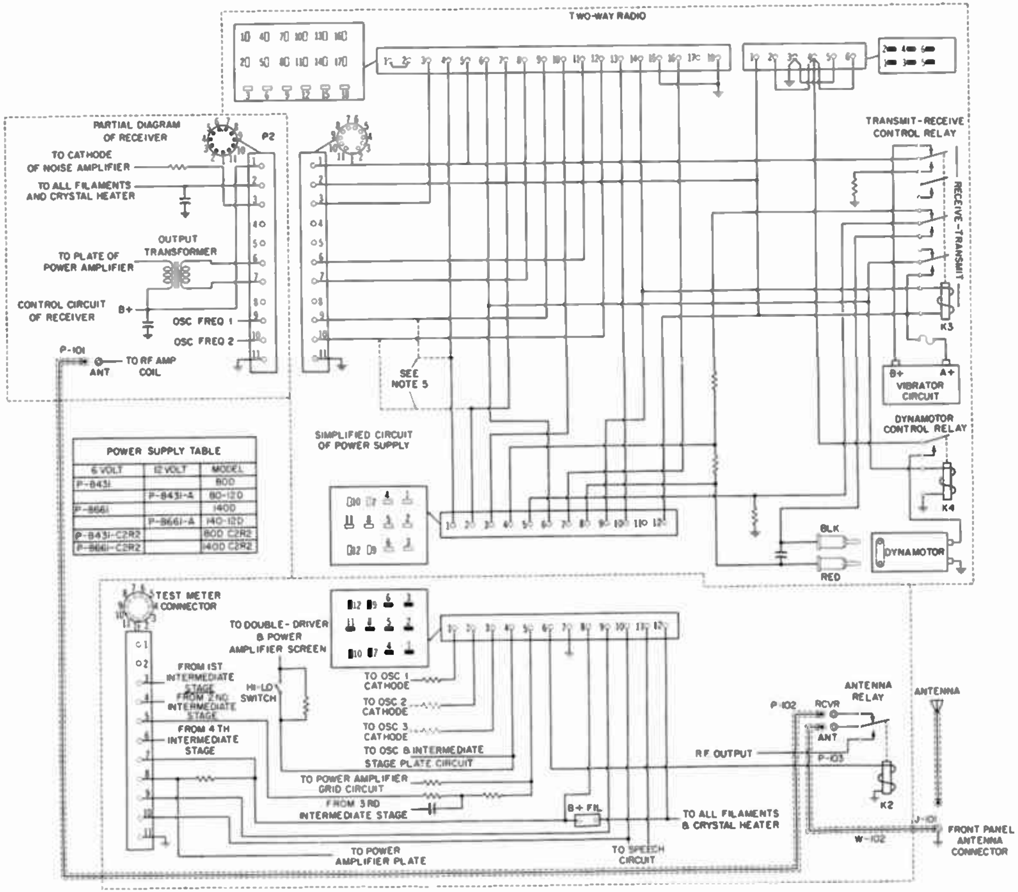
1 A,B&C ON TERMINAL BOARD E-3 ARE FOR REFERENCE ONLY
2 JUMPER JU-1 AS SHOWN FOR BASIC OPERATION
3. JUMPER JU-1 NOT USED FOR OPERATION WITH HANG-UP BOX
4 JUMPER JU-1 CONNECTED TO REFERENCE TERMINALS B & C FOR QUICK-CALL OPERATION
5 DOTTED JUMPERS ARE PART OF K-9085 JUMPER KIT USED IN C2R2 MODELS ONLY
6 THE LEAD CONNECTED TO TERMINAL B OF THE "A" POWER RELAY (CODED WHT) MAY BE REMOVED AND CONNECTED TO THE VEHICLE IGNITION SWITCH TO PROVIDE IGNITION SWITCH "ON-OFF" CONTROL OF THE EQUIPMENT

CONTROL HEADS

MODEL	DISCRIPTION
	MILITARY MIC 1 FREQ
P-9022-A	HANDSET, 1 FREQ
P-9022-B	MILITARY MIC, 2 FREQ
P-9022-C	HANDSET, 2 FREQ

BATTERY	MODEL	CABLE KIT
6V	80	K-9025-A
6V	140	K-9024-A
12V	80	K-9043
12V	140	K-9044

Fig. 4-4. Typical Motorola



POWER SUPPLY TABLE		
6 VOLT	12 VOLT	MODEL
P-843I		800
	P-843I-A	80-120
P-866I		1400
	P-866I-A	140-120
P-843I-C2R2		800 C2R2
P-866I-C2R2		1400 C2R2

intercabling arrangement.

high voltage is taken off at point 2 in this filter, and a somewhat lower voltage from point 3. This low B+ output is switched from receiver to transmitter by relay K301A. A small panel-mounted neon bulb (I301) glows when the equipment is receiving power, and another lamp (I302) does the same when the transmitter is keyed.

During DC operation the filaments are operated directly from the DC source, while only the crystal oven operates from the 6.3-volt filament winding of the transformer. The filaments are automatically connected for either 6- or 12-volt operation by jumpers in the power-cable plug. The vibrator (VB301) interrupts the DC input at a 115-cycle rate. The alternated DC is then transformed by T301 in the same manner as AC.

The power transformer (T301) is designed for 50- to 400-cycle operation so it can be used on almost any commercial power source throughout the world. Where required, a split 115/230-volt primary-winding transformer can be supplied that can be connected for either 115- or 230-volt operation, as desired. Operation on 6 or 12 volts DC remains identical to that of the standard transformer.

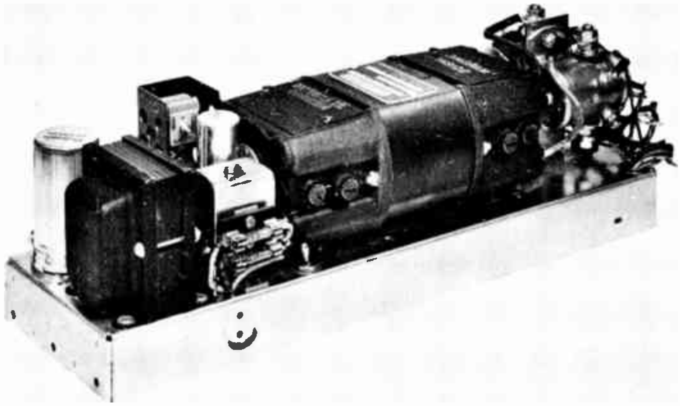
INTERCABLING

Fig. 4-4 shows the intercabling setup of a Motorola dynamotor-type two-way radio. Here only parts of the transmitter, receiver, and power supply are shown, and these only in relation to the control head. Since the power supply (Fig. 4-5) has a high current drain, battery power must be brought into it through a special cable. Another cable connects the trunk-mounted radio to the control head mounted on the dashboard, and also to the battery under the hood. Fuses F1 and F2, generally rated at 15 and 30 amps respectively, are connected to the battery. F1 is in the on-off switch line, and F2 is in the dynamotor line.

When the on-off switch in the control head is turned on, relay K1 is energized as battery current flows through it via F1, pin 5 of terminal board E2, the on-off switch, and pin 6 of E2. When this happens, contacts *H* and *B* of K1 transfer, thus connecting the battery (through F1) to the radio power supply via pin 1 of power connector J1. The filament line for the entire radio as well as the vibrator takes its power from this source. In this mode, the receiver is now ready to receive and the transmitter to send. Relays K2, K3, and K4 are shown in their normally de-energized (receive) positions.

With an RF signal of the correct frequency on the antenna and with antenna relay K2 in the position shown, the receiver will recognize and reproduce that signal as audio. This signal is fed into the control head and developed across the volume control. From here it goes to terminal board E2 and then to the speaker.

To transmit, the microphone push-to-talk button is depressed; this connects ground from E1, 4 through the push-to-talk switch in the microphone, and relay K3 is energized. When the contacts of K3 change positions, the bottom ones complete the circuit from the battery (A+) to dynamotor control relay K4 and antenna relay K2. Relays K2, K3, and K4 are now energized and will stay that way as long as the microphone button is depressed. The transmitter is now on the air, and when the operator speaks into the microphone, the sound is carried (through the control head) into the speech amplifier in the transmitter.



Courtesy Motorola C and E, Inc.

Fig. 4-5. Dynamotor power supply.

All other functions are accomplished by use of the control cable. They include control of the receiver squelch; selection of the transmitting channel, by use of the 2 frequency switch in the control head; automatic indication by lamp M1 when the transmitter is on the air; and automatic indication by lamp M2 when the radio is receiving power.

Chapter 5

Antennas

In free space, radio waves travel at the speed of light (186,000 miles, or 300,000,000 meters, per second). However, the RF energy in an antenna moves much slower because the *dielectric constant* of the antenna is greater than that of free space. Since the dielectric constant of air or a vacuum is equal to *1*, a constant greater than *1* will effectively retard the radio wave to a certain extent. It is this factor that creates the difference between the electrical and physical length of an antenna. One that is electrically one-half wavelength, for example, is somewhat shorter physically.

The actual difference between the electrical and physical length of an antenna is dependent on several factors. One is the physical construction of the antenna itself; the smaller the circumference, the less the velocity of the electromagnetic wave is affected. This simply means that a one-half–wavelength antenna with a small circumference is electrically longer than a one-half wavelength antenna with a larger circumference.

Another factor is stray capacitance, which lowers the dielectric constant of the antenna and thus the wave velocity. This capacitance can be caused by a nearby metal object, the insulators supporting the antenna, or the transmission line feeding it.

The gain of an antenna is the measure of its radiated field strength at a given distance from it. Consider two antennas operating at the same frequency, with the same power, and at the same height. One antenna may radiate a doughnut-shaped pattern—that is, one with equal field strength in all directions (omnidirectional). For the sake of illustration, let's say its gain is zero. Another antenna may radiate an oval pattern—

i.e., one that extends farther from the antenna in one or more directions. Such an antenna is said to have a directional pattern. This higher field strength in certain directions is available only at the expense of field strength in the other directions. This is analogous to a tin can—normally it is cylindrical, but flatten it and it becomes longer in the one direction and shorter in the other.

Fig. 5-1. Mobile half-wave antenna with 3-db gain.

Courtesy Antenna Specialists Co.

This elongated radiated pattern permits communications over greater distances between antennas, however. The ordinary one-quarter–wave mobile antenna used in the 144-174–mc range has a more or less doughnut-shaped pattern. Of course, practically no gain is realized at all; however, a recently developed one-half–wave mobile antenna with 3-db gain makes it possible to increase the coverage from existing systems. This antenna (Fig. 5-1) has a round pattern that hugs the earth

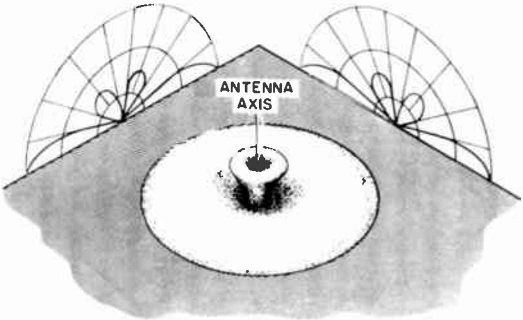
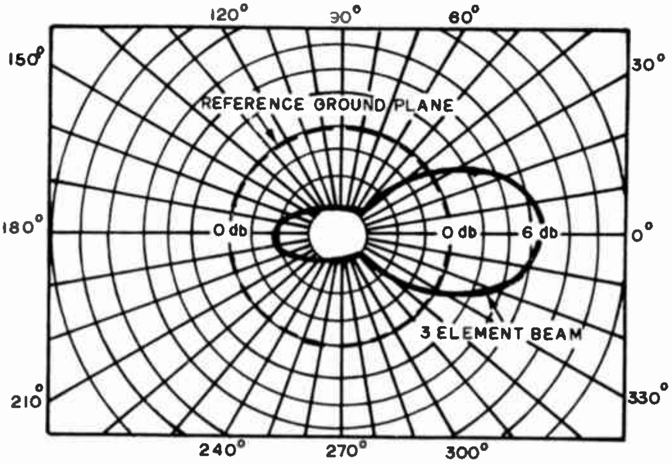


Fig. 5-2. Pattern of half-wave vertical antenna located one-half wavelength above ground.



Courtesy Antenna Specialists Co.

Fig. 5-3. Horizontal radiation pattern of a beam antenna.

(Fig. 5-2); very little energy is radiated toward the sky. This antenna, which has a loading coil in its base, is cut to the exact wavelength when installed on the vehicle.

Base-station antennas differ somewhat from mobile antennas. Most have gains as high as 5 to 10 db. In some systems, equidistant coverage is not required from the antenna. Take, for instance, a city that is more spread out in one direction than in another; an antenna that covers the city might have a pattern like the one in Fig. 5-3. Most generally, though, complete coverage is required in all directions. The 450-470–mc antenna shown in Fig. 5-4 exhibits the pattern in Fig. 5-5. As

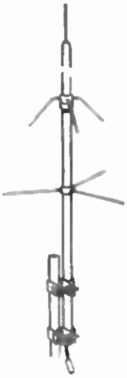
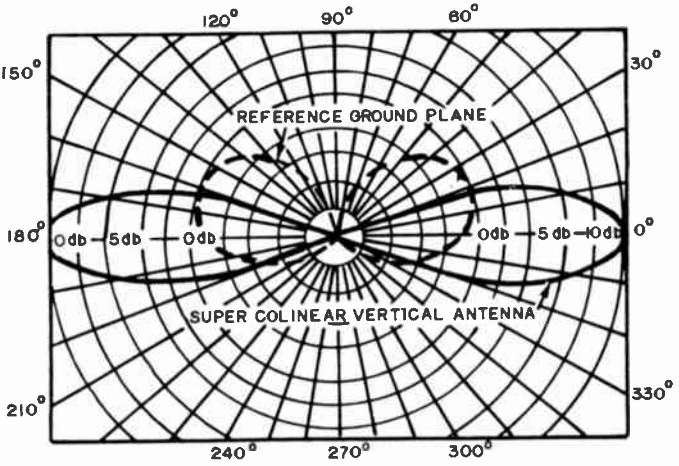


Fig. 5-4. Super colinear vertical antenna.

Courtesy Antenna Specialists Co.

you can see, there is very little sky wave; what would have been sky wave has been used as ground wave and thus an effective gain of 10 db realized.

With good high-gain base- and mobile-station antennas, powerful transmitters, sensitive receivers, and favorable terrain, commercial radiocommunication up to one hundred miles (ground wave) is possible. However, any one of these aforementioned conditions directly affects communications. Terrain alone accounts for more loss of communications than perhaps any other condition. When a mobile unit travels between tall buildings, where the field intensity of the base-station transmitter is normally weak anyway, communications might well be lost completely; or when the mobile is on a highway that dips behind a hill between the base and mobile, the transmitted signal will be practically nonexistent at the mobile antenna. For this reason, the base-station antenna is generally erected anywhere from 60 to 200 feet above the earth. Some antennas are even located on the roofs of tall buildings; the Empire State Building in New York City has several. As you can well imagine, the higher the antenna, the better the communications. Therefore, when designing a two-way radio system, pay particular attention to the types of antennas and their locations. After all, a communications system is only as good as its antenna.



Courtesy Antenna Specialists Co.

Fig. 5-5. Vertical radiation pattern.

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abc's of
MOBILE RADIO

by Richard Martin

Richard Martin attended Purdue University, where he studied advanced physics and electronics. Having successfully completed several courses in radio, television, and radiocommunications, he spent several years in the two-way radio maintenance industry gaining practical experience. He has written a number of magazine articles on two-way radio.

Two-way mobile radio is finding so many uses in our modern way of life that it has become almost as important as the telephone. In fact, at the end of 1961, the number of licensed mobile units in operation was fast approaching the three million mark. The reason for such rapid growth is easy to understand when you realize that commercial enterprises such as taxicabs, construction firms, and many other service businesses are using this means of communications to great advantage.

ABC's of Mobile Radio provides a complete introduction to the subject for owners and operators, as well as technicians who are now servicing, or plan to service, two-way radio equipment. Beginning with a basic explanation of two-way radiocommunications systems and their applications, and followed by easy-to-understand descriptions of transmitter and receiver operation, this book contains information of value to anyone desiring knowledge of two-way mobile-radio systems and equipment.

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