MOBILE A.M. AND F.M. COMMUNICATIONS

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For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

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MOBILE A.M. AND F.M. COMMUNICATIONS

General Considerations in Mobile Communications

MOBILE communications are becoming of increasing commercial importance. This name includes all the systems that permit two-way radio communication between cars, trucks, buses, ships, trains, airplanes, and even persons carrying mobile radio equipment, and between any of these and fixed stations. Both a.m. and f.m., in a variety of bands, are used for such communications.

We will study various types of mobile services in this Lesson. Because they have long been established on a commercial basis, we will first study marine harbor radiotelephone systems, which use amplitude modulation in the medium and high-frequency bands. Most of the rest of this Lesson, however, will deal with the more recently used v.h.f. bands.

The v.h.f. bands assigned for mobile operations are 39-44 mc., 72-76 mc., and 152-162 mc. We will particularly emphasize equipment and services for the 152-162 mc. band in this Lesson because of the extensive use of this band in many types of mobile services. The equipment widely used by police communications and other mobile services in the 30-44 mc. band will be taken up in another Lesson.

MECHANICAL LIMITATIONS

Communications equipment for mobile services has many limitations, of mechanical and electrical nature.

Space. Since space for the installation of communications equipment is limited in most vehicles, the equipment must be as small as possible. In automobiles, for example, the transmitter and receiver are generally located in the trunk compartment, where a considerable portion of the space is needed for the spare tire, tools, and storage. Fortunately, modern techniques make it possible to manufacture satisfactory equipment that is economical of space.

Weight. Weight is not usually much of a problem in mobile communications equipment, because, although it must be kept light, this requirement is generally taken care of by the fact that the equipment is designed to be small.

Shock and Vibration. Mobile communications equipment must also be rugged enough to stand the shock and vibration it meets in moving vehicles. Modern shock- and vibration-absorbing equipment and techniques are such that well-designed mobile equipment provides reliable operation with only a normal amount of preventive maintenance.

ELECTRICAL LIMITATIONS

One important restriction on the electrical design of mobile equipment is the limited capacity of the primary power source. In most cars, trucks, buses, and planes, this source is a 6- or 12-volt storage battery and charging system that was not designed for the additional drain that is necessary to operate a communications system. Although storage batteries with large ampere-hour capacities and high-rate generators are frequently used, it is nevertheless essential that the d.c. power for communications is kept to a minimum.

This is done primarily by limiting the power output. Most mobile transmitters, for example, operate with only 10-30 watts output. Fortunately, this amount of power is adequate at v.h. frequencies because the coverage is generally limited by the line-of-sight radiation properties rather than the power of the transmitter.

Power saving is also obtained by more efficient operation. A mobile transmitter, for example, is often designed so that the d.c. plate supply and the filament power for the tubes are turned off when the transmitter is in the "stand-by" condition, thus eliminating power drain. Quick-heating tubes and a quick-starting high-voltage supply (often a dynamotor) are used in such a case, thereby permitting the transmitter to be in full operation a fraction of a second after its operating switch is closed.

The primary power taken by the receiver in mobile equipment is comparatively small, about 6 amperes from a 6-volt source, even for highly sensitive multi-tube receivers. One manufacturer makes a marine receiver that uses dry cells, thus permitting continuous monitoring for calls without any drain on the 6-volt storage battery primary power source. Only when actually transmitting does this equipment take power from the storage battery.

Why F.M. Is Preferred. Another important consideration in mobile equipment is that the system used must be as noise- and interference-free as possible, because it must be capable of reliable operation over a wide range of receiving and transmitting conditions. For example, mobile equipment may sometimes be operated where the electrical noise level is high. Furthermore, the signal strength received may vary considerably as the mobile equipment moves from one location to another. To minimize undesirable effects caused by these conditions, frequency modulation is preferred for use in the mobile bands and is widely used in the 152-162 mc. band. The frequency deviation used is ±15 kc. (15 kc. corresponding to 100% modulation) with the audio response limited to the voice frequencies, that is, about 300-3000 cycles. Since highly sensitive receivers (generally with double amplitude-limiter stages) are used, the noise level of the received signal is quite low, and reliable communication can be maintained despite wide variations in the strength of the received signal.

▶ Although the modulation system used in these services is called frequency modulation, actually it is misnamed. The carrier is phase-modulated in every one of the systems now in use, and, since no pre-distorter is used, the output of the transmitter cannot be anything but a p.m. signal. The use of the wrong name probably arose from an early misconception of the kind of signal produced; the error has now been perpetuated by common use in manufacturers' literature and elsewhere, and it is unlikely that it will ever be corrected. We will follow the general custom in this Lesson and call these systems frequency-modulated; remember, however, that they are actually phase-modulated.

Antenna Systems. As a general rule, vertical polarization is used in mobile services. The reason is that the antennas used must be non-directional, and vertical antennas are the only non-directional type that can be conveniently used on most mobile vehicles. Practically all v.h.f. communications systems use some form of vertical quarter-wave radiator.

Another fact to remember as we start our study of mobile systems is that although they are referred to as "two-way," they are actually only "one-way" at a time—that is, it is not possible to transmit and receive at the same time. The operator in the mobile unit must take some action to switch from receiving to transmitting. Usually this action takes the form of pushing and holding in a microphone switch that is generally labeled PUSH-TO-TALK.

Marine Harbor Radio

Marine harbor radio had its origin in the need for communication between the shore and small harbor and coastal craft, such as tugboats, private yachts, coastal passenger ships, merchant craft, and fishing vessels. Experimental service which began in 1931 has proved the practicability of an amplitude-modulated radiotelephone system for this service. Since that time, commercial radiotelephone service has been provided along both coasts, the Gulf area, the Great Lakes, and the Ohio and Mississippi Rivers.

One factor that has helped to produce wide acceptance of the service is that only a restricted radiotelephone operator's license is needed to operate the ship-borne equipment. Since any U. S. citizen can obtain this license either by an examination on radio laws or by certifying that he needs one to obtain a job, it is not necessary for the ship owner to hire a trained operator to operate a radiotelephone. (However, an operator with at least a second-class phone license must be responsible for the repair and adjustment of the equipment. Also, anyone obtaining a restricted license by certification must pass an examination on radio laws if he later tries for a higher class license.)

Marine radiotelephone service has proved to be extremely useful in emergencies as well as for the uses for which it was intended. Many of the Coast Guard's calls for help come in over the radiotelephone from vessels with sick or injured aboard, or in mechanical difficulties, or otherwise in need of assistance.

EQUIPMENT REQUIREMENTS

The marine radiotelephone system consists of a radio receiving-transmitting system linked to land telephone lines. This arrangement permits calls to be made over long distances—in fact, to or from any place having telephone service—without need for high-power radio equipment. Also, it allows the whole coastal area to be serviced by a relatively few transmitters.

Since dependability is a very important requirement for marine radiotelephone service, the carrier frequency and power used for the radio link must provide field strengths of suitable magnitude, free from fading. However, excessive power causes increased interference, and economy both in original cost and upkeep demands smaller transmitters. A satisfactory compromise can be secured by using carrier powers of 50 watts or less in the 2100-kc. band for the ship-borne transmitters and 400 watts in the 2500-kc. band for the shore transmitter if the transmission path is almost entirely over water. Transmission in either direction is by ground wave, thereby minimizing fading.

SHORE STATION EQUIPMENT

The following brief description will show you how the radiotelephone link between vessels and the shore is interconnected with the land telephone network to provide commercial telephone service. We will base our description on the system used in the Boston Harbor area, since it has been in extensive operation for several years and has many advanced circuit features.

The shore station is located at Green Harbor in the town of Marshfield, Mass., on Massachusetts Bay, about 28 miles southeast of Boston. The station equipment consists of an amplitude-modulated radio transmitter with its antenna and power supply, a radio receiver with its antenna and power supply, and audio-frequency terminal equipment for maintaining proper speech volume, for monitoring the two-way conversations, for selective signaling of the boat stations, and for preventing echoes and "singing." All this equipment is of Western Electric design and manufacture.

The radio transmitter delivers 400 watts of carrier power, and operates on a frequency of 2506 kilocycles. The transmitter design is identical with that used at aviation ground stations. (We will study aviation systems later.) The carrier frequency is precisely maintained by a conventional crystal-controlled oscillator. Power is obtained from rectifiers operating from the a.c. supply lines.

The transmitting antenna consists of a single vertical wire 120 feet high suspended from cables extending from two 165-foot steel towers 500 feet apart. The transmitter is coupled to the antenna by a 500-ohm transmission line and a tuning unit that adjusts the antenna to resonance.

The radio receiver is a superheterodyne like those used at aviation ground stations. The receiver is coupled through a concentric transmission line and a tuning unit to a single vertical-wire receiving antenna that is 45 feet high and located 500 feet from the transmitting antenna.

To link the radio equipment to the land wire telephone network, apparatus similar to that provided at the terminals of the transatlantic radiotelephone circuit is used. This apparatus includes controls for adjusting the volume of speech into the transmitter, controls for adjusting the receiver output to the wire lines, and the usual "voice-operated device, anti-singing" (termed "vodas") used for the suppression of "singing" and echoes, feedback problems that are peculiar to telephonic communication. Power for the terminal apparatus is supplied by a motor-generator set operating from the a.c. mains.

The transmitter has associated with it a selective signaling arrangement (to be described shortly) that allows the central office to call any other station. The receiving equipment includes a "codan" (carrier-operated device, anti-noise) that insures relative quiet on the receiving line when the boat transmitter carrier is off the air.

The terminal apparatus, together with a volume indicator and equipment for talking, monitoring, signaling, and testing, is mounted in an apparatus bay at the front of the room. Adjacent to it is the receiving bay, which contains the receiver and noise-suppression device.

A licensed operator is constantly on duty at the apparatus bay, adjusting the controls during the progress of each call in accordance with the indications of the meters to insure the best possible connection under the conditions prevailing at the time.

SHIP STATION EQUIPMENT

Combination transmitters and receivers for operation on ships are made by several manufacturers. The equipment varies considerably in the power output and the number of channels available. For example, the Radiomarine ET-8028 has 10 watts output and operates on 4 channels, the ET-8027 has 25 watts and 6 channels, and the ET-8012-D has 75 watts and 10 channels.

The smaller units are generally entirely self-contained; that is, the transmitter, receiver, and secondary power source are all in one cabinet. The handset hangs on a hook on the side of the cabinet. In larger units, the handset may be at a remote control point, and the power supply may also be separate.

The receivers used are superheterodynes with crystal-controlled local oscillators. Each of the several receiver channels has a separate crystal. One channel is generally set to the channel assigned for marine 'phone operation in the area in which the boat is operating. A second channel is set to the frequency reserved for direct boat-to-boat communication. A third channel, used for emergency operation, permits direct communication with the Coast Guard. The fourth and other channels are set to frequencies permitting contact with other marine shore stations.

The channel selector switch also changes the crystal controlling the frequency of the transmitter. Thus, when the set is switched to operate on the channel assigned to Norfolk, Va., for example, the transmitter crystal frequency is 2142 kc., and the receiver crystal frequency is 2538 kc. plus or minus the i.f. of the receiver (depending on whether the local oscillator is intended to be higher or lower than the incoming signal in frequency). The equipment can be switched over by turning a single control to operate on the channel assigned to, say, Charleston, S. C., in which case the transmitter crystal frequency will be 2174 kc., and the receiver crystal frequency will be 2566 kc. plus or minus the i.f.

The output of the receiver is generally fed to a loudspeaker. This permits aural monitoring of the channel when selective calling equipment is not included in the receiver. When the handset is removed from its hook in either answering or initiating a call, the loudspeaker is muted.

The selective signaling unit, when one is used, is connected to the output of the vessel's radio receiver. When the particular code of pulses assigned to a ship's selector system is picked up, the selector closes a switch that turns on an electric calling bell. This selector system and calling bell make it unnecessary to maintain a continual watch at the radio receiver. Ordinarily, the shore station's call will ring the bell on only one ship; all ship selectors can also be set to operate on a master code of pulses as well, to permit the simultaneous calling by the shore station of all vessels in any one fleet.

The power supplies of these marine

installations are generally designed to operate from a 6-v. or 12-v. d.c. source. Vibrators or dynamotors are used to convert this low-voltage d.c. to the higher-voltage d.c. needed to operate the transmitter.

HOW THE SYSTEM OPERATES

To illustrate the operation of the Boston Harbor radiotelephone service, let us follow the routine of a call from an ordinary land telephone to a vessel and vice versa in the vicinity of Boston Harbor.

The marine traffic is routed through Boston, being handled at two positions on the Boston outgoing toll board that are especially modified for this purpose. The wire lines from Green Harbor station terminate at this point. The signals from vessels can be switched by the Boston marine operator to any other point in the world that is connected to this country's telephone system by wire lines or radio.

The normal wire lines running between Boston and Green Harbor are three loaded cable pairs. One pair is used for conducting speech signals from the land telephone system to the transmitter speech-amplifying and modulating equipment. The second pair carries speech signals that are received from a boat, and the third pair is used for communication between the marine operator at the toll board and the technical operator at the Green Harbor station.

Let us assume that a person in the vicinity of Boston wishes to talk with the captain of a fishing trawler. The call is placed in the usual manner and is routed to the Boston toll operator, then to the marine operator at Green Harbor, who dials the call signal assigned to the vessel being called. The pulses produced over the radio link actuate the signaling unit on this vessel, ringing its bell. The captain raises the handset from the switch hook on the control unit, presses the pushbutton in the handle of the handset, and announces the name of the vessel. The marine operator then completes the connection.

Let us now consider the routing of a call from a vessel near Boston to some telephone on the shore. The person making the call raises the handset from the switch hook and, pressing the pushbutton, calls, "Boston Marine operator." The latter, who is normally monitoring the channel asks for the name of the vessel and the number called. When he receives this information, the call is routed to the Boston toll operator, who completes the connection.

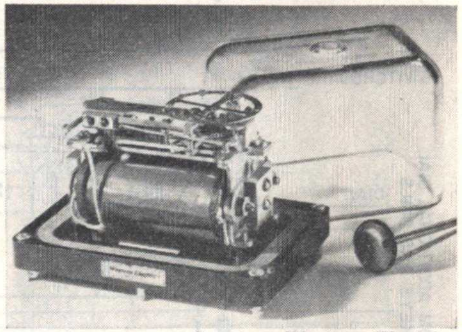
A third possibility is a call between one boat and another. Like the one just described, this call is started by the person on one vessel making contact with the Green Harbor operator. This operator then dials the other boat called. When an answer is obtained, either of two procedures can be followed. The usual one is for the technical operator at Green Harbor to operate a by-pass key that connects his radio receiver output with the radio transmitter input without including the "vodas" and other equipment associated with land circuits. The land line is bridged onto the circuit, however, so that the marine operator can be advised of any difficulties that may arise in carrying on the conversation. Alternatively, the marine operator may request both vessels to change to their second frequency and to carry on their conversation independently of the Green Harbor station. The latter form of conversation is, however, usually carried out between two vessels by prearranged calls on a schedule, the original call then being independent of the Green Harbor station. This also avoids the land line charges.

DIALING A SHIP AT SEA

Selective dialing of a ship at sea is accomplished through the use of a 107A-type selector in combination with a novel circuit arrangement for operating it. The 107A selector, shown in Fig. 1, consists of a polarized magnet, the armature of which advances a ratchet-wheel one step for each impulse received, provided that the consecutive pulses are of opposite polarity and occur at a definite rate. Mounted on the ratchet-wheel is another wheel that has holes drilled around its rim. Pins may be dropped into these holes, and a stop arm is provided that holds the ratchet-wheel at the position to which it has been turned if a pin is in the hole opposite the arm at the time the series of pulses ceases. If there is no pin at this point, the ratchet-wheel is returned to its initial position by a spring. After the wheel has rotated a definite amount (which is adjustable), it makes an electrical contact (which can be used to ring a bell).

Commonly, in ship-signaling applications, this contact is made after a rotation equivalent to 23 holes on the rim of the wheel. Since a five-digit dialing system is used, the sum of the five pulse groups must total 23 if the contact is to be made. Also, the pins must be in such positions that the ratchet-wheel will be held at the position reached after each of the five sets of pulses. Thus, a ship whose code number is, say, 7-8-2-3-3, must have pins in holes 7, 15, 17, 20, and 23. When this sequence of pulses reaches the selector on this ship, the ratchet-wheel will be held after each group, and the contact will be made at the end of the final group.

The selector on each other ship within range of the transmitter is also actuated by these pulses, but none of them has exactly this arrangement of pins. Consequently, somewhere in the dialing sequence, the ratchet-wheel of each will not be held by the stop arm at the end of a series of pulses; it will then return to its original position, and will therefore not be able to reach the position at which contact is made before the pulse groups end.



Courtesy Western Electric

FIG. 1. This Western Electric selector mechanism is the "heart" of the 107A selective signalling device used in marine telephone installations. This selector and its associated filter and relays provides full selective signalling with 2030 combinations available.

The required pulses of opposite polarity are obtained by transmitting alternate pulses of 600 and 1500 cycles. The signaling equipment required at the shore station and its connection to the terminal apparatus are shown in Fig. 2. It consists of an audio oscillator, controlled by a key and dial, that is used to produce both the 600- and 1500-cycle signals. The dial is an ordinary telephone dial whose contacts operate 8 to 11 times per second when the dial is returning to its home position. This gives pulses with durations of .09 to .125 second when a current is fed through the dial contacts. Both sets of contacts of the dial key are normally open; they close, however, whenever the dial is in motion.

When the dial, after having been moved to some position, is released and allowed to move back to its home position, the pulsing contacts XX alternately open and close. Normally, the contacts of relay OC ground the feedback circuit of the oscillator, so that neither frequency of oscillation is produced. When the dial is in motion, the dial key closes and completes the circuit through the field coil of relay OC; the relay then operates, breaking the connection between the oscillator and ground and thus permitting the oscillator to operate. Closure of the dial key also connects the field coil of relay FC to the dial contacts XX; this relay is then energized and de-energized when contacts XX close and open.

Condensers HF and LF determine the frequency of operation of the oscillator. When relay FC is energized, its contacts short condenser HF; the oscillator then produces a 600-cycle tone. When relay FC is de-energized (contacts XX open), condenser HF is in series with condenser LF; the oscillator then produces a 1500-cycle tone. The output level of the oscillator is controlled by the network EQ, which equalizes the outputs on the two signaling frequencies.

The selective response equipment used on board ship is shown in Fig. 3. It consists of the selector mechanism already described, plus equipment used to actuate the selector properly. It is connected to the radio receiver output through the contacts of a transfer relay that is controlled by the switch hook of the telephone handset. With the hook down, the contact of the transfer relay is connected to the radio receiver output. The output current passes through two filters in series, one tuned to 600 cycles and the other to 1500 cycles. The output voltages across each filter are connected to rectifiers that feed into two separate oppositely poled windings on the pulsing relay. A third winding on the pulsing relay is connected to a battery through the contacts of the pulsing relay; the direction of flow of the battery current through this winding, and therefore the polarization of the relay, depends upon whether or not the relay is energized.

The call selector on the ship will respond only to signal pulses with durations at least as long as .09 second (the minimum duration of a pulse from the shore transmitter). This prevents accidental operation of the

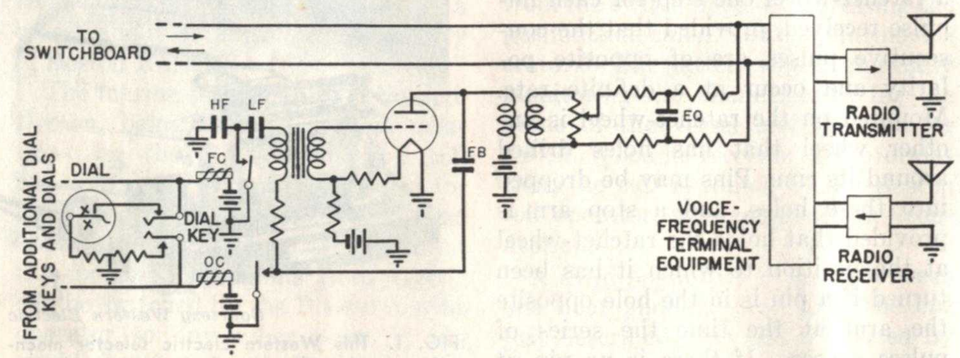


FIG. 2. Circuit diagram of dial, oscillator stage, and other apparatus used at the marine harbor shore station for selective signaling of ship stations.

equipment by static or voice signals, since the 600- and 1500-cycle components of these signals are of extremely short duration.

When a 600-cycle signaling pulse of sufficient length appears in the receiver output, current passes through the corresponding winding of the pulsing relay; the relay then operates so that its movable contact closes with contact a, thereby connecting the polarizing winding to its battery with a polarity such that the current flow through the winding is in a direction that tends to hold the relay in this position. When a 1500-cycle signal is received, current passes through the corresponding winding, and the relay operates so that the movable contact closes with contact b. This reverses the direction of current flow through the polarizing winding, with the result that the relay is held in its new position.

Thus, alternate pulses of 600- and 1500-cycle signals operate the relay in opposite directions, thereby alternately charging and discharging a condenser that is in series with the selector winding (see Fig. 3). The resultant reversals of current flowing through the selector winding move the selector switch mechanism once for each reversal received. After each series of reversals corresponding to a digit dialed at the sending station, the charging current drops to zero, and the selector returns to its home position unless it is prevented from doing so by its stop arm.

If the proper five digits are dialed at the sending station, the selector makes contact, ringing the bell at the receiving station. The call is answered by removing the handset from the switch hook. This operates the transfer relay, removing the selective response equipment from the receiver output and connecting the telephone receiver in its place. At the same time, direct current is sent through the selector winding, opening the contacts and stopping the ringing of the bell.

The 107A type selector will respond to 2030 different call signals.

► Incidentally, in this selective calling system no assigned number includes the digit 1, for this number is used by the telephone operator to clear all selector switches before dialing a mobile station.

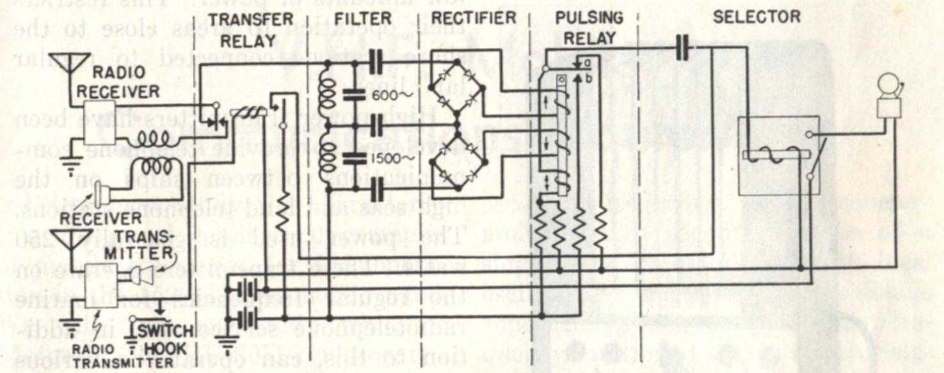


FIG. 3. Circuit diagram of selective response equipment used on board radiotelephone-equipped ship to ring bell when that station is called by the shore station.

COMBINATION MARINE RADIO INSTALLATION

In equipment for small boats, several radio services are often combined in one unit. An example of this is the Harvey-Wells Series 1200 combination unit shown in Fig. 4. The selector switch in the center of the panel of this set has positions for four crystal-controlled channels for marine radiotelephone operation, a fifth position for broadcast reception,

Courtesy Harvey-Wells, Inc.

FIG. 4. This is an example of a low-power radiotelephone transmitter-receiver for use on small boats. This Harvey-Wells unit has 4 channels in addition to standard broadcast reception.

and a sixth that permits the equipment to be used as a public address system for deck calling.

Two channels are preset by the manufacturer, one to 2670 kc. for communicating with the Coast Guard, and another to 2738 kc. for ship-to-ship operation. The other two-way channels can be set to the frequencies of any desired shore stations.

The other controls are used to adjust the squelch sensitivity, to switch the audio output from the speaker to the handset, to adjust volume, and to tune the broadcast receiver.

The transmitter uses a 6L6G in the r.f. output stage and has an output of 12 watts.

HIGH SEAS PHONE SERVICE

The marine radiotelephone installations we have just studied operate in the 2-3 mc. band with comparatively low amounts of power. This restricts their operation to areas close to the shore stations connected to regular land lines.

High-power transmitters have been developed to provide telephone communications between ships on the high seas and land telephone stations. The power used is generally 250 watts. These transmitters operate on the regular frequencies for marine radiotelephone service and, in addition to this, can operate on various specially assigned higher frequencies up to 23 mc. This flexibility in frequency of operation will generally permit at least one channel to be available for reliable communications despite the normal variations in skip distance encountered in this range of frequencies. Special marine stations have been established to provide two-way telephone service on these higher frequency channels.

Fixed-frequency receivers on the ships are used for monitoring the frequencies used for this service. Automatic selective signaling can be included as a part of the installation if desired.

AIRCRAFT TELEPHONES

The two-way telephone service available to boats has been extended to both commercial and private aircraft on exactly the same basis. An air-borne radiotelephone set can, because of the height of an aircraft during flight, operate over greater distances than can comparable equipment in a boat. Nevertheless, the range is limited; the useful area at present is near the sea coast, the Great Lakes, and the stations on the Mississippi and Ohio Rivers. Greater use of this service will permit more inland stations to be established for a complete coverage of the United States.

This air-borne telephone equipment is separate from the usual communications and navigation equipment carried by aircraft and its service supplements them.

V.H.F. Mobile Communications Equipment

Let us now study the characteristics of several commercial examples of mobile equipment for f.m. operation in the 152-162 mc. mobile band. We will start our study with the Motorola FMTRU-30D equipment.

MOTOROLA EQUIPMENT

The FMTRU-30D consists of two units, a 30-watt f.m. transmitter with a dynamotor power supply and a 16-tube receiver with a synchronous vibrator power supply.

Mobile Receiver. The receiver chassis is shown in Fig. 5; its block diagram is given in Fig. 6. The set is a crystal-controlled, double superheterodyne that receives on a single frequency. It uses a first i.f. of 7.2 to 8.0 mc. and a second i.f. of 1.7 mc. The high first i.f., plus the fact that two r.f. amplifier stages are used, gives the set considerable ability to reject images. The second i.f. stage provides most of the selectivity.

Frequency quadrupling in the oscillator and in a separate multiplier stage produces a local oscillator frequency that is 16 times the crystal oscillator frequency. This frequency multiplication permits the use of a single crystal to produce both local oscillator signals needed for a double superheterodyne receiver. The frequency-multiplied local oscillator signal will, when mixed with the incoming signal, produce an i.f. of from 7.2 to 8.0 mc., depending on the frequency of the input signal. As an example, if, as shown in the block diagram, the input is 153 mc., the crystal

Courtesy Motorola, Inc.

FIG. 5. A view of the chassis of the Motorola PA-8333 mobile f.m. receiver. It operates on 6 volts d.c. in the 152-162 mc. band.

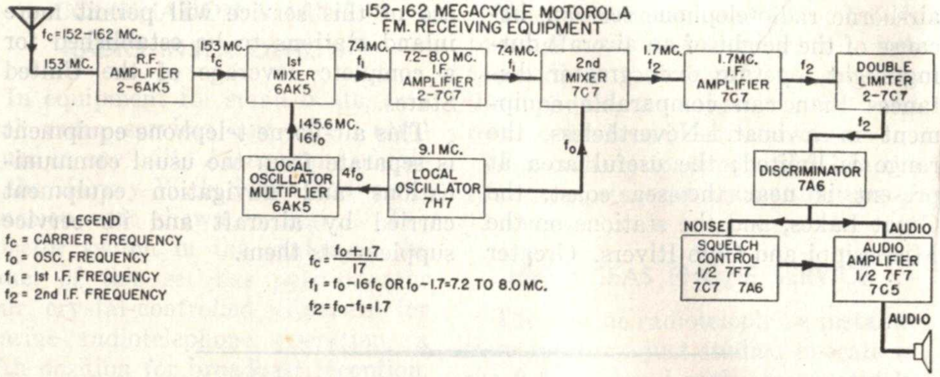


FIG. 6. This is the block diagram of the Motorola PA-8333 mobile f.m. receiver.

frequency is 9.1 mc., the local oscillator output is 145.6 mc., and the first i.f. is 7.4 mc. This 7.4 mc. signal, when it is mixed with the unmultiplied crystal-oscillator output produces the 1.7 mc. second i.f.

The second i.f. is applied to two amplitude limiter stages, then to a frequency discriminator. The output audio signal of the discriminator is applied to a two-stage audio amplifier.

Noise is normally present in the output of a sensitive f.m. receiver, such as this, when no carrier signal is being received. In this set, this noise is used to "squelch" the audio section when no signal is being received. The high-frequency noise components are amplified and rectified to produce a dc. voltage that biases the audio amplifier beyond cutoff. As you have already learned from your previous study of f.m. systems, the noise is effectively suppressed when a carrier is present; the squelch does not then operate and the audio amplifier amplifies in the normal manner. The squelch can be adjusted to operate on signals from 0.1 microvolt to 1.5 microvolt. It will not operate on random noise. The audio output is normally fed to a loudspeaker, but headsets can be used.

R.F. Section. The r.f. section of this Motorola receiver is shown in detail in Fig. 7. It differs from a conventional circuit in that high-Q resonant lines are used for the tuned circuits to improve gain and selectivity. The coupling from one stage to the next in this section of the receiver is through the inherent capacitive coupling in the wiring of the circuit.

The input r.f. signal is coupled through C_1 to a tap on resonant line L_1 that matches it to the antenna impedance. Line L_1 is tuned by C_2 to the desired frequency. Although electrically a quarter wavelength, it is physically much shorter than the 18 inches that corresponds to a quar-

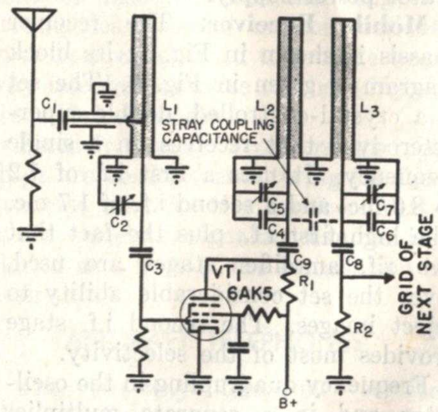
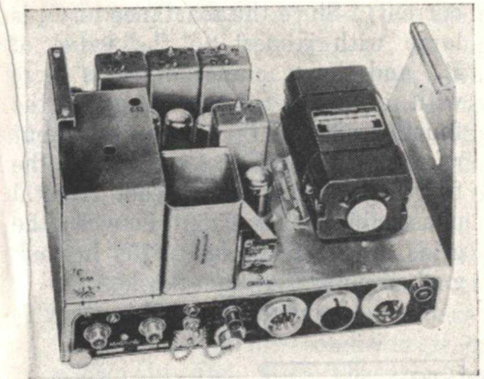
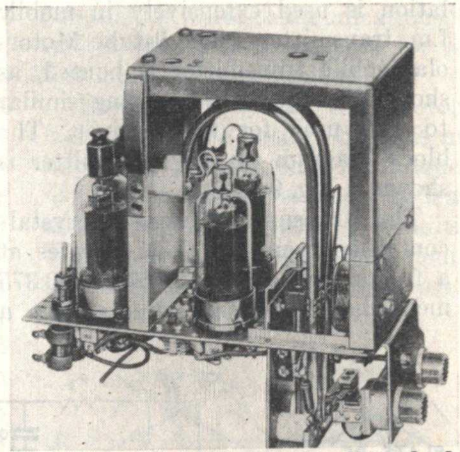


FIG. 7. Resonant lines (L_1, L_2, L_3) are used for tuned circuits in the r.f. sections of the PA-8333 Motorola 152-162 mc. receiver.



Courtesy Motorola, Inc.

FIG. 8. The Motorola mobile f.m. transmitter. This unit is a part of the Motorola FMTRU-30D equipment.



Courtesy Motorola, Inc.

A view of the r.f. output stage used in Motorola 152-162 mc. transmitter. Instant-heating tubes are used, the driver stage is on the back of this sub-chassis. Note that resonant lines are used in the final tank circuit.

ter wave at this frequency. The reason for this is that C_2 and the stray capacitance in the circuit effectively lengthen the line.

The output of the first r.f. stage is shunt-fed by R_1 and C_9 to line L_2, which is tuned by C_4 and C_5. The stray capacitance in the wiring couples L_2 to L_3, which, in turn, is tuned by C_6 and C_7, and coupled to the grid of the next stage by C_8 and R_2.

Two more pairs of lines are used to couple the second r.f. stage to the mixer and the frequency multiplier stage to the mixer.

The current drain of this 16-tube receiver is only 6 amperes, including the 0.5-ampere intermittent drain of the crystal heater oven.

To make it easier to adjust and repair this receiver, provision is made to plug in an external meter; a meter switch on the front panel then permits measurements in several circuits of the receiver. Two large plugs are used to connect the power and control circuits to the receiver.

Transmitter. As you have already learned, f.m. signals can be produced either by reactance-tube modulation of an LC oscillator or by phase modulation of a crystal-controlled oscillator. Since the frequency stability required for this service is quite high, reactance-tube modulation would necessitate crystal-reference center frequency stabilization. This stabilization system would be more complex than the additional frequency multiplier stages required in phase modulation. For this reason, phase modu-

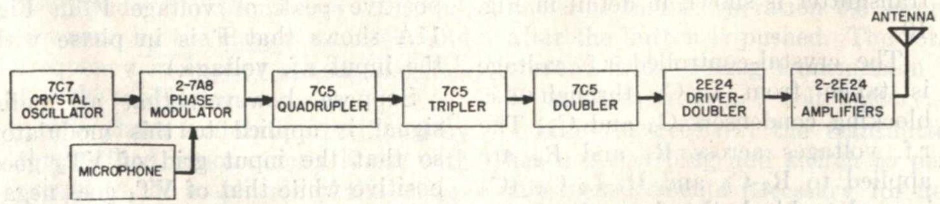


FIG. 9. The block diagram of the Motorola FMTRU-30D mobile transmitter. Phase modulation of a crystal-controlled oscillator is used to produce a ±15-kc. deviation in the 152-162 mc.

lation is used extensively in mobile f.m. transmitters. The 9-tube Motorola mobile transmitter is housed, as shown in Fig. 8, in a casing similar to that used for the receiver. The block diagram of this transmitter is shown in Fig. 9.

The transmitter uses a crystal-controlled oscillator that operates at a frequency between 3.167 and 3.375 mc., and is phase-modulated by a pair of balanced modulators to produce a deviation of ±400 cycles. This signal is then multiplied by 48 in the quadrupler, tripler, doubler, and driver-doubler stages to produce an output frequency in the 152-162 mc. band with a deviation greater than ±15 kc. Two 2E24's are used in the output to obtain 30 watts of r.f. power.

Phase Modulator. The circuit for obtaining phase modulation in this transmitter is shown in detail in Fig. 10.

The crystal-controlled r.f. voltage is taken from L_1-C_1 through d.c. blocking condensers C_3 and C_4. The r.f. voltages across R_1 and R_2 are applied to R_3-C_5 and R_4-L_2-C_6 (C_6 is used to block the d.c. voltage developed across R_5-C_7 by the grid current). Since the reactance of C_5 is large with respect to the value of R_3, and the reactance of L_2 is large with respect to R_4, the voltage on the fourth grid of VT_1 will lag the input r.f. from L_1 and the voltage on the fourth grid of VT_2 will lead. A total phase difference of 150° between the grids is easily obtained (75° in each grid circuit).

Since the plates of VT_1 and VT_2 are connected in parallel, the resultant r.f. plate voltage, shown by curve F in Fig. 11A, is the sum of the r.f. plate voltages D of VT_1 and E of VT_2. When there is no audio modulation, voltages D and E are equal, and voltage F is in phase with the input r.f. voltage. (The broken line labeled "input r.f. voltage reference line" in this figure represents a positive peak of the input r.f. voltage. The fact that it goes through the positive peak of voltage F in Fig. 11A shows that F is in phase with the input r.f. voltage.)

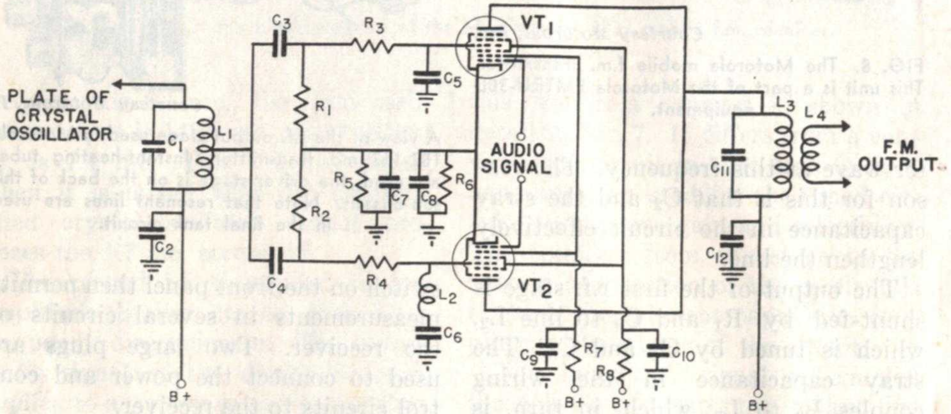


FIG. 10. The basic phase-modulation method used in Motorola f.m. transmitters.

Suppose, however, that an audio signal is applied to this modulator so that the input grid of VT_2 goes positive while that of VT_1 goes negative. This means that, as shown in Fig. 11B, voltage E increases and voltage D decreases, and that the resultant F lags the input r.f. by angle θ. On extreme modulation peaks where D becomes zero, the output will lag by 75°—that is, the output will be voltage E. In a similar manner, on the next half cycle of the audio input, E will decrease and D will increase, causing the resultant F to lead the input r.f. by an angle that depends on the relative amplitudes of D and E. (This condition is not shown in Fig. 11.) The maximum phase lead is 75° when E is zero, since voltage D is then the output voltage.

You can see, therefore, that a maximum phase deviation of 75° on each side of the carrier can be obtained by applying an audio voltage to the grids of modulator tubes VT_1 and VT_2. This ±75° deviation will produce a 400-cycle deviation in the output circuit L_3-C_{11} for a minimum audio signal of 300 cycles. This output is coupled by L_4 to succeeding multiplier stages; there it is multiplied by 48, giving a final output with a frequency deviation of almost 20 kc.

Condenser C_2 in Fig. 10 is an r.f. by-pass; C_8, C_9, C_{10}, and C_{12} are audio and r.f. by-passes. Cathode bias is developed across R_6; R_7 and R_8 are voltage-dropping resistors for the screen grids.

As you can see by comparing the amplitudes of F in Fig. 11A and 11B, this system of phase modulation also amplitude-modulates the r.f. signal. Amplitude variations are removed, however, by the class C amplifier and frequency multiplier stages that follow the modulator.

The phase modulation produced by this method is not exactly linear with regard to the amplitude of the modulating signal. This produces a distortion in the output signal that is tolerable in voice communications, but makes the circuit unusable for high fidelity f.m. transmission.

Power Supply. In this Motorola transmitter, the battery drain is minimized by keeping only the filaments of the first 6 tubes on when the transmitter is in its stand-by condition. The filaments of the driver-doubler and final r.f. amplifier tubes are of the "instant heating" type. These filaments are turned on by lifting the microphone or handset from the hang-up box and are turned off by replacing it. The B+ voltage for all stages is supplied by a dynamotor that operates only when the transmitter is turned on by pressing the PUSH-TO-TALK button. This dynamotor action is very quick; the transmitter is in full operation 0.3 second after the button is pushed. The total current drain during transmission is 39 amperes from a 6-volt battery.

Like the receiver, the transmitter has a meter plug and switch to permit measurements necessary for adjusting and repairing it. There is also a plug on the panel for plugging in a

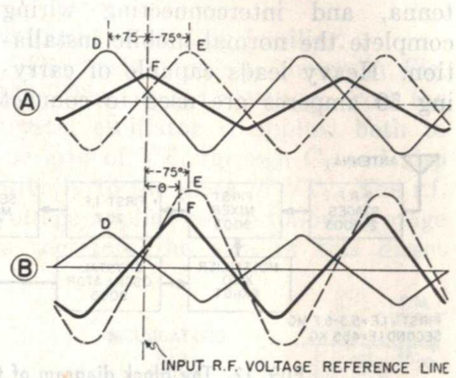


FIG. 11. The sum F of two sine waves D and E that are 150° out of phase will, as shown in part A, be midway in phase between the two signals. If D and E are amplitude-modulated so one increases as the other decreases, as shown in part B, the resultant will change in phase.

microphone; this makes it possible to check performance at the transmitter rather than at the control point, which is generally some distance from the transmitter.

Accessories. A control box (with on-off, volume, and squelch controls), a hang-up box, a loudspeaker and a microphone (or a handset, in which both are combined) with push-to-talk button, a quarter-wave (18") antenna, and interconnecting wiring complete the normal mobile installation. Heavy leads capable of carrying 50 amperes are used to connect the 6-volt storage battery to these combined units.

KAAR F.M. TRANSMITTER

Block diagrams of the Kaar mobile 152-162 mc. transmitter and receiver are shown in Figs. 12 and 13. As you can see from these, the Kaar units bear a strong resemblance to the Motorola equipment you just studied. The audio and f.m. modulator section of the Kaar FM-50X and FM-100X transmitter are worth studying because they have features especially useful in mobile services. The schematic diagram of these sections is given in Fig. 14.

F.M. Modulator. The modulator section of this transmitter using VT_1 and VT_2 is similar in operation to the modulator shown in Fig. 10. It differs from the Motorola circuit in that beam power tubes and plate modulation are used.

The r.f. from the crystal oscillator is tuned by L_1 and C_1. Because B+ is applied to the center tap on L_1, the r.f. voltages at its ends are 180° out of phase. One of these voltages is applied through d.c. blocking condenser C_3 to the grid of VT_1. The other is applied to the grid of VT_2 through the network C_2, R_1, C_4. C_4 is a small condenser whose reactance is about 1/5 the resistance of R_1. This fact causes a voltage lag in C_4 that makes the voltage applied to the grid of VT_2 less than 180° out of phase with that applied to the grid of VT_1. The actual phase difference between the two is about 165°.

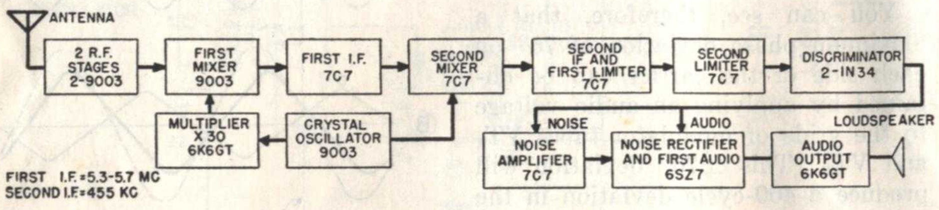


FIG. 12. The block diagram of the KAAR 152-162 mc. f.m. receiver.

The r.f. outputs of both VT_1 and VT_2 are coupled to the tank circuit L_2-C_{10}, that of VT_1 directly, and that of VT_2 capacitively through C_7. Thus, the two r.f. voltages add in this tank circuit.

The plate voltages for VT_1 and VT_2 are taken from the two halves of T_2. Therefore, an audio signal across T_2 from VT_3 will cause the amplitude of the r.f. signal outputs of VT_1 and VT_2 to vary in accordance with the modulating signal. This action, as you have already learned from Fig. 11, will cause the phase of the resultant r.f. voltage to vary.

Audio System. A single - button carbon microphone is used in this receiver. The voltage drop across R_{10}, filtered by C_{14}, is used to operate the microphone. Notice that the entire output of motor-generator G flows

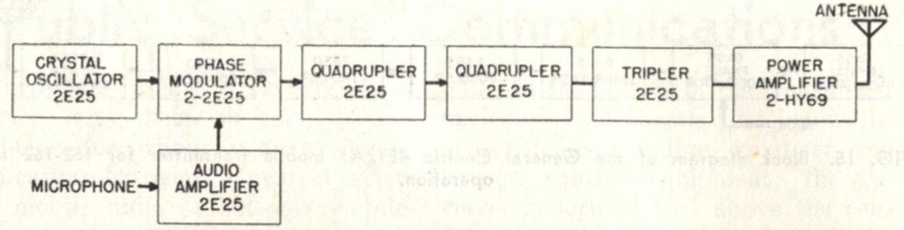


FIG. 13. A block diagram of the KAAR FM-50X and FM-100X f.m. transmitter for operation in the 152-162 mc. band. All tubes are "instant-heating" types, which are turned off when the transmitter is not operating. Thus, the stand-by current for this transmitter is zero.

through R_{10}.

Resistor R_9 is used to limit the current flow through the microphone. The negative voltage across R_{10} is also applied through R_8-C_{13} as d.c. bias for the audio amplifier VT_3.

The audio output across the secondary of microphone transformer T_1 is applied to the grid of VT_3 through R_6, R_7, C_{12}, and C_{13}. The low-pass RC filter R_6, R_7, and C_{12} (C_{13} is an audio by-pass condenser) eliminate voice frequencies above about 3000 cycles.

Filtering for the d.c. power supply is supplied by C_{15}, choke CH, and C_{11}.

VT_3 acts essentially as a triode amplifier, since C_{16} is an audio by-pass condenser. R_{11} is used to reduce the d.c. voltage on the screen.

G. E. MOBILE EQUIPMENT

The General Electric 4ET2A1 is an example of the 152-162 mc. mobile f.m. equipment manufactured by that company. Its block diagram is shown in Fig. 15.

In this transmitter, the crystal oscillator output is phase-modulated, frequency-multiplied by 48 to obtain the desired carrier and frequency deviation, and then applied to a power amplifier to obtain 15 watts output. We will discuss only the phase modulator circuit of this transmitter, since it is the only circuit in it with which you are not already familiar.

The basic circuit is shown in Fig. 16A. The input r.f. voltage from the crystal oscillator is applied both to the grid of VT_1 through C_1 and also directly to the plate of VT_1. The r.f. voltage applied to the following stage is therefore the sum of this direct

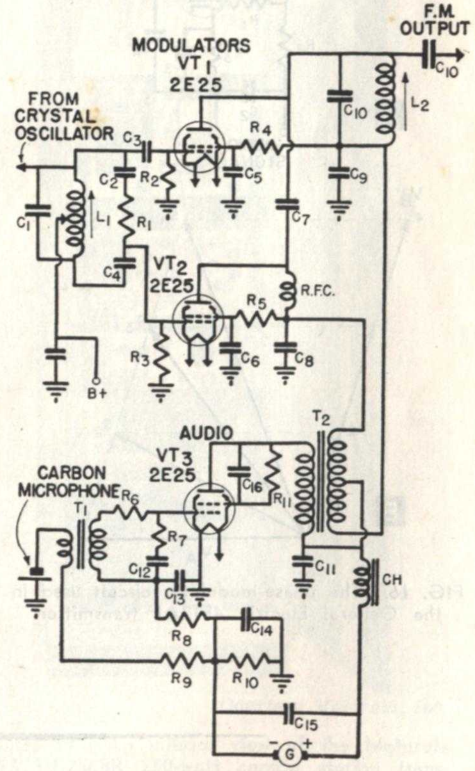


FIG. 14. The phase modulator and audio amplifier sections of the KAAR FM-50X and FM-100X f.m. transmitters.

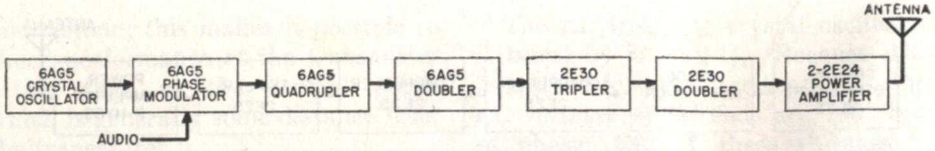


FIG. 15. Block diagram of the General Electric 4ET2A1 mobile transmitter for 152-162 mc. operation.

voltage and the amplified voltage output of VT_1.

A vector diagram of these two voltages is shown in Fig. 16B. The voltage coupled directly to the plate is represented by vector V_A, the amplified voltage output of VT_1, by V_B.

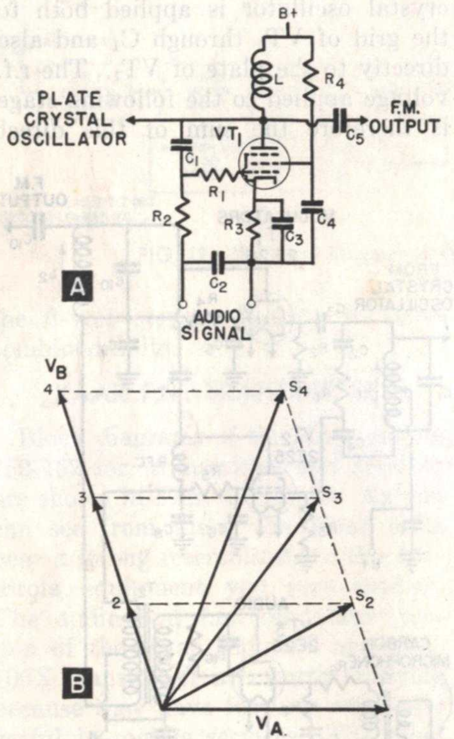


FIG. 16. The phase-modulator circuit used in the General Electric 4ET2A1 transmitter.

Since the reactance of C_1 is appreciable with respect to R_2, there is a phase shift in the grid voltage applied to the tube, so the amplified voltage V_B is less than 180° out of phase with V_A. The value of V_B can be varied by applying an audio signal to the grid of the tube through R_2 (C_2 is an r.f. by-pass condenser). When there is no modulating signal, the circuit is adjusted so that V_B equals V_A (point 3 on the V_B line). The phase of the resultant S_3 is then halfway between those of V_A and V_B. When there is a modulating signal, V_B varies in length—say from 2 to 4. The phase angle between the resultant vector and V_A also varies, becoming larger as V_B increases and smaller as V_B decreases. You can see, therefore, that an audio signal applied to the grid of VT_1 will produce phase modulation of the output signal.

The amplitude variations in the resultant signal are, of course, eliminated in the frequency multiplier stages.

Notice that the action of this phase modulator is similar to that of those shown in Figs. 10 and 14, and that the vector diagram in Fig. 16B is just another way of representing the phase-shifting action shown in Fig. 11.

Public Service Communications

There are many businesses that operate large fleets of cars, trucks, or buses for whom two-way communication between a central office and mobile units or between mobile units greatly facilitates operation. This service is especially useful for directing taxicabs, delivery trucks, and maintenance and service crews of gas, water, and electric companies.

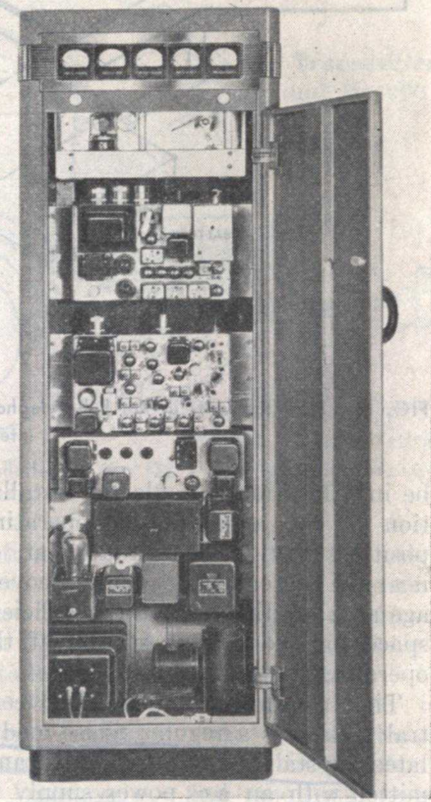
Such communication can be provided by subscribing to the regular telephone mobile service, which we will study shortly. However, when a direct tie-in between mobile units and land telephone lines is not necessary, many private companies establish and maintain their own two-way systems. Where a sufficient need for the service is established, the FCC permits operation on certain frequencies in the mobile bands (30-44 mc., 72-76 mc., 152-162 mc.). Of these, the 152-162 mc. band is the most used.

The Motorola FSTRU-250BR 250-watt central station and FMTRU-30D 30-watt mobile combination transmitter - receiver are the major components of a widely used point-to - point communications system operating in this band. We have already studied the mobile components of this system; now, let's take a quick look at the central station equipment.

CENTRAL STATION EQUIPMENT

A general view of the FSTRU-250BR station equipment is shown in Fig. 17. This unit is a remotely controlled 250-watt f.m. transmitter and 17-tube crystal-controlled, triple-detection, superheterodyne receiver. The power supplies, which operate from 110-volt 60-cycle a.c., are located in the bottom of the transmitter enclosure; the chassis just below the center holds the line equalizer and station control equipment; the receiver is located just above the center; the low-power circuits of the transmitter are located on the chassis above the receiver; and the final r.f. output stage is just below the row of meters on the top.

This complete unit can be remotely operated as far as 10 miles from the control office. Either a single tele-

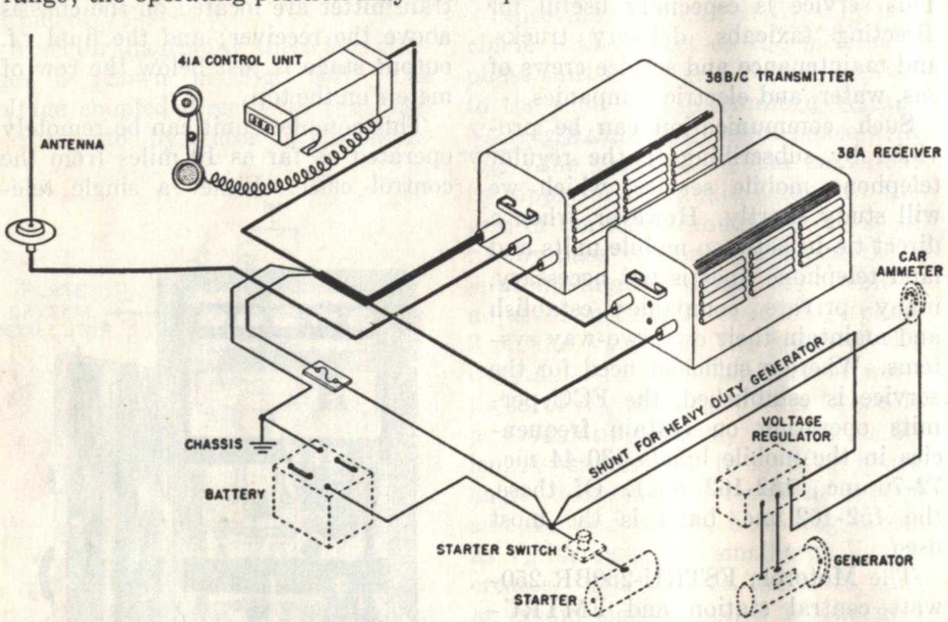


Courtesy Motorola, Inc.

FIG. 17. An interior view of the Motorola FSTRU-250BR 250-watt central station transmitter-receiver for operation in the 152-162 mc. band. This equipment operates from a.c. power lines.

phone pair or other two-wire line can be used. No operator is needed at the central station.

There are several reasons for locating the central station away from the control position: it is desirable to locate the station and its antenna at a high elevation for maximum range; the operating position may not



Courtesy Western Electric

FIG. 18. How the units in the Bell Telephone Company 238 Urban radiotelephone systems are interconnected.

be in a location suitable for installation of the antenna; the operating position may not be situated at, or near the center of the required coverage area; or there may be insufficient space for the central station at the operating position.

The transmitter in this fixed central station is a regular phase-modulated, crystal-controlled, mobile transmitter with an a.c. power supply to replace the dynamotor normally used. This transmitter drives two 4-125A tubes used as a push-pull power amplifier. It is capable of 20-kc. deviation each side of the carrier; the modulating frequencies are from 300 to 3000 cycles. The stand-by power taken by the central station is 240 watts; during transmission, the power consumption is 1350 watts.

The receiver used is a 16-tube mobile unit with a rectifier power supply added to adapt it to 110-volt operation.

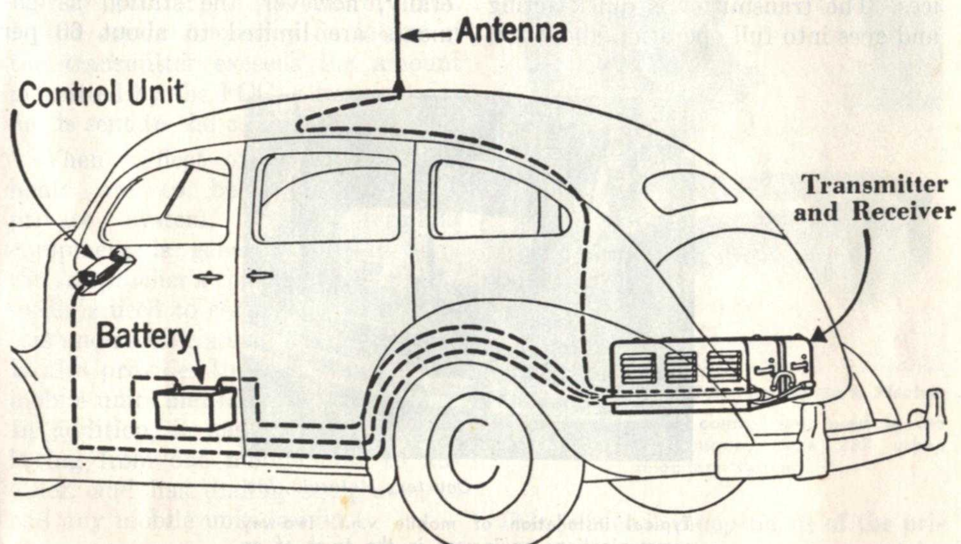
MOBILE TELEPHONES

The Bell Telephone Company has developed a system of mobile telephone service for operation from cars, trucks, buses, trains, and boats. This service is used by doctors, ambulances, deliverymen, public utility maintenance crews, and many others because of its convenience and ease of operation. No FCC license is required to operate the equipment, although, of course, a properly licensed person must be responsible for transmitter adjustments.

The system has two branches—

urban service in the 152-162 mc. band, and highway service in the 30-44 mc. band. Urban service is generally confined to an area close to the city that is being served; the low-frequency highway service permits operation from cars, trucks, and buses at greater distances from metropolitan areas.

Three classes of service are provided: 1, a general two-way tele-



Courtesy Western Electric

FIG. 19. The layout of a typical automobile installation of the 138 Urban Telephone two-way communications systems.

phone service between any regular telephone and any mobile unit; 2, a special two-way dispatch service between a particular telephone and specified mobile units (as between the dispatcher and a group of taxis, buses, deliverymen, or maintenance crews); and 3, a one-way signaling service to mobile units.

The equipment for this service can be rented by the customer from the telephone company and will be installed and maintained by them. However, equipment meeting the electrical and mechanical requirements necessary to operate in conjunction with the telephone fixed (land) equipment may be purchased from independent manufacturers. The telephone company assigns call numbers to and collects tolls from the operators of such equipment.

MOBILE EQUIPMENT

Frequency modulation with a deviation of 15 kc. is used in this telephone service system. The interconnection of the components is shown in Fig. 18. A typical automobile installation is shown in Fig. 19.

Receiver. The receiver used is very sensitive; the signal input needed for complete limiting is about 5 microvolts, and the maximum squelch sensitivity is 1 microvolt. The output of the receiver is 250 milliwatts; this is used to operate the selective calling unit when the handset is on the hook. However, when the handset is off the hook, a negative feedback circuit improves the fidelity of reproduction and reduces the output to about 10 milliwatts, a power that is sufficient to operate the handset receiver.

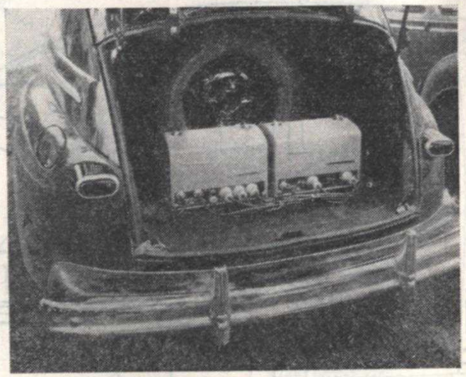
Transmitter. The transmitter for urban service has a 15-kc. deviation and a power output of 15-35 watts; for highway service, the deviation is 12 kc. and the power is 20-40 watts. Phase modulation of a crystal-controlled r.f. source is used in both services. The transmitter is quick-acting and goes into full operation about 300 milliseconds after the push-to-talk button is depressed.

Both the transmitter and receiver units are generally mounted in the trunk compartment in the back of the car or in any convenient place in a truck or bus.

Antenna. The antenna used for urban service is generally an 18-inch (quarter wave) vertical whip mounted on the top of the vehicle.

Control Unit and Handset. The control unit and handset are shown in Fig. 20. A calling bell and light, an on-off switch, and a light that indicates when the equipment is operating are located here.

A selective calling system very similar to that used in marine telephone services is part of this mobile telephone system. A 23-step relay is used. Each mobile installation is assigned a five-digit number preceded by a channel designation of two letters—for example, WJ-37553. The total of the five digits must always be 23. There are 2030 number combinations possible in each channel; generally, however, the station assignments are limited to about 60 per channel. Since operation is on a party line basis, the amount of activity determines the number of assignments on each channel.



Courtesy Motorola, Inc.

Typical installation of mobile v.h.f. two-way communications equipment in the trunk of an automobile.

FIXED STATIONS

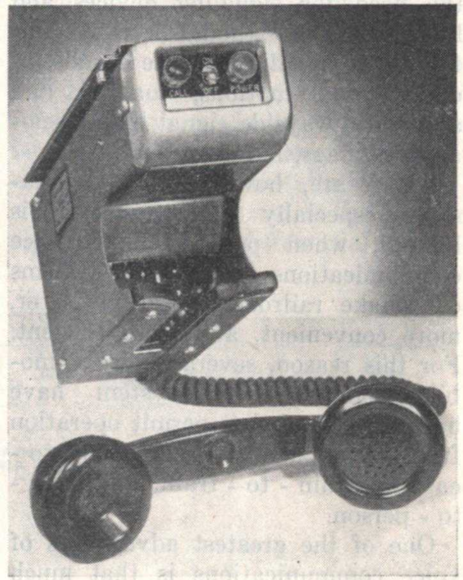
For complete coverage of the area serviced, 250-watt phase-modulated transmitters are used. In some installations only one transmitter is used; in some of the larger cities, however, two or more are used. These transmitters can be operated either directly or by remote control.

Generally a main transmitter and a spare (test) transmitter, a frequency monitor, and two or more receivers are located at the remote position. The test transmitter is generally used to check the land receivers which, in a large city, are located at several different points to provide complete coverage. This transmitter is on the same channel as the mobile units, and when turned on should cause the land receivers to operate. Telephone lines are used to connect each of these remote transmitters (including the frequency monitor) to the control point. If the center frequency deviation of the transmitter exceeds the amount permitted by the FCC, a warning signal is sent to the control point.

When a fleet of cars, trucks, or boats are to be regulated in a private system, control terminal equipment is generally installed in the dispatcher's office. This equipment is used to control the transmitters and receivers at the remote point. It also provides the link between the mobile units and land telephone lines. In addition, it has facilities for relaying from one mobile unit to another, and has dialing equipment to call any mobile unit desired.

RAILROAD TELEPHONES

This 152-162 mc. telephone system has been extended to railroad trains for general public use. The equipment and service is practically the same as that provided by the telephone company for cars and trucks.



Courtesy Western Electric

FIG. 20. The 41A control unit used in the Bell Telephone Company type 238 urban telephone system.

This service is independent of the private communication systems used by the railroad companies, which we will now study.

Railroad Communications

The railroads have long realized the need for signaling devices and have developed standardized systems for visual signaling. These signals include hand motions, manual and automatic wayside signal lights, semaphores, flags, lanterns, and flares.

There are, however, many occasions, especially when visibility is limited, when point-to-point voice communications in railroad systems can make railroad operation faster, more convenient, and more efficient. For this reason, several railroad mobile communication system have been developed that permit operation from dispatcher - to - cab, cab - to - caboose, train - to - train, and train - to - person.

One of the greatest advantages of voice communications is that much more information can be conveyed than is possible with ordinary signal devices, which generally indicate only STOP, CAUTION, or PROCEED. Radio communications not only can tell an engineer to stop his train but also can give the reasons for doing so. This valuable information can be conveyed in a few seconds.

It must be remembered, however, that radio communications in railroad systems are only supplements to the signaling devices already in use—not replacements for them. Mechanical signaling devices, though limited in the amount of information that they can convey, are automatic and need no human intervention. Their action is dependable and reliable. Very few train accidents are caused by the failure of signaling devices.

Furthermore, radio messages can only convey information—they cannot make the person receiving the information act on it. The human error that causes an engineer to go through a CAUTION or STOP signal, for example, is not likely to be eliminated by radio signals. Therefore, radio signaling systems will probably not add greatly to the safety of railway travel.

Problems. Railroad communications has many problems peculiar to that service. One is the fact that it is necessary to pick up and to reproduce voice signals in very noisy locations. The noise in an engine cab or caboose is especially high while the train is in motion. Considerable electrical interference is also encountered: many railroads are electrified, and therefore have high background electrical noise levels; and railroads frequently operate near or in large industrial plants where the electrical equipment may cause considerable interference. Finally, operation in or near large steel buildings, in underpasses, or in tunnels cause considerable variations in the amplitude of the signal received.

These problems have led to two general types of railroad communication systems. The first system, which is widely used, is space radio—that is, the usual two-way radio system in which the r.f. signal is radiated through space from one point to another. The second system is induction radio, in which modulated radio signals are fed into regular or specially constructed telephone and telegraph lines adjacent to the railroad tracks and are thus guided from one point to another by these wires. The frequency of the carrier in this latter

system is kept low to extend the size of the induction field and to minimize radiation losses.

SPACE RADIO

Space radio systems for railroad communications generally follow the techniques of other services in the 152-162 mc. band. F.M. is used to provide a reliable interference-free signal under the various operating conditions encountered in railroad service.

Westinghouse System. As an example of a space radio system, let us study the Westinghouse equipment for railroad use.

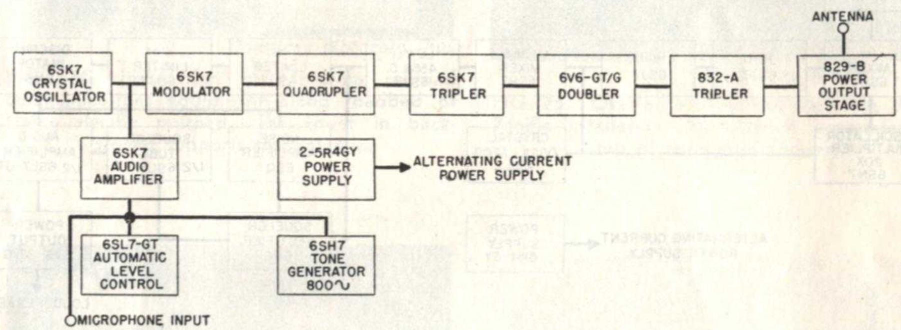


FIG. 21. Block diagram of the Westinghouse transmitter used for railroad communications.

The transmitter used in both mobile and fixed locations is a 152-162 mc., f.m. transmitter, with 25 watts output power. Its block diagram is shown in Fig. 21. It has the same general characteristics as the other 152-162 mc. f.m. transmitters you have already studied. Frequency multiplication of 72 is used to obtain a 15-kc. deviation in the output. In this system, an 800-cycle tone is used for a calling signal.

A power supply that normally operates from 117-volt, 50 to 70-cycle a.c. is used. When it is operated as a mobile transmitter, in which case the primary power source is 32-volt d.c. or 64-volt d.c., a rotary converter with built-in voltage-regulating equipment must be used.

The receiver used in this system is shown in block form in Fig. 22. It resembles other 152-162 mc. f.m. receivers in that it is a crystal-controlled, double superheterodyne with two limiter stages and a squelch system. It also operates from a.c., which is supplied by a rotary d.c.-to-a.c. converter in mobile installations.

The microphone used in this mobile equipment is a differential noise-reducing type that is suitable for operation in steam locomotives and under adverse weather conditions.

This and all other mobile railroad equipment is specially designed to withstand the shock and vibration encountered in train operation.

A block diagram of a typical mobile installation of railroad space communications system is shown in Fig. 23.

Motorola System. For railroad installations, Motorola uses equipment practically identical with the mobile f.m. equipment already studied. Fig. 24 shows one installation used by the Union Pacific Railroad. The mobile transmitter and receiver operates from a.c. power supplies. Mounted beneath these chassis is the meter and indicator panel.

The antenna for this installation is placed on a high tower to provide good coverage of the area served. A view of the complete installation is shown in Fig. 25.

Fig. 26 shows a typical installation of the mobile components of this equipment in a Union Pacific switch engine. The two units are mounted

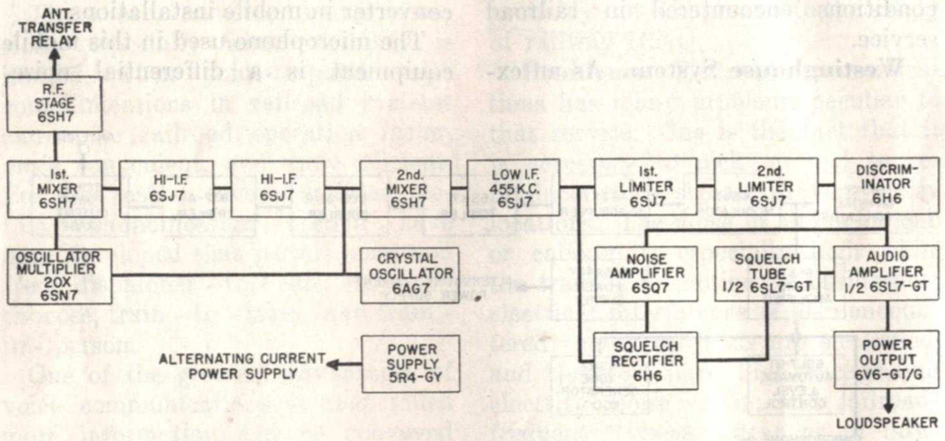


FIG. 22. Block diagram of the Westinghouse 152-162 mc. f.m. receiver used in railroad space radio communication systems.

to reduce mechanical shock and vibration.

It is often desirable to communicate with switchmen, conductors, or other personnel who may be some distance away from either mobile or fixed stations. Hand-carried combination transmitters and receivers have been developed for doing so. Fig. 27 shows a typical example, the Motorola FHTR-1 unit. This unit has a collapsible antenna and is equipped with a standard handset with a push-to-talk button. The only other control on the equipment is the on-off switch.

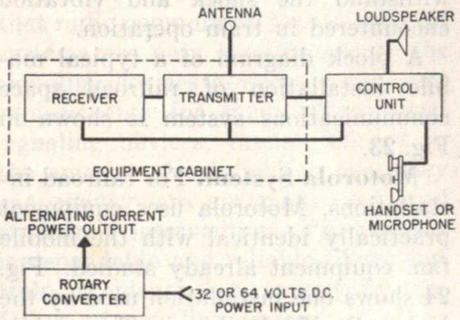
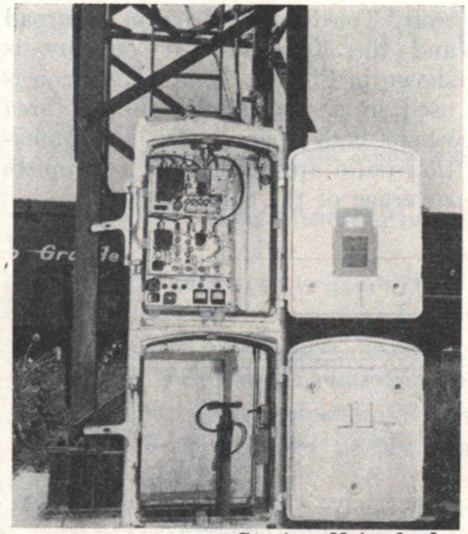


FIG. 23. Mobile station block diagram showing the units that are used in a railroad space radio system.

INDUCTION RADIO

Practically all railroads have telephone and telegraph lines paralleling the railroad tracks. Some railroad systems use these wires to provide radio communications to points that cannot be served by space radio.

In induction radio, a frequency-modulated or amplitude-modulated r.f. carrier is applied to the telephone and telegraph lines without disturbing the normal functioning of these lines. This r.f. signal is then picked up at remote points by capacitive or inductive coupling from these lines. Signals can be sent relatively long distances over the lines; yet, since the carrier frequency is low, there is so little radiation that the signal can be

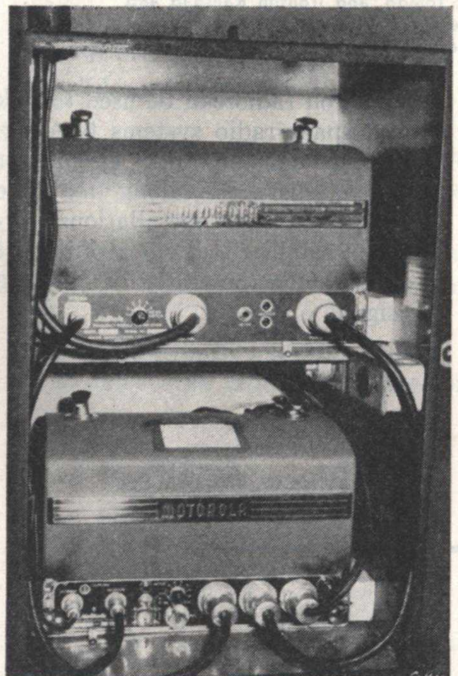


Courtesy Motorola, Inc.

FIG. 24. Installation of Motorola railroad communications equipment along roadbed of Union Pacific railroad. The tower in background supports the antenna.

Courtesy Motorola, Inc.

FIG. 25. Over-all view of the Motorola Union Pacific installation. The antenna is mounted on top of the support tower.



Courtesy Motorola, Inc.

FIG. 26. Motorola railroad communications equipment in a Union Pacific switch engine.

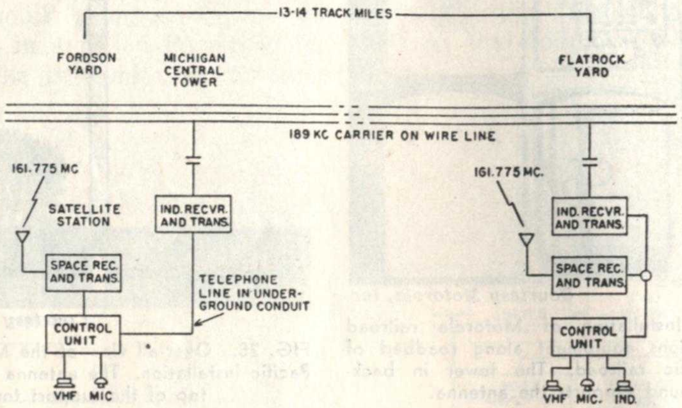
Courtesy Motorola, Inc.

FIG. 27. The Motorola Model FHTR-I portable transmitter-receiver.

received only a short distance from the lines.

It is possible to communicate with moving trains by this system. The slight amount of radiation from the wires and the capacitive coupling between the train and the wayside wires are generally sufficient to permit the operation of both a transmitter and a receiver on the train for two-way communication.

The frequency of induction systems is quite low, generally 50-300 kc. An example of a combination space radio and carrier system used by the Detroit, Toledo, and Ironton Railroad and the Ford Motor Company is shown in Fig. 28. This installation is used in a congested industrial area where both space radio and induction radio are needed for a complete coverage of the entire area.



Courtesy Farnsworth

FIG. 28. An example of how space and induction radio systems are used in combination by the Detroit, Toledo, and Ironton Railroad and the Ford Motor Company to facilitate switching in a congested industrial area.

Induction radio can be used to link several space radio systems together, and to extend the radio circuit for unlimited distances along mainline trackage. In such installations, unattended satellite stations are used at intervals along the track for boosting the signal.

Lesson Questions

Be sure to number your Answer Sheet 49RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. Why is f.m. preferred for mobile v.h.f. services?

2. What value of frequency deviation is considered to be 100% modulation in mobile communication systems?

3. Why are the tubes in a mobile transmitter (especially in the high level r.f. stages) generally "quick heating" direct emitter types?

4. For what fundamental reason is vertical polarization principally used in v.h.f. mobile services?

5. Why won't voice signals or static interference operate the selector mechanism in the calling system of a ship equipped for radiotelephone service?

6. Why is a frequency multiplier used in the local oscillator sections of a single frequency crystal-controlled double superheterodyne receiver?

7. Why are squelch circuits used in f.m. receivers of mobile communications systems even though f.m. receivers give high signal-to-noise ratios?

8. Why isn't reactance tube type of modulation of an LC oscillator used in v.h.f. mobile f.m. transmitters?

9. How is the amplitude modulation eliminated in a phase-modulated v.h.f. mobile transmitter?

10. For what two reasons are low carrier frequencies used in induction field radio systems?

SHOULD YOU DEPEND ON LUCK?

Accident—chance—luck—have very little bearing upon the production of any great result or true success in life. Of course, there have been many discoveries and accomplishments which may *seem* to be the result of "luck."

For instance: Newton "discovered" the law of gravity by watching an apple fall from a tree. Galileo "invented" the telescope after hearing of a toy constructed by a spectacle-maker. Brown "invented" the suspension bridge after watching a spider throw its web.

But these discoveries and inventions were made by men *trained* to take advantage of what they observed. Thousands of *untrained* men had seen the same things and paid no attention.

The new discoveries in Radio—Television—Electronics will be made by men *trained to take advantage of what they observe.*

J. E. SMITH