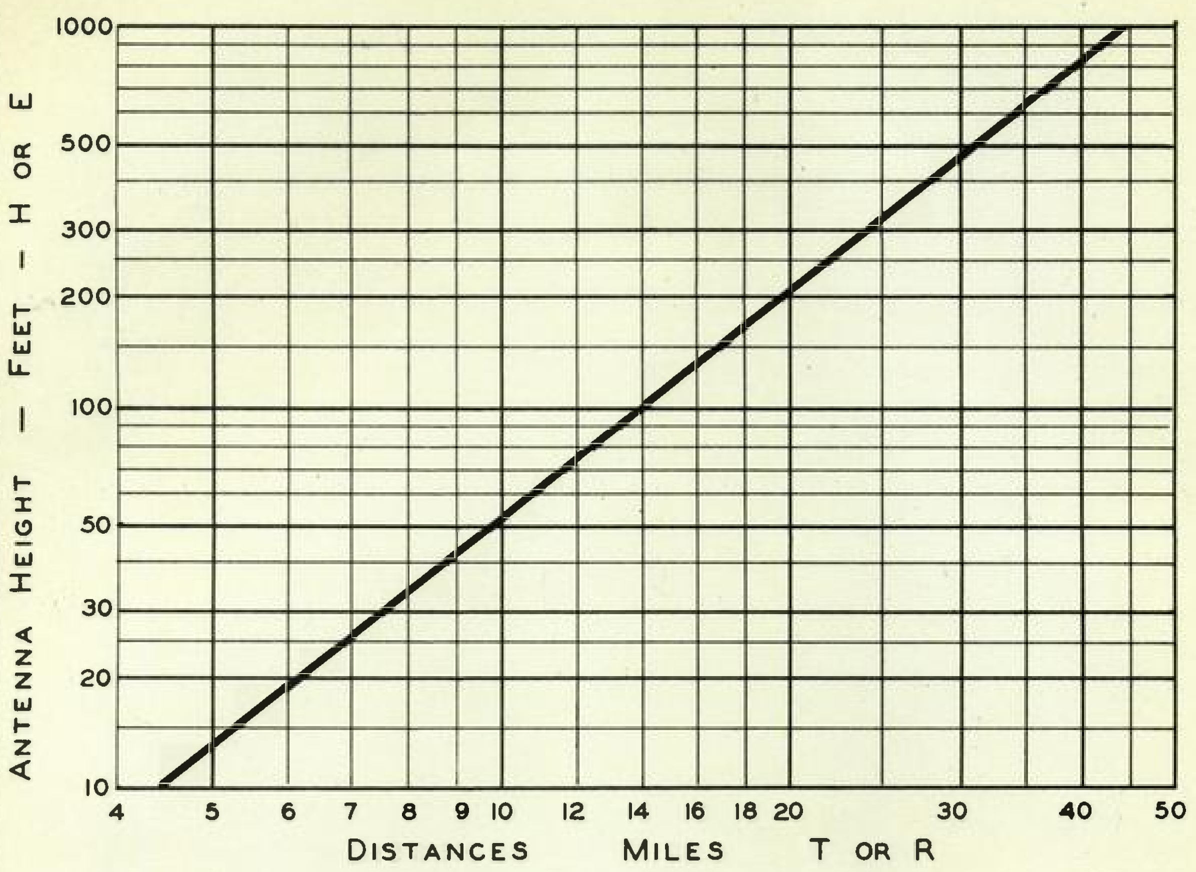

FM RECEPTION AND RECEIVERS

LESSON 74 RA

RADIO-TELEVISION TRAINING SCHOOL, INC.
5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

F-M RECEPTION AND RECEIVERS

At the very high frequencies used for transmission of frequency-modulated signals the radio waves behave in ways which seem peculair to anyone familiar with reception in the standard broadcast and lower frequency short-wave bands. At frequencies around 100 megacycles, where most of the f-m transmission is carried on, the radio waves act like rays of light. Were you to stand at the location of the receiving antenna, and were there a powerful searchlight at the transmitting antenna, you would have to be able to see the beams from the searchlight were there to be satisfactory reception of the f-m signals.

In Fig. 1 are represented radio waves from a transmitting antenna. The waves travel in straight lines, like light beams. A receiver located anywhere between the transmitter and the position marked "Horizon", such as at point A, would normally have good reception from waves traveling in directions such as that marked 1. The transmitted wave marked 2 glances across the horizon and travels onward. This wave might be picked up by receivers located at points such as B and C. It is apparent that a receiving antenna located at B would not have to be so high in the air as one at C in order to catch wave number 2. Were antennas at these positions to be at heights less than those indicated by the diagram they would intercept no waves from the transmitter and there would be no reception. Neither would it be possible, at lower positions, to see the beam from a searchlight at the transmitting antenna.

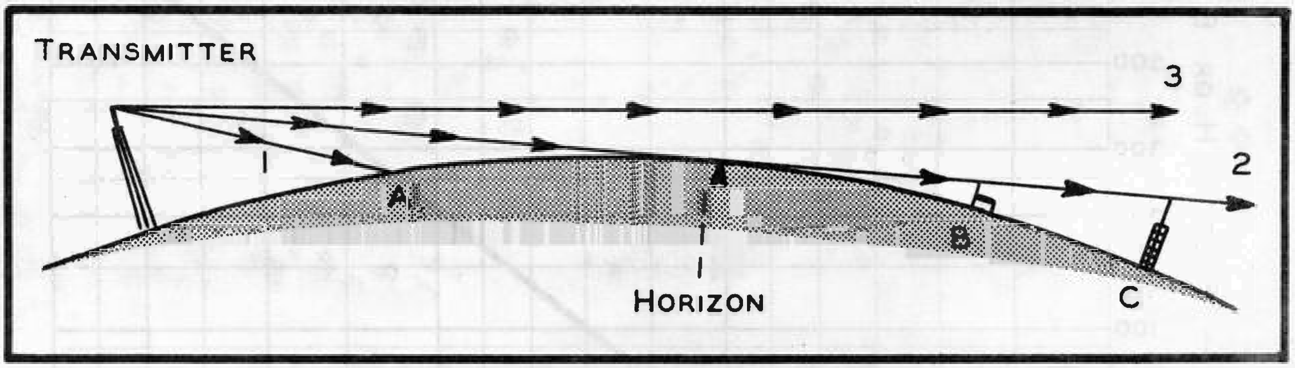

FIG. 1. Radio waves at the very high frequencies travel in straight lines.

Waves traveling in the direction of the one marked 3 in Fig. 1 would be wasted unless, somewhere along their straight path, there were a receiving antenna high enough to intercept them.

With receiving antennas at heights usually attainable at residential buildings, the maximum distance from a transmitter at which there will be satisfactory reception is the distance from the transmitting antenna to its horizon. This horizon distance depends on the height of the transmitting antenna.

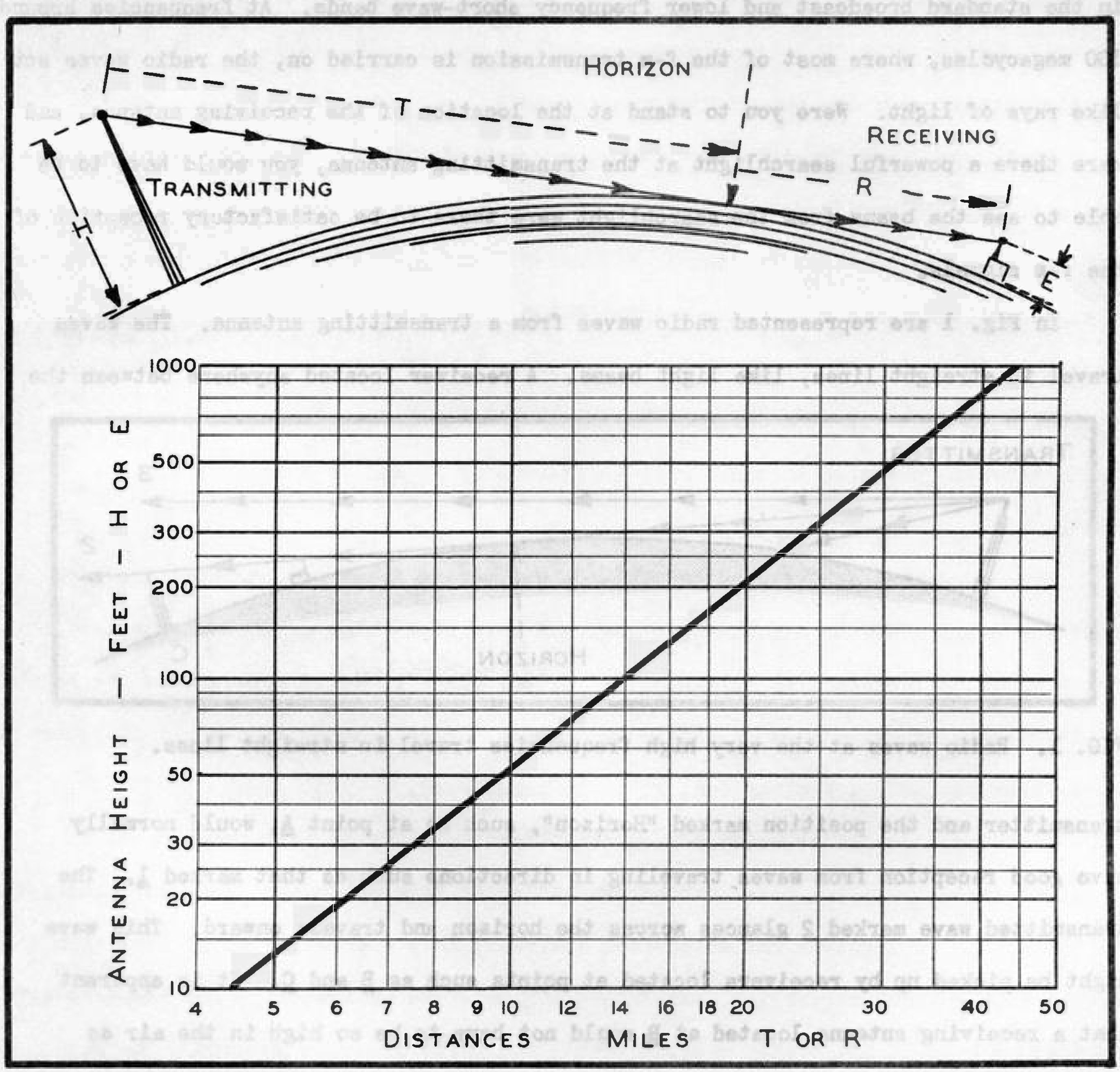

FIG. 2. The graph for computing maximum distances for satisfactory reception.

In Fig. 2 are represented a transmitting antenna of heigh H and a receiving antenna of height E. The distance from the transmitting antenna to its horizon is T, and from the receiving antenna to its horizon in the direction of the transmitter is R. Distance T becomes greater with increasing height H of the transmitting antenna, as does distance R with incfeasing height of the receiving antenna E. The maximum reception distance is the sum of distances T and R.

Distances T and R may be read from the graph of Fig. 2. The left-hand vertical scale of heights applies to both transmitting and receiving antennas, and the lower horizontal scale of miles applies to distances T and R. As an example, supposing that the transmitting antenna is at a height of 500 feet, and the receiving antenna at a height of 30 feet. The graph shows fof a 500-foot height a distance of about 31 miles, and for a 30-foot height a distance of about 7½ miles. Then the maximum reception distance between these two antennas will be the sum of 31 and 7½ miles, of will be 38½ miles.

Even were the feceiving antenna as low as 15 feet above gfound level the total distance still would be almost 36½ miles, and were it as high as 50 feet the total distance would be incfeased to only about 41 miles. Thus it would appeaf that the height of the feceiving antenna is of little importance. Such a conclusion would be incorrect, because there afe other factofs to be considered.

High-frequency fadio waves behave like light not only in that they travel in straight lines, but also because they are reflected from conductive and semi-conductive surfaces much as light is feflected from a mirror, they afe refracted of bent when passing through regions of varying temperature and moisture of humidity, and they are diffracted of bent slightly when passing across the edges of solid objects. The higher we place the feceiving antenna, the less tfouble there will be from reflections of the waves and the less will be the chances of the wave energy being absorbed or stopped by surrounding buildings, trees, and other obstructions. Furthermore, the higher the receiving antenna, the farther it will be from most sources of electrical interference such as motors and other electrical machines, and from power lines, which may produce radiations picked up by the antenna.

F-M ANTENNAS

The type of antenna usually recommended for f-m reception is a horizontal dipole. A dipole, as shown by Fig. 3, consists of two straight conductors in line with each other, slightly separated at their adjacent ends, and connected to the receiver by the two conductors of a transmission line which are connected to these ends of the dipole.

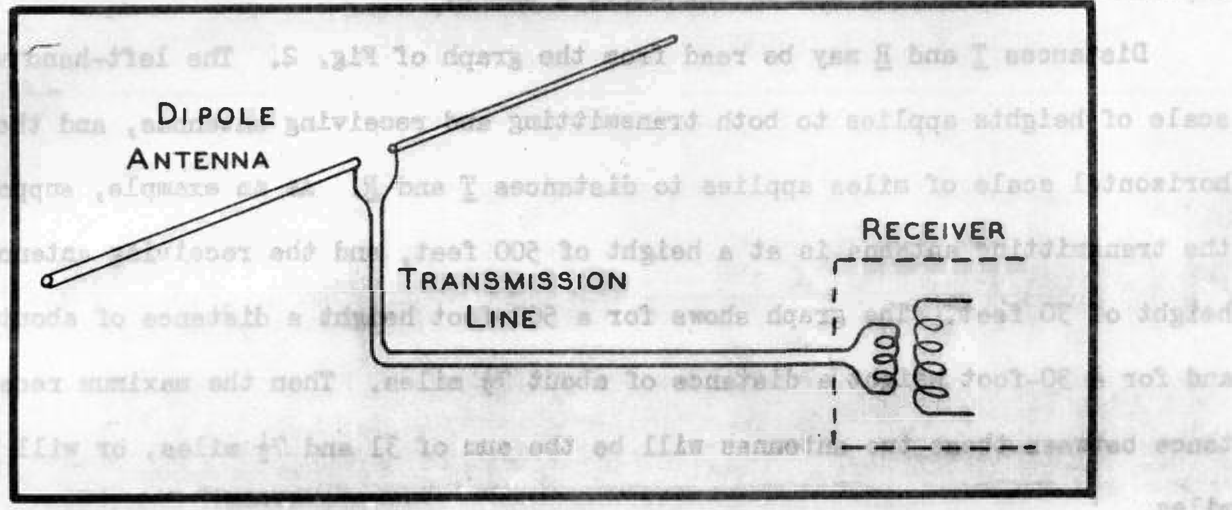

FIG. 3. A horizontal dipole antenna.

The two antenna conductors usually are straight rods or tubes made of aluminum, copper, brass, or some suitable alloy, of one-quarter inch or greater diameter. These conductors are securely and rigidly supported by insulation, with the whole arrangement carried at the top of a vertical pole or mast. The ends of the transmission line are soldered or tightly clamped to the inner ends of the antenna pieces. Two straight wires, suitable supported by insulation at their ends, sometimes are used instead of the rigid rods or tubes.

The overall length of the two dipole conductors should be suited to the wavelength (or frequency) of the radio waves to be received. The reason is shown by Fig. 4. At the top is represented a radio wave in space, assumed to be traveling from left to right. In the wave there are regions of zero energy and of maximum energy. There comes a point in which the energy is maximum in one direction, which may be called positive(+), then comes a point in which energy is maximum in the other direction, which may be called negative(-). These two points of maximum energy are one-half wavelength apart. If the dipole is of such length that one of its ends is in a region of maximum positive energy while the other end is in a region of maximum negative energy, there will be a maximum potential difference induced between the ends, and there will be maximum resulting current in the antenna conductors, the transmission line, and the connected coil inside the receiver.

A little later, as the wave continues to travel along, the polarities in the wave and in the antenna will be reversed, as at the right in Fig. 4. Then we shall have maximum antenna potential and current in the opposite direction. In the coil of the receiver there will be produced an alternating current whose frequency is the same as that of the radio wave. With a longer or shorter antenna, there will not be maximum potential and energy differences at the same instant, and the induced potential and current will be weaker.

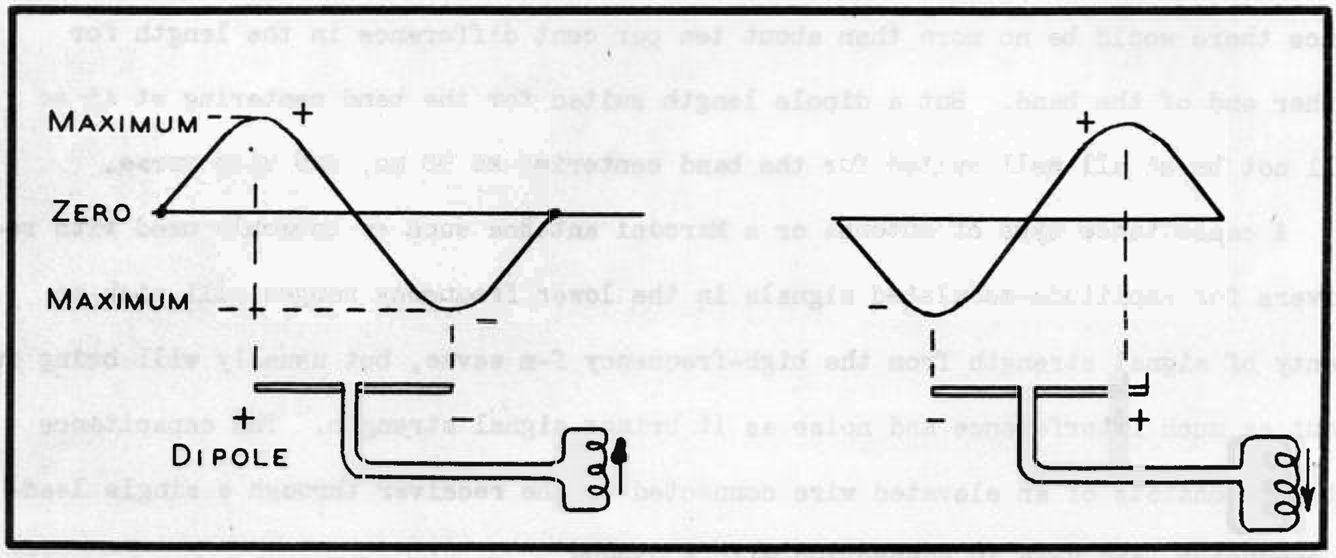

FIG. 4. A dipole half as long as the radio wave acquires maximum potentials.

For best signal pickup the overall length of the dipole should, theoretically, be equal to one-half wavelength of the radio waves to be received. Because of capacitance effects at the antenna conductors the actual length should be a little less than one-half wavelength. The accompanying list gives overall end-to-end lengths of the two dipole conductors for reception at the lower and upper frequencies, and the middle frequencies, of the old and new f-m bands.

HALF-WAVE DIPOLE LENGTHS, OVERALL

Frequency	Inches	Feet-inches		Frequency	Inches	Feet-inches	
42 mc	131.4	10	11.4	88 mc	62.7	5	2.7
45 mc	122.6	10	2.6	98 mc	56.3	4	8.3
48 mc	115.0	9	7.0	108 mc	51.1	4	3.1

From the list of dipole lengths it is apparent that an antenna whose length is suited to the middle frequency in either of the bands will serve for the entire band, since there would be no more than about ten per cent difference in the length for either end of the band. But a dipole length suited for the band centering at 45 mc will not be at all well suited for the band centering at 98 mc, and vice versa.

A capacitance type of antenna or a Marconi antenna such as commonly used with receivers for amplitude-modulated signals in the lower frequency ranges will pick up plenty of signal strength from the high-frequency f-m waves, but usually will bring in about as much interference and noise as it brings signal strength. The capacitance antenna consists of an elevated wire connected to the receiver through a single lead-in conductor, and used in connection with a ground.

With the maximum reception distance averaging something like 50 miles, there will be good signal strength over this whole distance when there is any signal at all. That is, in a distance of only fifty miles, there is little weakening or attenuation of the radiated wave. All of the difficulties arise in the last few miles, near the horizon distance, where the wave is glancing along so close to the surface of the earth that it encounters all manner of energy absorbing and reflecting obstacles. Here it is that a high receiving antenna is of great help. The signal is not weakened by the distance through which it has traveled, but is weakened by the energy losses in the last few miles of the distance.

Up to the region in which the radio wave comes close to the surface of the earth, the signal field strength is great enough, and the amplification or gain in most f-m receivers is so high, that almost anything in the way of an antenna will serve the purpose provided it does not pick up too much interference. Excellent results are obtained with high-gain receivers by using the power and lighting line for signal pickup, with the primary winding of the tuned antenna coupler fed through a capacitor of about 100 mmfd capacitance connected to the ungrounded side of the power line.

Fig. 4 shows that the length of a dipole antenna should be at right angles to the direction of wave travel if there is to be maximum energy pickup, for only then will points of maximum wave energy be at opposite ends of the antenna at the same time. This is shown again by Fig. 5. For maximum pickup the dipole should be at right angles toward the transmitter whose signals are to be received. If the dipole is placed at right angles with the line of wave travel there will be maximum pickup, for the entire dipole will lie in a region of the wave where there is the same energy.

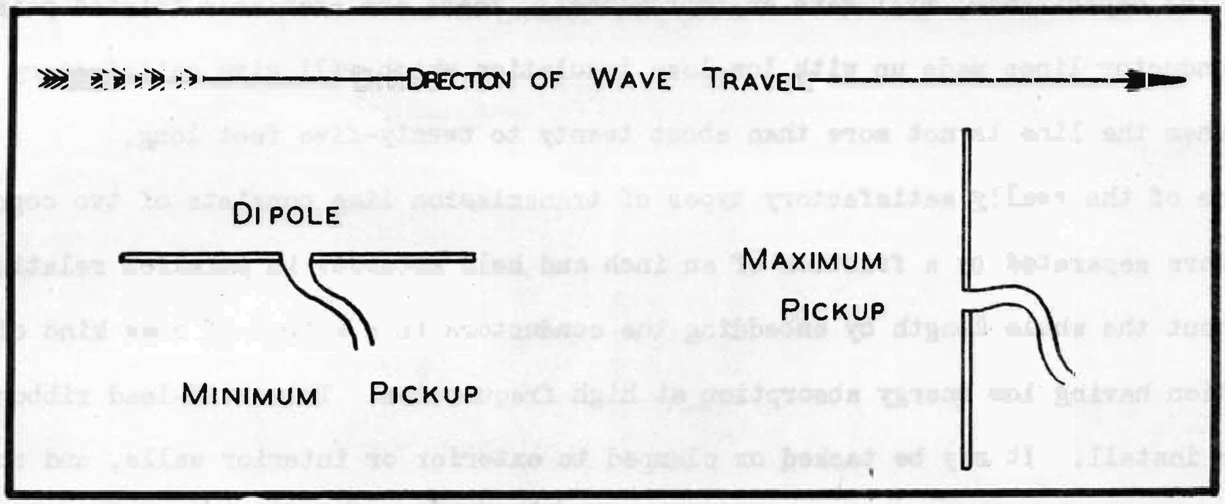

FIG. 5. For maximum pickup, the dipole should point in the direction of wave travel.

As a dipole is rotated slowly while a signal is being received, there will be found one particular position of the antenna in which reception drops almost to zero. If some strong signal is to be cut out, the dipole may be turned for near-zero reception on that signal. While the point of zero reception is quite sharply defined, the point of maximum reception cannot be closely identified. There is good signal strength and good reception during a large part of the antenna rotation, so that all stations in directions which are anywhere near at right angles to the dipole length will be received about equally well.

TRANSMISSION LINES

The transmission line which connects the dipole antenna and the receiver is as important as the antenna itself in obtaining satisfactory reception. One of the poorest transmission lines is ordinary two-conductor lamp cord or drop cord. Such a line, if more than about ten feet in length, can almost completely destroy an otherwise satisfactory signal. This is due largely to the close spacing and large capacitance between the conductors, and to the kind of insulation, which has very great energy absorption or loss at high frequencies. Separating the conductors by an inch or more, to lessen the capacitance, will make an improvement. There are available twisted pair and twin-conductor lines made up with low-loss insulation which will give satisfactory results when the line is not more than about twenty to twenty-five feet long.

One of the really satisfactory types of transmission line consists of two copper conductors separated by a fraction of an inch and held securely in parallel relation throughout the whole length by embedding the conductors in a ribbon of some kind of insulation having low energy absorption at high frequencies. This twin-lead ribbon is easy to install. It may be tacked or clamped to exterior or interior walls, and run over or under window sills and frames, and over doors, without any additional insulation.

In order that there may be the best possible or practicable transfer of energy all the way from antenna to receiver, it is necessary to pay attention to the matching of impedances between antenna and line, also between line and receiver. As shown by Fig. 6, the impedance at the center of a dipole of correct length for the received frequency is about 73 ohms. The standard input impedance for f-m receivers is 300 ohms. There is maximum energy or power transfer when the impedances of source and load, such as antenna and line, are exactly equal, but there is nearly as much transfer when the load impedance is considerably greater than the source impedance. As a consequence, there will be satisfactory matching when using a transmission line whose own impedance is 300 ohms.

The 300-ohm line is preferred because it has less energy loss per foot of length than those lines whose impedance is less than 300 ohms. At a frequency of 100 megacycles the loss per hundred feet of length is 2.1 decibels in a 300-ohm line, is 2.7

decibels in a 150-ohm line, and is 5.0 decibels in a 75-ohm line. Transmission line conductor is regularly available in any of the impedances mentioned; 300, 150, and 75 ohms. The specified losses are those for twin-lead lines embedded in low-loss insulation, as mentioned earlier. A transmission line of lower impedance would allow satisfactory energy transfer into a receiver having 300-ohm input impedance, but there would be more energy loss in the line.

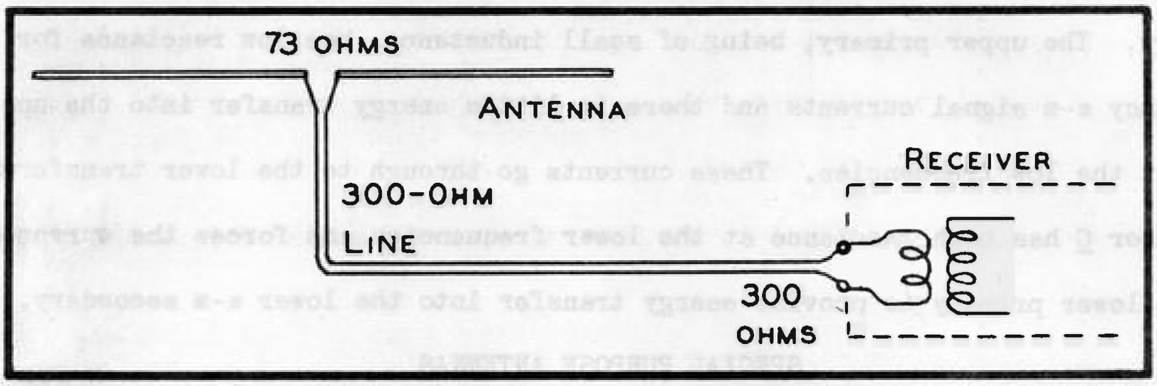

FIG. 6. Impedance relations of the dipole, the line, and the f-m receiver.

Impedance matching transformers may be used for maximum energy transfer between antenna and line, line and receiver, or at both places. As at the left in Fig. 7, a matching transformer at the antenna would have its primary connected between the inner ends of the dipole conductors, and its secondary connected to the line. At the right is shown an arrangement sometimes employed with a single antenna for both f-m and a-m reception. Currents from the line flow in the primaries of both the upper and lower

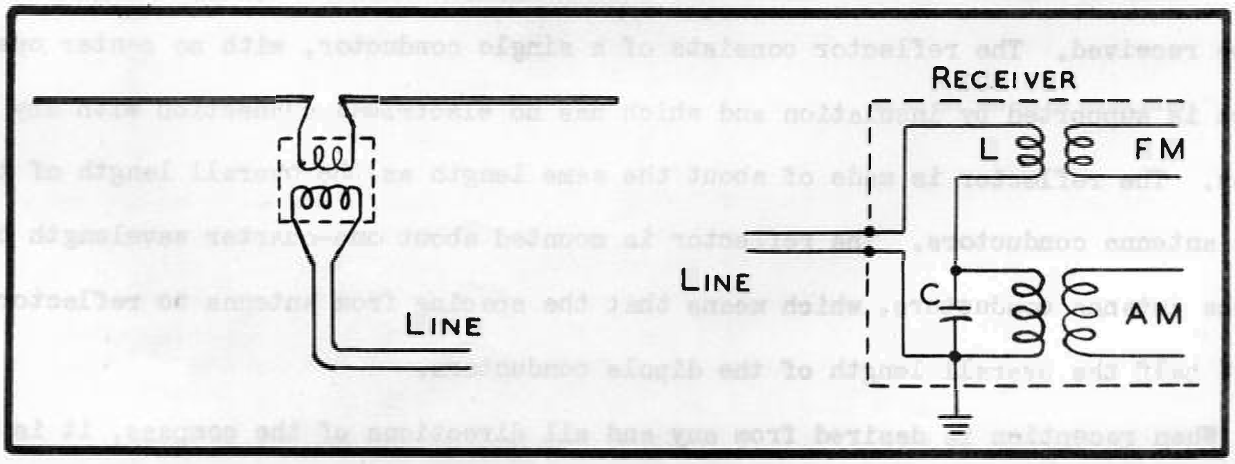

FIG. 7. Transformers may be used for impedance matching.

transformers. The upper primary has high reactance for the high-frequency f-m signal currents, and energy is transferred into the upper secondary. Bypass capacitor C has low reactance, for the high-frequency f-m currents, and carries them around the lower primary. The upper primary, being of small inductance, has low reactance for the lower frequency a-m signal currents and there is little energy transfer into the upper secondary at the low frequencies. These currents go through to the lower transformer, where capacitor C has high reactance at the lower frequencies and forces the currents to act in the lower primary to provide energy transfer into the lower a-m secondary.

SPECIAL PURPOSE ANTENNAS

Many modifications of the basic dipole antenna are employed to meet special requirements and to suit special purposes. Some of the modified forms are shown by Fig.8. The folded dipole may be used in locations where signal field strength is weak and where it is necessary to collect all possible energy. It consists of a long loop lying in a vertical plane, with one side above the other, and with an opening or gap in the lower side to the ends of which are attached the transmission line.

When reception is desired from only one general direction, rather than from the two opposite directions which are possible with the regular dipole, a reflector may be mounted back of the dipole or on the side of the dipole which is away from the stations to be received. The reflector consists of a single conductor, with no center opening, which is supported by insulation and which has no electrical connection with any other parts. The reflector is made of about the same length as the overall length of the dipole antenna conductors. The reflector is mounted about one-quarter wavelength back of the antenna conductors, which means that the spacing from antenna to reflector is about half the overall length of the dipole conductors.

When reception is desired from any and all directions of the compass, it is possible to use two dipoles mounted at right angles to each other to form a four-way arrangement of conductor rods. The double-V antenna, and some other spread-out arrangements of the conductors, may be used when there is to be reception over a very great range of frequencies, as in both the old f-m band centering at 45 mc and also in the new band centering at 98 mc.

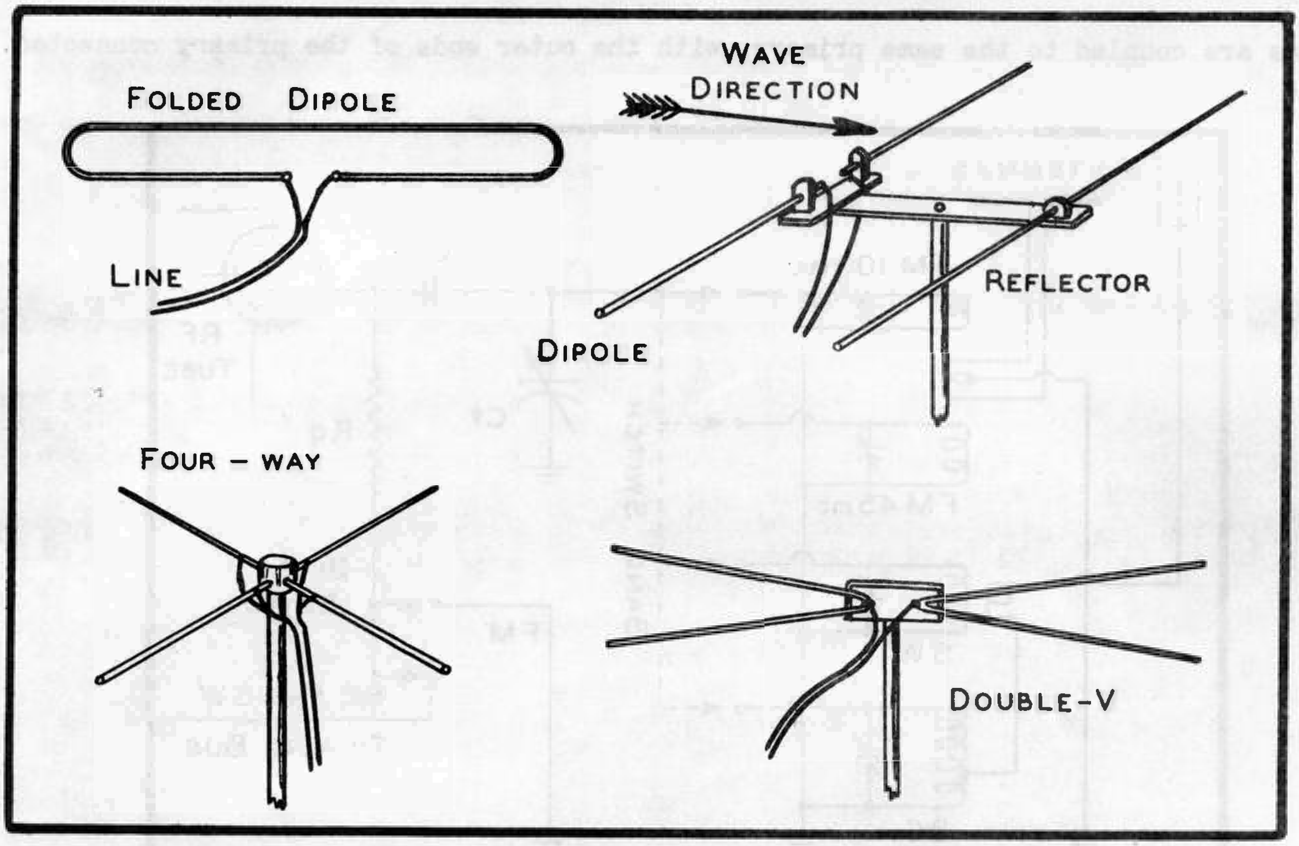

FIG. 8. Modified forms of dipole antennas.

ANTENNA AND R-F STAGE

Very few receivers are designed and built for reception of only f-m signals. Nearly all have provision for reception also in the standard broadcast band. Many are arranged for reception in some of the short-wave bands, especially in bands carrying international broadcasts. A good many receivers provide for reception in both old and new f-m bands; in the one centering at 45 mc and in the other centering at 98 mc.

When reception may be had in two or more frequency bands the band switching arrangements may be more or less complicated. There are no general rules, nor any particular switching arrangements which have been standardized. The exact method of switching has to be learned from a circuit diagram of each receiver or else traced out on the receiver itself.

In some receivers there are separate antenna couplers for each of the frequency bands as shown by Fig. 9. At the top is the coupler for the higher-frequency f-m band, with below it the coupler for the lower-frequency f-m band. Both of these secondaries are coupled to the same primary, with the outer ends of the primary connected

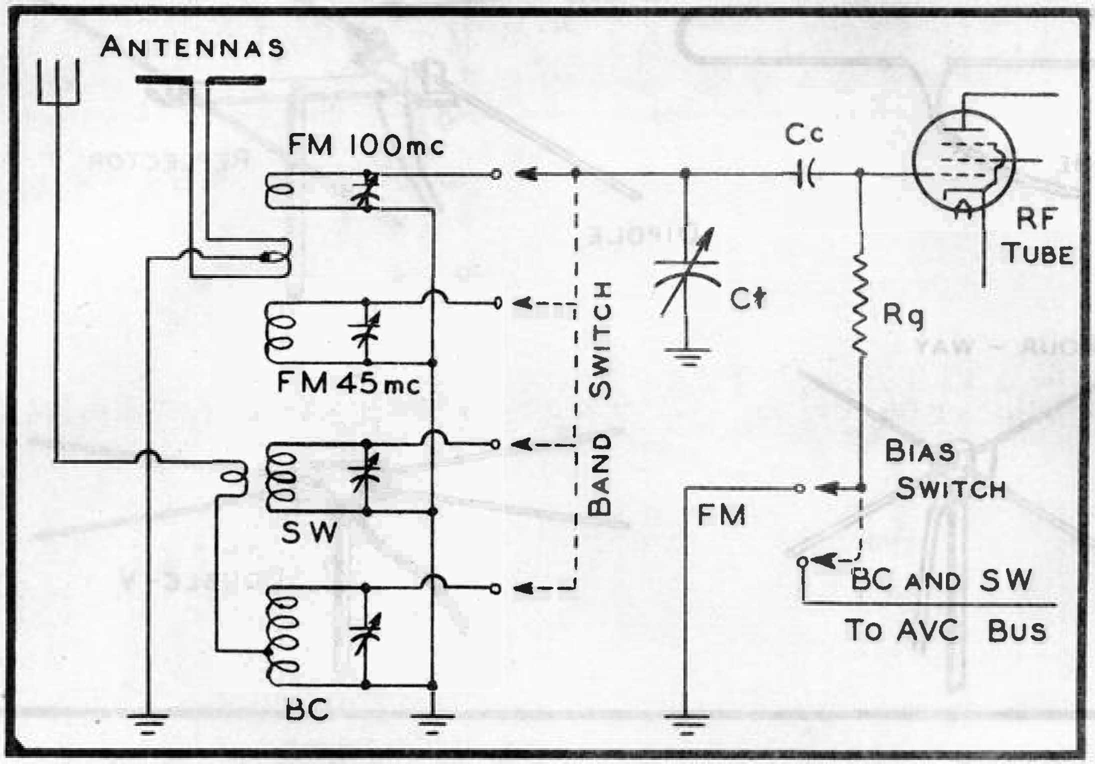

FIG. 9. Separate antenna couplers for each of four frequency bands.

to a dipole antenna and the center tap grounded. The short-wave coupler has its primary winding in series with the external capacitance type antenna. The low reactance of this primary at frequencies in the standard broadcast band allows the lower-frequency currents to go through to the broadcast coupler, through the lowermost turns of this coupler and to ground.

Each of the secondary windings in the couplers has its own trimmer capacitor. By means of the band switch any one coupler may be connected to the main tuning capacitor Ct and through coupling capacitor Cc to the control grid of the r-f tube. Operated as part of the band switch is the bias switch. For the two f-m bands this switch connects the tube grid through resistor Rg to ground, allowing grid rectification bias or grid leak bias by means of capacitor Cc and resistor Rg. For the standard broadcast and the short-wave bands, the tube grid is connected through Rg to the automatic volume control bus. There is no avc action on the f-m bands.

Fig. 10 shows an antenna coupling arrangement for reception in the standard broadcast band and in the old and new f-m bands. The loop antenna is used for standard broadcast pickup, being tuned by means of variable tuning capacitor Ct and adjusted by

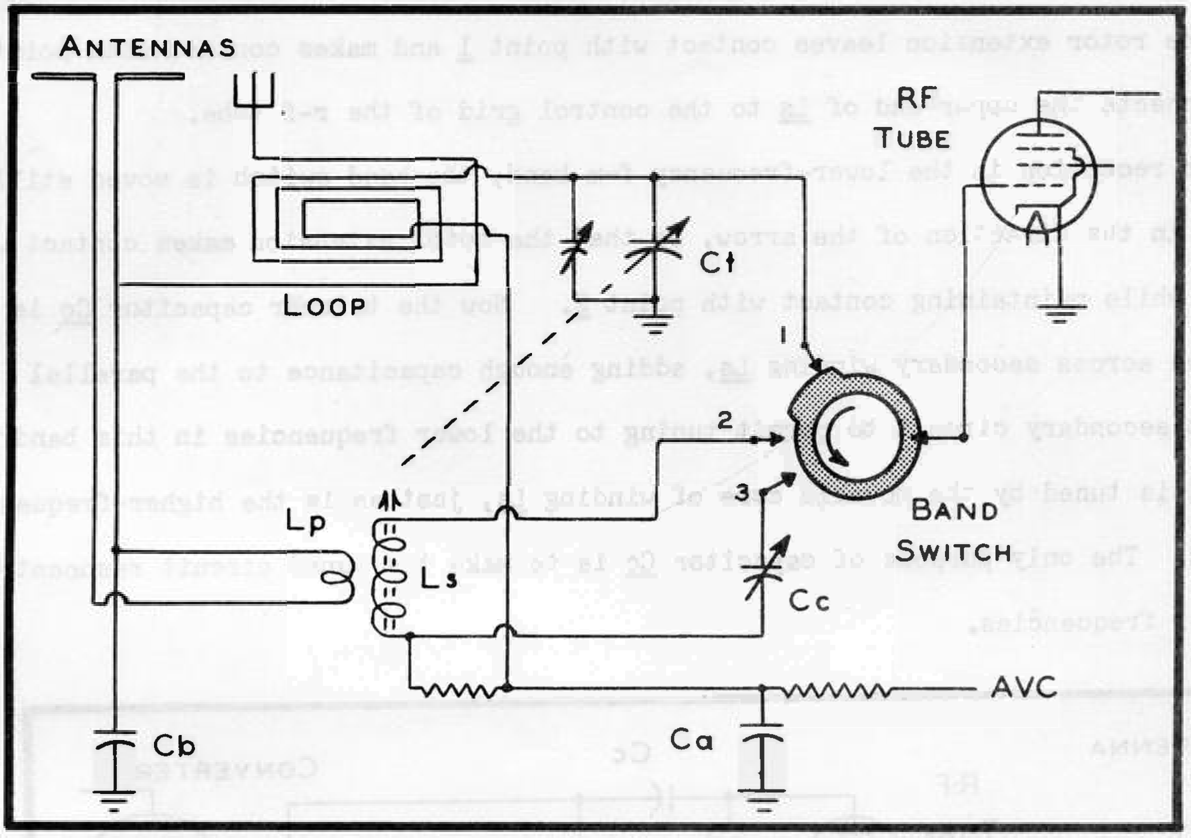

FIG. 10. A loop and a capacitance antenna for a-m reception, with dipole for f-m.

the small paralleled trimmer capacitor. The upper end of the loop is connected through the band switch to the control grid of the r-f tube. The lower end of the loop is grounded to the chassis for r-f potentials through capacitor Ca and is connected to the avc bus, thus permitting automatic volume control of the r-f tube for standard broadcast reception. The external capacitance type antenna may be used when it is desired to have greater pickup of standard broadcast signals. Turns in series with this antenna are around the loop; these turns acting as the primary of a coupler, with the loop as the tuned secondary winding. The capacitance antenna turns connect to the chassis ground through capacitor Cb.

For f-m reception, there is a dipole antenna connected to primary winding Lp, with one side grounded to the chassis through capacitor Cb. The secondary winding, Ls, is tuned by means of a movable powdered iron core which is operated by the panel tuning knob simultaneously with tuning capacitor Ct. This secondary, with its permeability tuning, is used alone for reception in the higher-frequency f-m band. For this band, the band switch rotor is turned in the direction indicated by the arrow until the rotor extension leaves contact with point 1 and makes contact with point 2. This connects the upper end of Ls to the control grid of the r-f tube.

For reception in the lower-frequency f-m band, the band switch is moved still farther in the direction of the arrow, so that the rotor extension makes contact with point 3 while maintaining contact with point 2. Now the trimmer capacitor Cc is connected across secondary winding Ls, adding enough capacitance to the parallel resonant secondary circuit to permit tuning to the lower frequencies in this band. The band is tuned by the movable core of winding Ls, just as is the higher-frequency f-m band. The only purpose of capacitor Cc is to make the tuned circuit resonant at the lower frequencies.

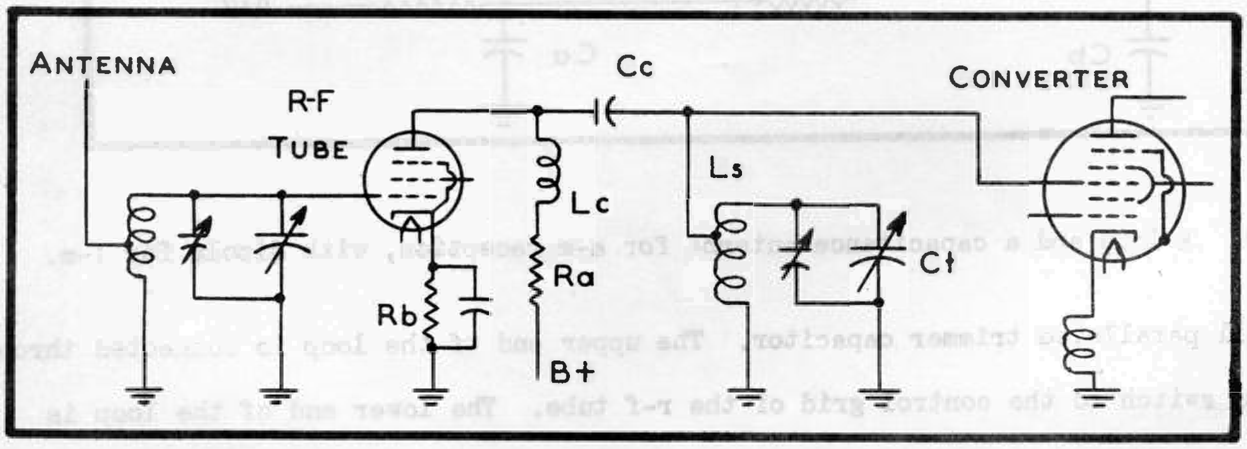

FIG. 11. Interstage coupling with parallel feed to tuned grid circuit.

Fig. 11 shows connections for an r-f amplifier tube with a tuned antenna circuit and with tuned coupling between the plate of this tube and the signal grid of the following converter tube. Coupling from any type of antenna is through the lower part of the tuned winding in the r-f control grid circuit. Note that this r-f tube has selfbias or cathode-bias by means of cathode resistor Rb which is by-passed with a fixed capacitor. Coil Lc is a radio-frequency choke, Ra is a voltage-dropping resistor in the plate circuit, and Cc is a coupling capacitor carrying signal potentials to the signal grid circuit of the converter. The signal grid circuit is tuned by coil Ls and a section of the multi-gang main tuning capacitor which is marked Ct.

The tubes used as r-f amplifiers in nearly all of the later models of f-m receivers are pentodes designed especially for satisfactory operation in the frequencies around 100 megacycles. They are distinguished by exceedingly small internal capacitances between control grid and plate. These tubes are of the semi-remote cutoff type, wherein amplification is reduced by increasingly negative control grid bias in a manner between that found with the remote cutoff types and the sharp cutoff types. The semi-remote cutoff gives good control either with grid-leak bias, cathode-bias, or automatic volume control.

The coils used in tuned antenna coupling circuits and in interstage tuned couplings between r-f and converter tubes for f-m receivers are of small size, have few turns, and have small inductances. Typical tuned coils may have two turns or one and a fraction turns on forms one-half to three-quarters of an inch in diameter. The leads to these coils usually supply an important portion of the total inductance, and, of course, must not be altered during service operations. Typical variable tuning capacitors may have maximum capacitances of 25 micro-microfarads or less, with minimum capacitances of five to eight micro-microfarads. Coils which are tuned by movable powdered iron cores will have more turns than those tuned wholly with variable capacitors, since with the iron-cored tuning coils, most of the capacitance required for resonance will be distributed capacitance between coil turns and in the connections, and capacitance between tube elements to which the coils are connected.

When we know either the inductance or the capacitance in a resonant circuit, the other factor may be determined for any given frequency by using the oscillation constant for that frequency. The oscillation constant for a frequency is a number which may be divided by the capacitance to determine the necessary inductance, or divided by the inductance to find the necessary capacitance. The accompanying oscillation constants, for frequencies in the f-m bands, are for use when the capacitance is in micro-microfarads and the inductance in microhenrys.

OSCILLATION CONSTANTS

Frequency	Constant	Frequency	Constant
86 mc	3.423	40 mc	15.83
88 mc	3.271	42 mc	14.36
98 mc	2.638	45 mc	12.51
108 mc	2.172	48 mc	11.01
110 mc	2.093	50 mc	10.13

As an example, supposing that we wish to have a circuit resonant at a frequency of 88 mc, and we know the capacitance is 30 mmfd., what is the required inductance? The constant for 88 mc is 3.271. Dividing this constant by 30 (the capacitance) gives 0.109 microhenry as the required inductance.

If you have been used to working with capacitances and inductances which tune in the standard broadcast band, or even in the lower frequency short-wave bands, the values of capacitance and inductance for circuits working in the f-m bands seem rather strange. In the standard broadcast band, we are used to working with rather large inductances used with the smallest variable tuning capacitor which will give enough of a change of capacitance to cover the frequency band. The range of the standard broadcast band is from 550 to 1,500 kilocycles, a frequency ratio of 1 to 2.725. To tune through such a ratio of frequencies, either the capacitance or the inductance must be varied in a ratio of about 1 to 7.5. That is to say, if you have a total maximum capacitance of something like 400 mmfd with the tuning capacitor plates turned all the way into mesh, you will have to have a minimum total capacitance, with the plates all the way out, of about 53 mmfd - which we determine from dividing 400 mmfd (maximum) by 7.5 (the required ratio). With an inductance of about 209 microhenrys, this change of capacitance from 400 down to 53 mmfd would tune through the range from 550 to 1,500 kilocycles.

Now let's look at a typical problem in tuning through the f-m frequency range from 88 to 108 megacycles. In order that we may be sure of covering both the lower and upper frequency limits, it will be well to figure capacitance and inductance which will tune through the range from 86 to 110 mc, leaving some leeway at both ends. The principal parts of the tuned circuit are shown by Fig. 12.

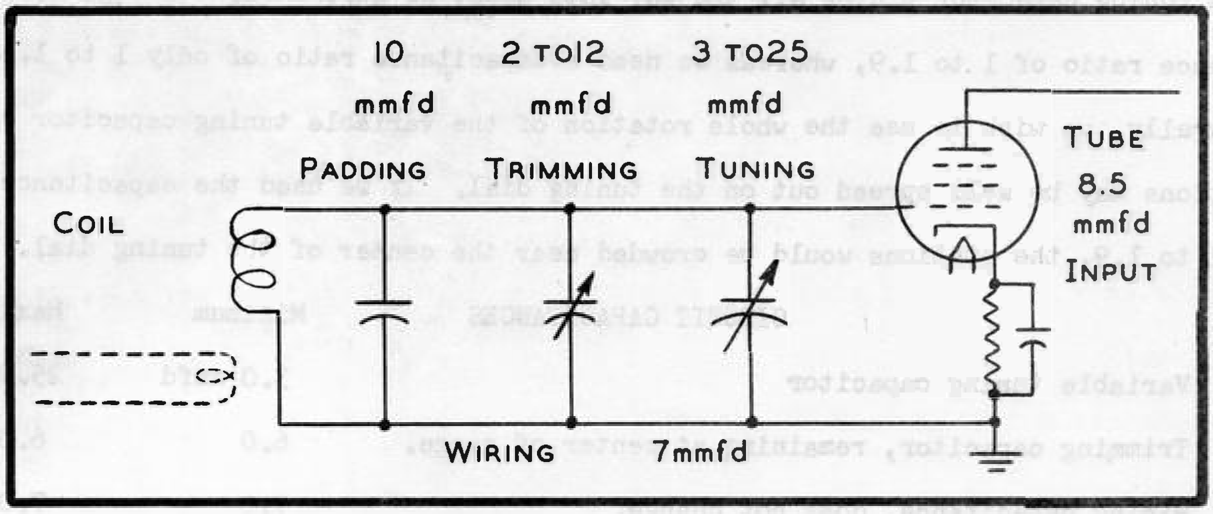

FIG. 12. Tuning elements for resonance from 86 to 110 megacycles.

There is one tuning coil and there are three capacitors; a padding capacitor, a trimming capacitor, and a tuning capacitor. The padding capacitor is used to lessen the variation of capacitance as the variable tuning capacitor is rotated. This is necessary because our ratio of frequency, 86 to 110 mc, is only 1 to about 1.28. The ratio of change of capacitance must be the same as the ratio of the oscillation constants for the upper and lower tuned frequencies. The constant for 110 mc is 2.093, and for 86 mc, it is 3.423. The ratio is 1 to 1.635. Compare these small ratios with the big ones found in the standard broadcast band.

Now we may compute the total maximum capacitance, which will tune to 86 mc, and the total minimum capacitance, which will tune to 110 mc. We shall assume that the trimming capacitor, whose range is 2 to 12 mmfd, is set for 6 mmfd all the time. The distributed capacitance in wiring and connections is taken as 7 mmfd. The tube itself acts like a capacitor across the circuit. Tubes used in f-m receivers have "input capacitances" on the order of 8.5 mmfd, which we shall assume for our circuit.

With the capacitances considered so far, which do not include the padder, we have the minimum and maximum total capacitances shown in the accompanying list. The variable capacitor supplies the only capacitance which is changed. The minimum capacitance, with the tuning capacitor plates all the way out, is 24.5 mmfd. The maximum, with tuning capacitor plates all the way into mesh, is 46.5 mmfd. This gives a capacitance ratio of 1 to 1.9, whereas we need a capacitance ratio of only 1 to 1.635. Naturally, we wish to use the whole rotation of the variable tuning capacitor so that stations may be well spread out on the tuning dial. If we used the capacitance ratio of 1 to 1.9, the stations would be crowded near the center of the tuning dial.

CIRCUIT CAPACITANCES	Minimum	Maximum
Variable tuning capacitor	3.0 mmfd	25.0 mmfd
Trimming capacitor, remaining at center of range.	6.0	6.0
Wiring capacitance, does not change.	7.0	7.0
Tube input capacitance, does not change much.	8.5	8.5
Total circuit capacitance	24.5 mmfd	46.5 mmfd

The next step would be to try various padding capacitances until finding a value which will bring the capacitance ratio to the value we want; 1 to 1.635. It turns out that a 10.0 mmfd padder will be satisfactory. Adding 10.0 mmfd to both the minimum and maximum capacitances will give a new minimum of 34.5 mmfd and a new maximum of 56.5 mmfd. The ratio of these capacitances is about 1 to 1.638, which is close enough.

Next we determine the inductance required in the coil. We have a total of 34.5 mmfd capacitance for tuning at 110 mc. The oscillation constant for this frequency is 2.093. Dividing 2.093 by 34.5 gives 0.0607 as the required inductance in microhenrys. As a check on the computations, we may take the oscillation constant for 86 mc, which is 3.423, and divide it by the maximum total capacitance, 56.5 mmfd, to find a required inductance of 0.0606 microhenrys. The two values of inductance are practically the same. A tuning coil having an inductance of 0.06 microhenry might be made with two turns of wire spread over a length of 5/8 inch on a form 3/4 inch in diameter.

CONVERTERS

Most of the f-m receivers use a converter tube, which is a combined mixer and oscillator, in a circuit following the general principles shown by Fig. 13. The signal grid, which is grid number 3, connects to the output of the preceding r-f stage. The oscillator grid, which is grid number 1, connects through the band selector switch to either of two tuned oscillator circuits, one for f-m reception and the other

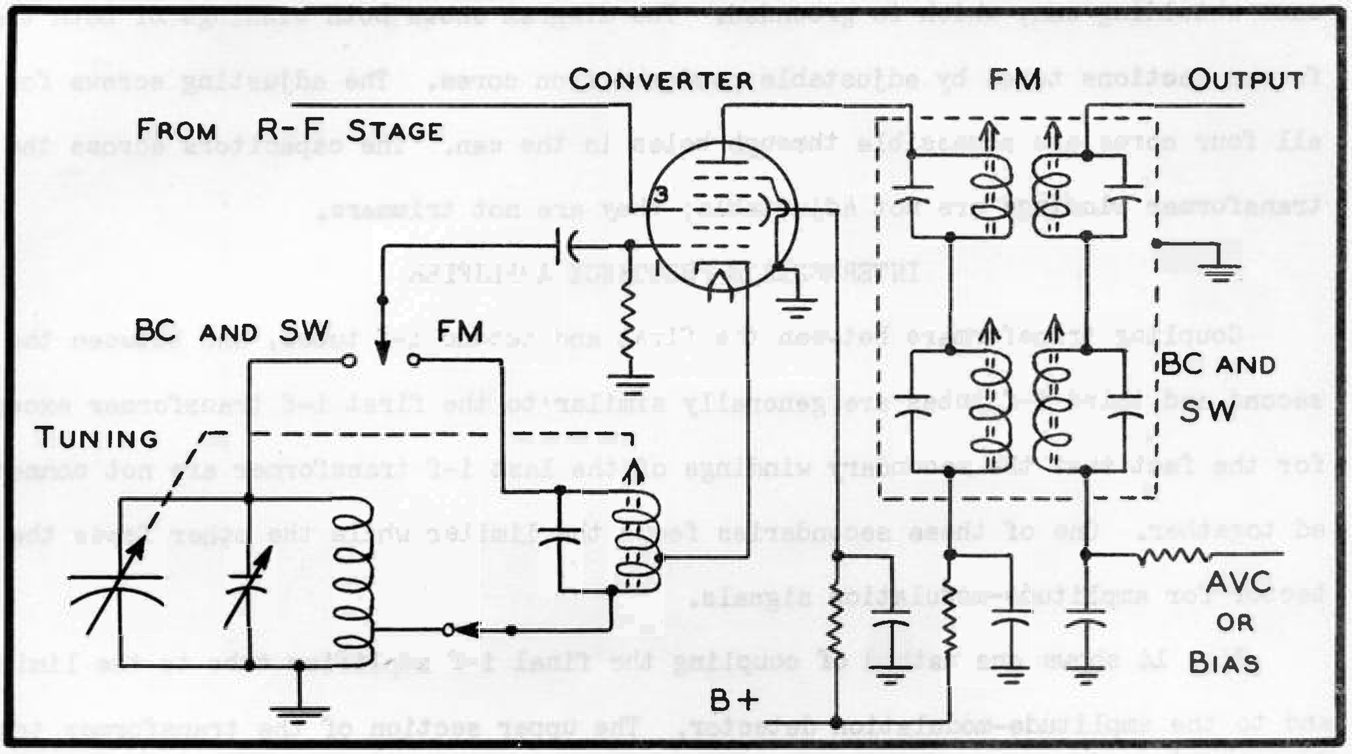

FIG. 13. Connections in the two grid circuits and in the plate circuit of a converter tube.

for standard broadcast and short-wave reception. The broadcast and short-wave circuit is shown in the diagram as being tuned with one section of the main tuning capacitor and a paralleled trimmer capacitor. The f-m oscillator circuit is shown as being tuned with a movable powdered iron core operated from the same tuning control as the capacitor for the other oscillator circuit. Either or both oscillator circuits might be tuned with variable capacitors or with movable iron cores.

In the plate circuit of the converter are the primaries of two double-tuned i-f transformers whose secondaries would be coupled or connected to the control grid of the following i-f amplifier tube. Intermediate-frequency potentials and current at the f-m frequencies, usually eight to ten or more megacycles, act in the upper f-m transformer which is tuned to the appropriate frequency, but pass freely through the lower transformer. The broadcast and short-wave intermediate frequency, usually 455 or 456 kilocycles, passes freely through the upper transformer and acts in the lower one which is tuned to this frequency.

Both i-f transformers or both sections of the dual transformer are housed in the same shielding can, which is grounded. The diagram shows both windings of both transformer sections tuned by adjustable powdered iron cores. The adjusting screws for all four cores are accessible through holes in the can. The capacitors across the transformer windings are not adjustable; they are not trimmers.

INTERMEDIATE-FREQUENCY AMPLIFIER

Coupling transformers between the first and second i-f tubes, and between the second and third i-f tubes are generally similar to the first i-f transformer except for the fact that the secondary windings of the last i-f transformer are not connected together. One of these secondaries feeds the limiter while the other feeds the detector for amplitude-modulation signals.

Fig. 14 shows one method of coupling the final i-f amplifier tube to the limiter and to the amplitude-modulation detector. The upper section of the transformer transfers f-m signals at the f-m intermediate frequency to the limiter stage. The lower section handles the a-m signals, with its secondary connected to the diode plates in the double-diode triode tube which acts as a-m detector (of the diode type), first audio-frequency amplifier, and automatic volume control tube. The negative potential for automatic volume control is taken from one of the diode plates. Since the avc line is connected to only the amplitude-modulation system, there will be appreciable potential only while amplitude-modulated signals are coming through the preceding i-f amplifier. The audio output from the detector goes through a filter and coupling capacitor Cc to the volume control resistor VC. Resistor Rg is for grid rectification biasing of the triod audio amplifier section of the combination tube.

Fig. 15 shows another coupling arrangement between the final i-f amplifier and the limiter and a-m detector. The circuit follows the same general principles as the one in Fig. 14 except that there is a connection from the upper f-m section of the coupling transformer to the avc line. The grid bias of tubes controlled from the avc line is made somewhat more negative by greater amplitude of the f-m signal coming through the i-f amplifier.

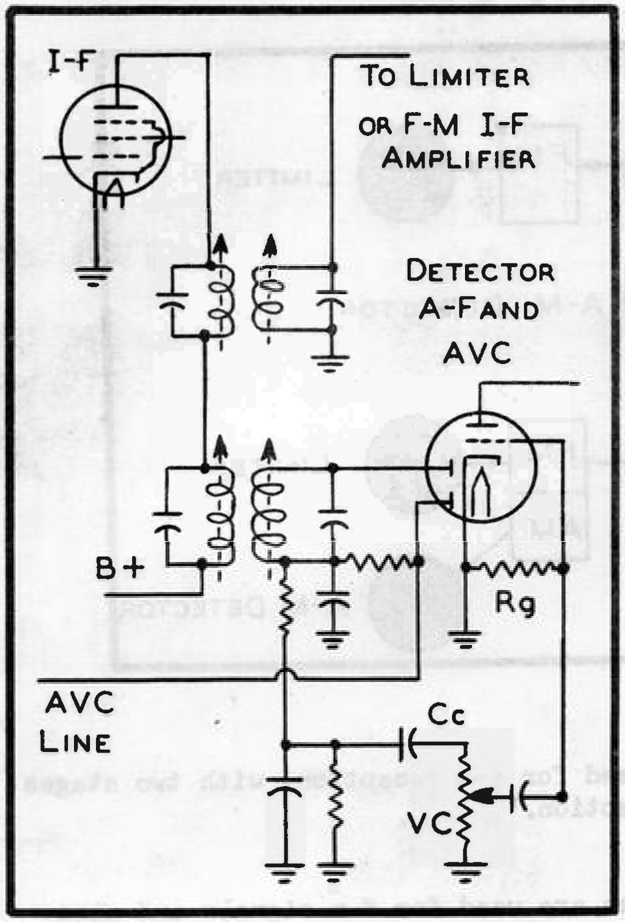

FIG. 14. Coupling from an i-f tube to the limiter and the a-m detector.

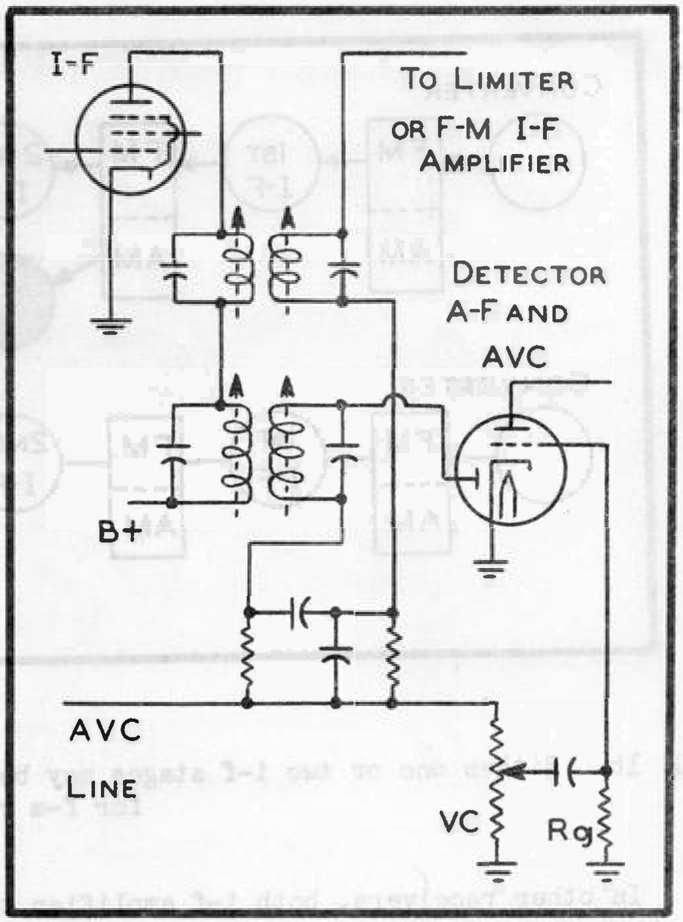

FIG. 15. A second type of coupling from an i-f tube to the limiter and a-m detector.

In some fm-am receivers, as shown at the top in Fig. 16, both the first and second i-f amplifier tubes are used for f-m reception, while only the first i-f amplifier is used for a-m reception. The i-f signal for the a-m detector is taken from the second i-f transformer, for which the connections would be of the general type shown by

Figs. 14 and 15. Then, between the second i-f tube and the limiter tube, there will be a single transformer having only one primary and only one secondary, both tuned for the f-m intermediate frequency.

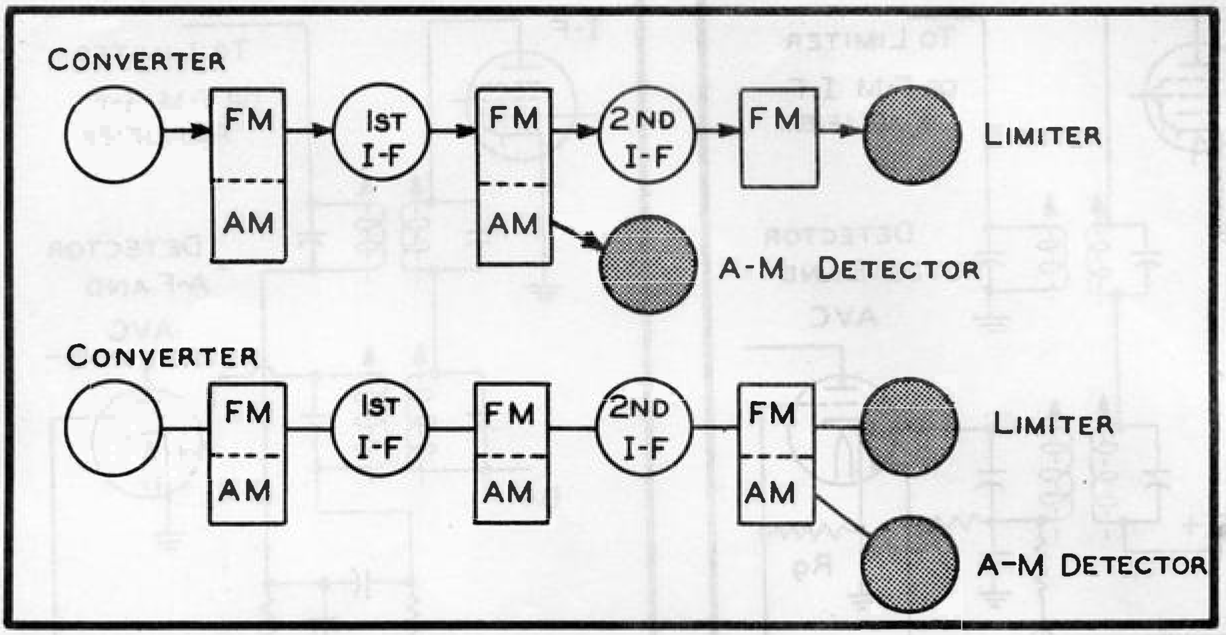

FIG. 16. Either one or two i-f stages may be used for a-m reception, with two stages for f-m reception.

In other receivers, both i-f amplifier tubes are used for f-m signals and also for a-m signals, as shown at the bottom in Fig. 16. Here all three coupling transformers are of the dual type, with connections for the third transformer of the types shown by Figs. 14 and 15. This arrangement provides a two-stage i-f amplifier for both f-m and a-m signals.

The intermediate frequency used for f-m reception usually is chosen so that there can be no reception of signals which are of the image frequency. The image frequency for any given signal frequency is a frequency which differs from the signal frequency by twice the intermediate frequency.

Here is an example. Supposing that we are using an intermediate frequency of 10.7 megacycles and are receiving a frequency of 98.1 megacycles. If the oscillator frequency is being maintained higher than the received frequency, as usually is the

the case, then the oscillator frequency must be 108.8 megacycles, because the difference between this oscillator frequency and the incoming signal frequency is 10.7 megacycles, which is our intermediate frequency. Supposing too that there is another signal at 119.5 megacycles reaching the signal grid of the converter or mixer. The difference between 119.5 megacycles and the oscillator frequency of 108.8 megacycles is 10.7 megacycles. This difference is our intermediate frequency and this other signal will be amplified in the i-f amplifier. The "other signal" at 119.5 megacycles is at the image frequency of the tuned signal at 98.1 megacycles. The image (119.5 mc) differs from the tuned frequency (98.1 mc) by 21.4 mc, and this difference is equal to twice the intermediate frequency of 10.7 mc.

Were the oscillator frequency maintained lower than the tuned signal frequency, the oscillator frequency would be 87.4 mc for a tuned frequency of 98.1 mc and an intermediate frequency of 10.7 mc. Then the image frequency would be at 76.7 mc, which is lower than the tuned frequency by twice the intermediate frequency.

In order that all image frequencies may fall outside of the band of frequencies which may be tuned on a receiver, the intermediate frequency must be something more than one-half of the band width. For the higher-frequency f-m band, the range is from 88 to 108 mc. The band width is the difference between these limiting frequencies, and is 20 mc. Half of 20 mc is 10 mc, and so the intermediate frequency should be more than 10 mc.

Were the receiver tuned to the bottom of the band, 88 mc, and were the intermediate frequency 10 mc, the upper image would be at 20 mc above 88 mc, which is at 108 mc. This image is right at the top of the band. Were the intermediate frequency anything greater than 10 mc, the upper image would fall higher than the top of the band, and could not be tuned in. Similarly, when tuned to the top of the band, 108 mc, the lower image frequency will be below the bottom of the band with any intermediate frequency greater than 10 mc, which is half the band width.

With the older f-m band of 42 to 50 mc, the band width is 8 mc. Half the width is 4 mc. Any intermediate frequency greater than 4 mc will prevent image interference.

An intermediate in general use for the older band was 4.3 megacycles.

Of course, the intermediate frequency may be any amount greater than half the band width and still prevent image interference. Image interference is greatly reduced by having a tuned r-f stage between the antenna and the converter. With both the antenna circuit and the interstage coupling from i-f tube to converter tuned to the desired signal frequency, there is little chance of a signal at an image frequency coming through to the converter with much strength.

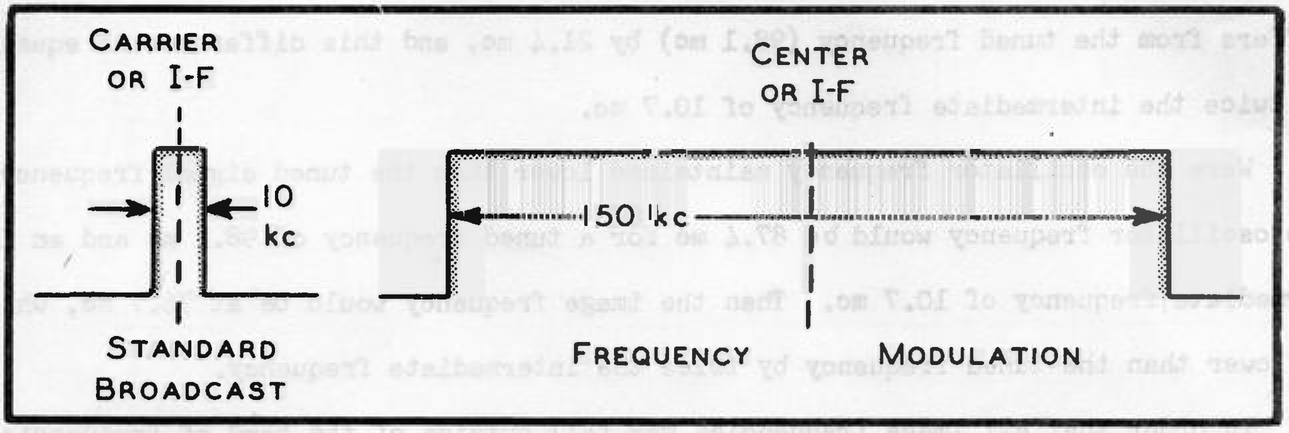

FIG. 17. Relative i-f amplification band widths for standard broadcast and for f-m reception.

The i-f amplifying system for f-m reception must provide fairly uniform amplification for a range of frequencies much greater than need be handled for amplitude modulation. Most of the standard broadcast channels are only 10 kc wide, which calls for fairly uniform amplification to only 5 kc each side of the carrier frequency or, in the i-f amplifier, each side of the intermediate frequency. For maximum deviation of 75 kc either way from the center frequency with f-m reception, the i-f amplifier has to do a good job over a range of twice 75 kc or a total of 150 kc. The relative band widths to be amplified are shown by Fig. 17.

The voltage input to the limiter, and the output from the i-f stages, might be somewhat as shown by Fig. 18. This is the familiar double-hump resonance curve of amplification or gain produced by transformers having both primary and secondary tuned to the same frequency and with rather close coupling between primary and secondary.

The gain in percent, and the resulting limiter input voltage, are quite uneven over the range covered by deviation below and above the center frequency or intermediate frequency which is represented by zero deviation. There is a peak of about 95 per cent near a negative deviation of 40 kc., a slightly lower peak at a positive deviation of 40 kc, and a dip down to about 82 per cent at the center frequency. At the usual maximum deviations of 75 kc each way from the center frequency, there is a gain of about 70 per cent.

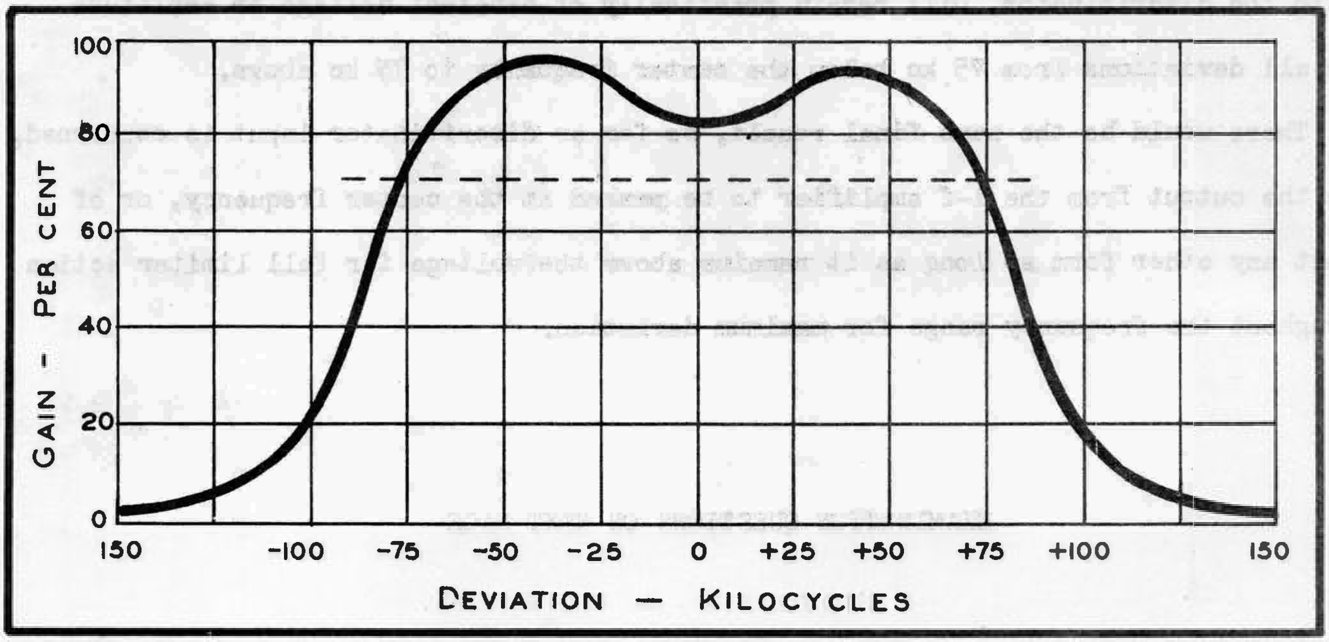

FIG. 18. A graph of voltage variations with frequency at the output of the i-f amplifier, and the manner in which the limiter levels its own output.

Let's assume that with the gain of 70 per cent on the graph of Fig. 18, the input to the limiter is 10 volts. Then let's adjust the operating voltages and the automatic grid bias of the limiter so that there is full limiting action with an input of 10 volts. This means that, with any input greater than 10 volts, the output from the limiter will exceed 10 volts hardly at all.

Going back to the graph of Fig. 18, we observe that with all deviations up to 75 kc on both sides of the center frequency, the gain is more than 70 per cent. Consequently, with all such deviation frequencies, the input to the limiter will be 10 volts or more, and the output from the limiter for this whole range of deviations will remain at almost exactly 10 volts. In effect, we have cut off the top of the gain curve along the broken line on the graph, and the output from the limiter, which is the input to the discriminator, will remain practically of constant voltage or amplitude with all deviations from 75 kc below the center frequency to 75 kc above.

There would be the same final result, so far as discriminator input is concerned, were the output from the i-f amplifier to be peaked at the center frequency, or of almost any other form so long as it remains above the voltage for full limiter action throughout the frequency range for maximum deviation.

EXAMINATION QUESTIONS ON NEXT PAGE