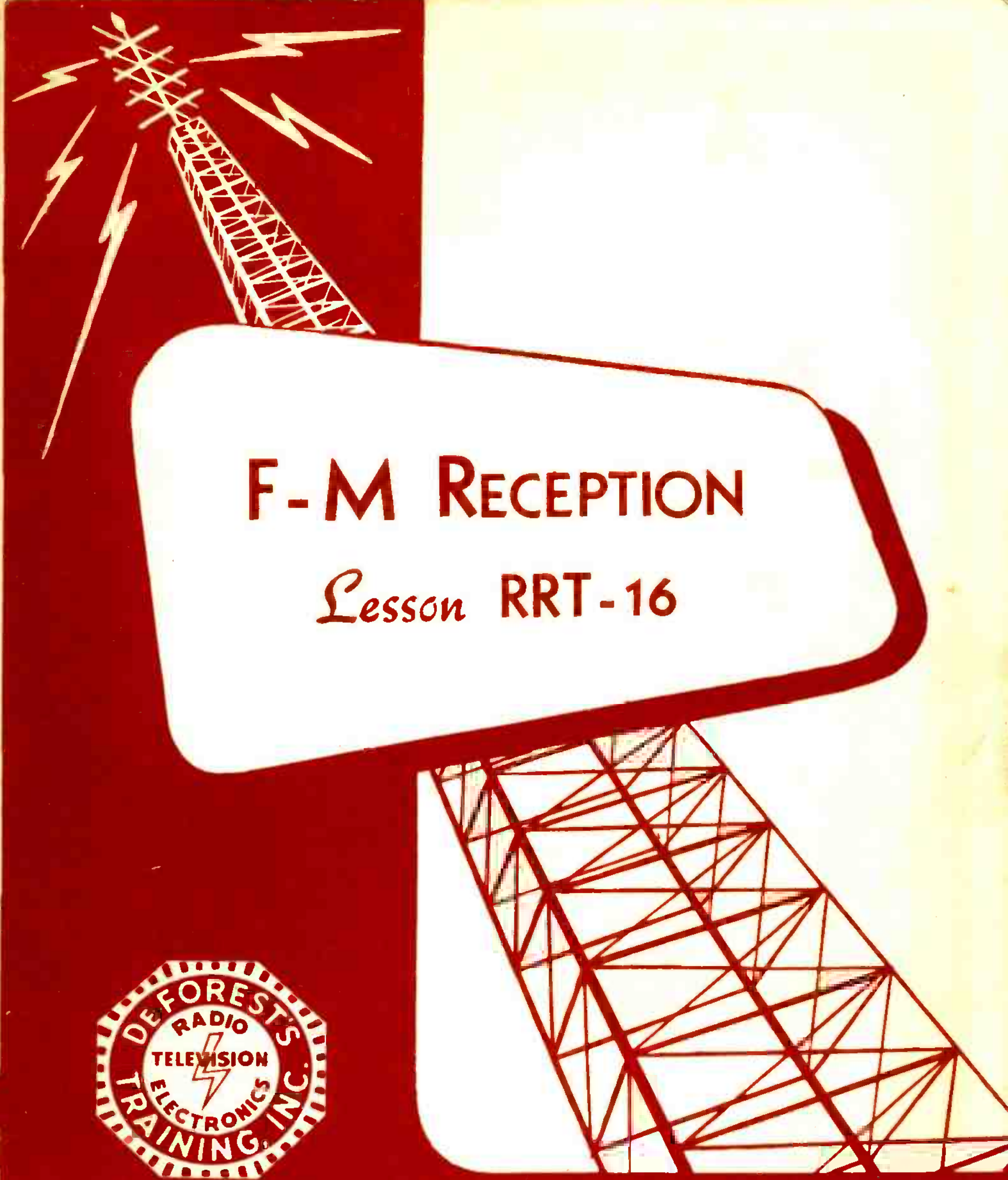

F-M RECEPTION

Lesson RRT-16

DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

RRT-16

Radio Reception
and Transmission

LESSON RRT-16

F-M RECEPTION

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1927—The first conversation was carried on, via radio, between an engineer in a locomotive and a brakeman in a caboose 1¼ miles away.

1927—The pentode radio tube was developed. Also, the world's first successful short-wave long-distance broadcast was made.

1928—Television images were transmitted successfully across the Atlantic by Baird.

1928—Radio Station WGY broadcast the first television play, "The Queen's Messenger". WGY then became the pioneer television station with a regular broadcast schedule. Also, E. F. Anderson made the first successful demonstration of television reception in the home.

DE FOREST'S TRAINING, INC.
2533 N. ASHLAND AVE., CHICAGO 14, ILLINOIS

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-16

F-M RECEPTION

INDEX

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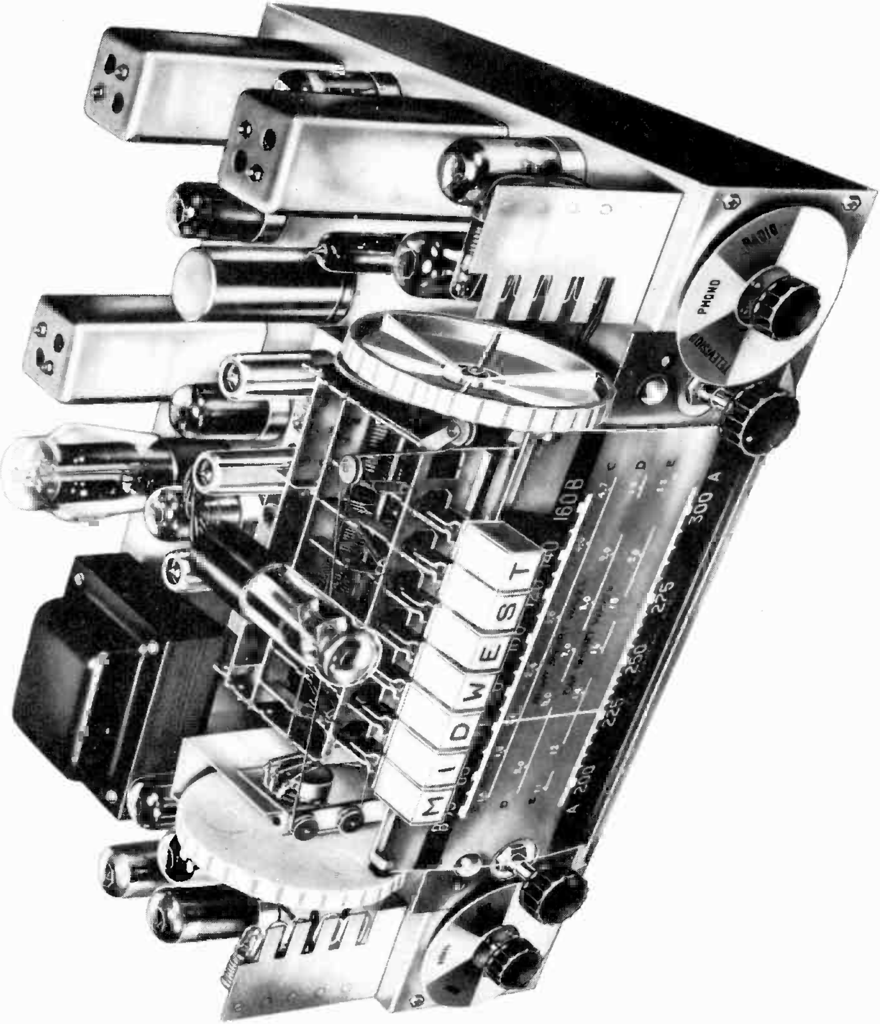
HARNESSING MOODS

"Moods are expensive luxuries," says an inscription in Chester Cathedral's cloister. But though moods may sometimes be costly, they can be harnessed with good effect, and the right kind of mood can often be created by self-treatment for every kind of task. The important thing is always to feel at one's best, which really means self-adjustment. And the man who learns this art of self-adjustment is master of every situation.



Modern F-M, A-M, and short-wave receiver chassis.
Courtesy Midwest Radio & Television Corporation

F-M RECEPTION

THE SUPERHETERODYNE F-M RECEIVER

While it is possible to adapt trf and regenerative receivers for f-m reception, practically all modern f-m receivers are of the superheterodyne type, in order to provide maximum sensitivity and selectivity at the high frequencies of the f-m broadcast carriers.

In external appearance, there is little difference between the more numerous a-m receivers and the later types of f-m receivers therefore, the block diagrams of Figure 1 have been drawn to aid in making a more detailed comparison. The blocks of Figure 1A represent the sections or stages of an a-m superheterodyne receiver while the blocks of Figure 1B represent the sections or stages of an f-m superheterodyne receiver.

Starting at the left, the first three blocks of both receivers are identical and the antenna connects to an r-f amplifier. In both cases, this preliminary r-f amplifier is not included in all models and when omitted, the antenna connects directly to the mixer. In the mixer, the incoming modulated carrier and local oscillator output heterodyne to provide the lower intermediate frequency which carries the modulation of the carrier. From the output of the mixer, the modulated intermediate frequency passes through one or more stages of the i-f amplifier.

In the a-m receiver of Figure 1A, the output of the i-f amplifier is impressed across the detector or demodulator circuit and the resulting audio or signal frequencies are then carried through the a-f amplifier, the output of which drives the speaker. The functions of these various "blocks" have been explained in detail in the earlier lessons therefore we will not repeat.

In the f-m receiver of Figure 1B, the output of the i-f amplifier is carried over to the limiter, a block which does not appear in the a-m receiver. The modulated f-m carrier has uniform amplitude but, between the transmitting and receiving antennas, it may be amplitude modulated by "static" or other types of interference which would produce noise in the speaker. Therefore, the function of the limiter is to remove any variations of amplitude which may be present in the i-f amplifier output.

The output of the limiter connects to the f-m detector which performs the same overall function as the a-m detectors but operates on a different principle. Here, the modulation is in the form of frequency variations which the f-m detector must convert into a voltage with corresponding variations of amplitude. As in the case of a-m receivers, there are a number of different types but the basic requirement of every f-m detector system is that its output consist of a voltage with amplitude variations proportional to the amount of deviation of the f-m carrier, and with a frequency equal to the rate of carrier deviation.

Folded dipole f-m antenna installed on roof of home.
Courtesy The Ward Products Corporation

Finally, since modulation frequencies as high as 15,000 cycles per second are used in f-m systems, the receiver of Figure 1-B must contain an audio amplifier and loud speaker of the high fidelity type, so that full advantage can be taken of the wide range of audio frequencies that are transmitted. Because the corresponding circuits of the f-m receiver closely resemble the previously described circuits of the a-m receiver, to continue the comparison between them, we will start at the f-m antenna and follow the path of the signal. At each important point, variations due to the type of modulation or the higher frequencies of the f-m carriers will be explained in detail.

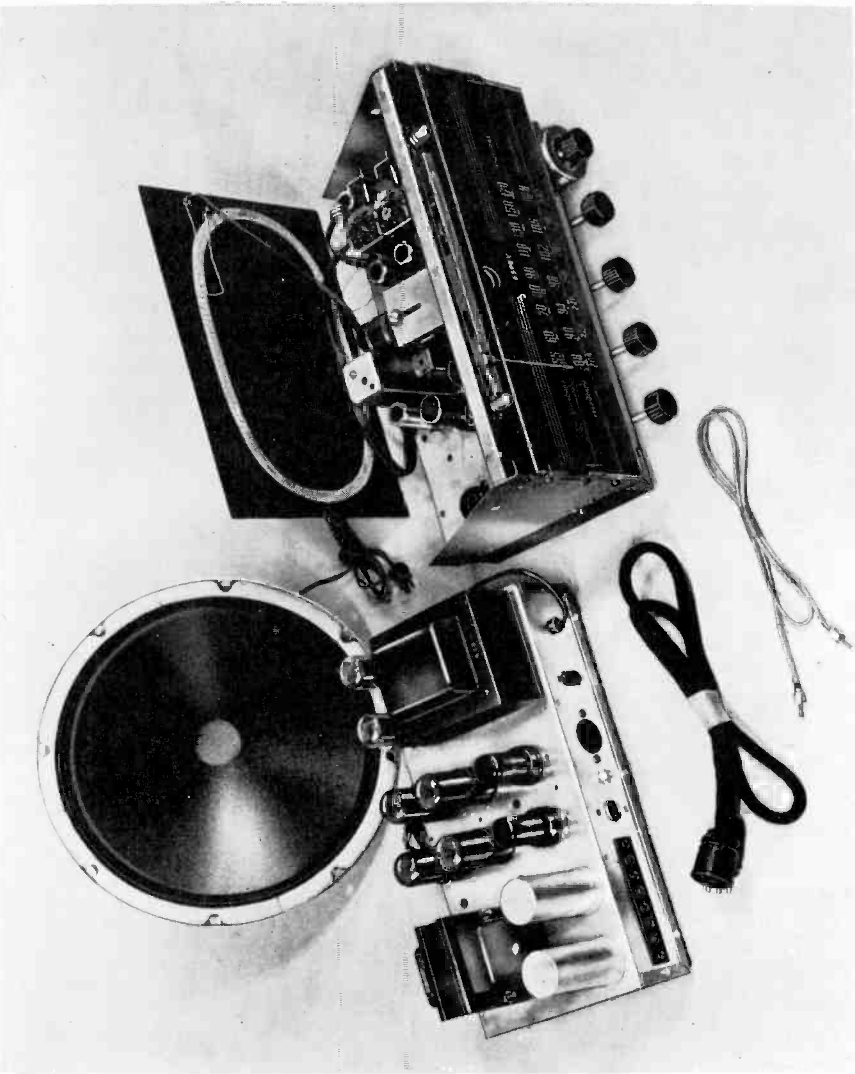
F-M ANTENNAS

Because the f-m broadcast band lies in the very high-frequency region, generally it is necessary to employ a highly efficient receiving antenna. It is possible to use "indoor" antennas, or to pick up the signal energy from the power lines in particular cases where the receivers are located fairly close to powerful local transmitters. However, in most instances, the transmitting distance is sufficiently great, or the receiver is shielded by intervening steel buildings or other obstructions, so that a good antenna is necessary to provide the receiver with a signal input of sufficient strength to over-ride the noise pickup. Also, in some cases it is necessary that the antenna possess directional characteristics in order to minimize the reception of unwanted signals as well as noise.

A number of f-m antenna arrangements are in common use, the simplest of which is the half wave dipole illustrated in Figure 2A. This consists of two wires or rods, placed end-to-end but not touching, with their combined length equal to that of one-half wave at the frequency of the carrier to be received. The separation, s, indicated between the inner ends of the dipole rods, is approximately one inch. While their length determines the resonant frequency, the diameter of the dipole elements affects the bandwidth to which the antenna responds, the greater the diameter, the broader the band.

The dipole antenna pickup varies from maximum, for signals arriving from directions at right angles to its length, to minimum for signals arriving from directions parallel with its length. Because of this directional characteristic, during installation it is desirable to rotate the antenna until it is oriented broadside to the direction from which maximum pickup is desired.

The choice of this direction is dictated by the particular circumstances of each individual case: 1. reception may be desired from a certain station more than from any other; 2. due to distance or others factors, the signal from a certain station may be very weak; 3. a strong local station may interfere with a weaker station, in which case the orientation may have to be such that one end of the dipole points directly toward the strong station, even



F-M and A-M tuner, amplifier, and power supply.
Courtesy Espey Manufacturing Company

though the direction toward the weak station is then not exactly at right angles to the antenna length; 4. a certain station may be received best by making use of a reflected wave.

The antenna can be tuned to the carrier frequency of the station most desired by cutting the dipole rods to the proper length, but, as the electrical equivalent of an LC circuit, it tunes broadly over a band of frequencies. However, its center or resonant frequency can be located at any desired point in the range (88-108 mc) allocated to f-m, by cutting the elements so that the overall length L is equal to:

$$L = \frac{468}{F} \text{ feet.} \qquad (1)$$

when

F = the resonant frequencies in megacycles.

For example, if F is chosen near the center of the band, say 100 mc, then the total length, L, Figure 2A, is equal to 468 ÷ 100 or 4.68 feet.

When an additional element is placed parallel to the dipole, as shown in Figure 2B, it has a considerable effect on the antenna response characteristic. If this element is made about 5% longer than the dipole, the pickup is increased greatly from the direction indicated by the arrow, and the element is called a "reflector". The reflector, spaced ¼ wavelength (.25λ) from the dipole, also acts to attenuate the pickup from the direction opposite to that indicated by the arrow. This increase in pickup ability and change in directivity make the dipole-reflector type of antenna especially useful where difficult problems of interference, etc., present themselves.

If the added element is made about 4% shorter than the dipole, it becomes a "director", and the directional properties of the assembly are the opposite of those described for Figure 2B. When even greater signal pickup capability is required, or where interference problems are especially severe, an assembly employing both a director and a reflector can be used, as shown in Figure 2C. Here again, the pickup is greatest for signals coming from the same side as the director, and is greatly reduced for signals coming from the side on which the reflector is located. These added elements are not connected to the dipole or the receiver in any way, their action being due to their length, as mentioned, and inductive coupling controlled by their spacing from the dipole.

The importance of the directional characteristics of the dipole antenna can be illustrated by the quite common conditions of Figure 3. Here, the direct path between the transmitter and receiver is blocked by an obstruction such as a tall building or hill. As explained previously, the high frequency f-m carrier can be received mainly by a line of sight path therefore, in Figure 3, the direct wave signal will be weak or blocked entirely. Due to its "quasi-optical" properties, the high frequency carrier can be reflected from any substantial surface, similar to that of the obstruction, and as shown, by orienting the dipole so that it is broadside to the reflected wave, the signal may be received satisfactorily.

The antenna arrangements illustrated in Figure 2 are basic, but there are many variations in commercial use, one of the most popular of which is the "folded dipole", with the general shape shown in Figure 4A. This form has greater pickup than the simple dipole, and its total length L can be calculated by means of formula (1) given above. The folded dipole has the same directional properties as the single dipole, and likewise can be used in conjunction with additional elements such as the reflector shown in Figure 4B.

In effect, all of these special forms of antennas are the equivalent of a circuit, tuned to resonance at the carrier frequency and, as such, provide a greater input signal for the receiver. This is due to the resonant conditions in a tuned circuit as explained in the earlier lessons.

TRANSMISSION LINES

In order to obtain full benefit of the energy induced in the antenna, it must be connected to the receiver input so as to provide maximum transfer of energy, together with minimum noise pickup. This transfer of energy is the function of the transmission line, or what is known commonly as the lead-in, connected between the antenna proper and the receiver input circuit. The two types in most common use at the present time are the twin-lead and coaxial cable, cross-sections of which are shown in Figures 5A and 5B respectively.

The twin lead of Figure 5A consists of a pair of parallel conductors encased in some type of non-conductive coating or ribbon; while the coaxial cable of Figure 5B consists of a solid conductor which is held at the center of a hollow cylindrical conductor by means of insulating beads or other filling. Because the outer conductor also acts as a shield, the coaxial line is superior as far as noise pickup is concerned. A more expensive shelded twin-lead type of line also is available, but the cable in Figure 5B causes less attenuation of the signal due to the electrical characteristics provided by the coaxial construction.

In order to accomplish the most efficient transfer of energy, the transmisssion line must provide correct impedance matching between the antenna and the line and also between the line and the receiver. The characteristic impedance of the single dipole in Figure 2A is about 72 ohms, while that of a folded dipole is 300 ohms. Most commercial broadcast f-m receivers have a 300 ohm input impedance, although some have a 72 ohm input. Both twin-lead and coaxial cables are available in a variety of surge impedance values, and thus the matching problem is that of choosing the proper line to connect between a 72 or 300 ohm antenna and a 72 or 300 ohm receiver input circuit.

If the antenna has the same impedance as the receiver input circuit, they can be connected directly by a lead-in of the same characteristic impedance value. However, to connect a 72 ohm dipole antenna to a receiver having a 300 ohm input impedance, it is advisable to use a "matching section" as shown in Figure 6. This section consists of a transmission line of one-quarter wavelength, at the resonant frequency to which the antenna is tuned, with an intermediate value of impedance, as determined by the formula:

$$Z_m = \sqrt{Z_A \times Z_L} \qquad (2)$$

when:

Z_A = **the impedance of the antenna**

Z_L = **the characteristic impedance of the line.**

The antenna, transmission line, and receiver input impedance values can be obtained from the manufacturer's specifications for the particular units in question.

For the conditions of Figure 6, assume the 72 ohm dipole is cut for a frequency of 100 mc. Then,

$$\text{Wavelength} = \frac{300}{\text{mc}} = \frac{300}{100} = 3 \text{ meters}$$

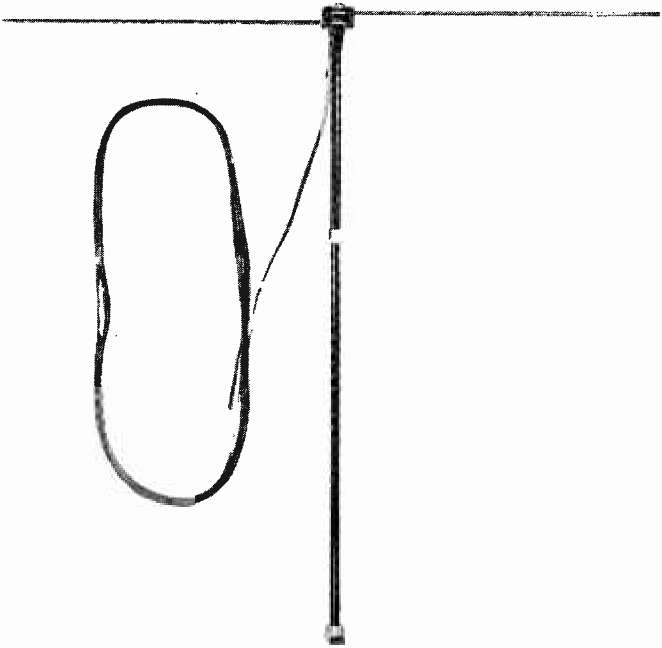
As one meter equals 39.37 inches, three meters equal 3 x 39.37 = 118.11 inches as the wavelength. For ¼ wavelength, the section should be 118.11 ÷ 4 = 29.53 inches long. To match the 72 ohm and 300 ohm impedances, its characteristic impedance should be,

$$Z_m = \sqrt{Z_A \times Z_L} = \sqrt{72 \times 300}$$
$$= \sqrt{21{,}600} = 147 \text{ ohms}$$
$$= 150 \text{ ohms (approx.)}$$

R-F AMPLIFIER

Because of the low level of the signal voltage in the high-frequency input circuits of an f-m receiver, usually an r-f amplifier stage is employed to improve the signal-to-noise ratio. In every receiver, f-m or a-m, a source of random noise voltage is the emission of electrons in groups, rather than in a steady stream, from the cathodes of the tubes. Also, the plate current of an electron tube varies continuously due to the fact that it consists of the bombardment of the plate by a hail of separate particles (electrons) rather than a smooth continuous flow. These plate current variations create small fluctuating voltages across the plate load, and are often called the "shot effect". Still other plate current fluctuations are caused by variations of the ratio in which the emitted electrons are divided among the plate, screen grid, and any other collecting electrodes of the tube.

The randomly changing output voltages, due to these causes are called "tube noise", and add to any other noise voltages present in the circuit. The amount of tube noise is especially important in the first stage of a receiver because here its amplitude is comparable with that of the weak input signal. Since the following stages amplify the first-stage tube noise by the same amount as the signal, it is in the first stage that the



Simple dipole f-m antenna with twin-wire leadin cable.
Courtesy The Ward Products Corporation

receiver signal-to-noise ratio is established. In later stages, the level of the generated noise voltages is insignificant compared to that of the amplified signal.

When a tube is operated as a mixer, the tube noise it produces is greater than when it is used as an amplifier, therefore, a better signal-to-noise ratio is obtained when the first stage of a receiver is an r-f amplifier. Even though a higher overall receiver gain would be provided by the addition of a stage of i-f amplification, the r-f stage is preferred because of the resulting improvement in signal-to-noise ratio.

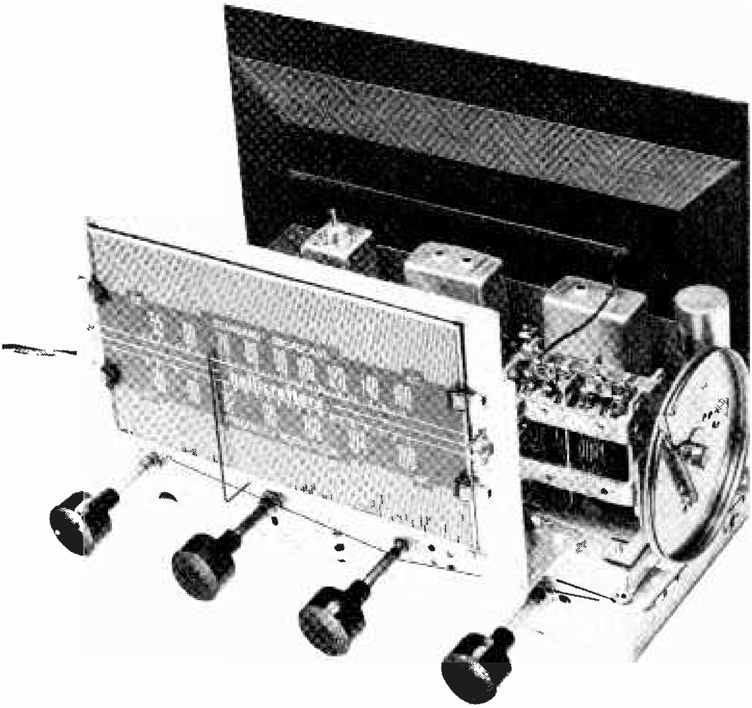
As in the a-m superheterodyne receiver, other advantages provided by the r-f amplifier are that the additional tuned circuit aids in the rejection of image and intermediate frequency signals, reduces radiation of the local oscillator and, by adding to the overall receiver gain, reduces the amount of gain required in the mixer and i-f stages.

MIXER AND OSCILLATOR

At the higher carrier frequencies employed in f-m, separate mixer and oscillator tubes generally provide greater oscillator stability than the single converter tube method, in which there is a tendency for interaction between the oscillator and r-f input sections. Whatever arrangement is employed, it is important that the i-f output of the mixer circuit have as high an amplitude as possible, with respect to the other output frequencies, so that it can be separated easily by the following i-f tuned circuits. Therefore, the mixer or converter tube should have a high "conversion transconductance", which is defined as the ratio of the i-f current in the mixer plate circuit to the r-f voltage applied to the signal input grid.

The output of the oscillator should be as large as possible, without overloading the mixer, and should be very stable in regard to amplitude and frequency over the range that it must tune. The frequency of the oscillator may be either above or below that of the incoming carrier by the amount of the desired intermediate frequency. For example, if the carrier has a frequency of 90 mc, and an i-f of 10.7 mc is required, the oscillator may operate at either 79.3 mc or 100.7 mc when that particular station is tuned. The choice of operating the oscillator above or below the carrier lies with the designer because each system has its advantages, and both have been used in the various makes of f-m receivers.

The standard broadcast band extends from 550 kc to 1600 kc, and an i-f of 455 kc is used in most receivers. In this case, if the oscillator were to operate below the carrier, it would have to tune from 550 − 455 or 95 kc to 1600 − 455 or 1145 kc. This would require the oscillator coil and condenser combination to tune from the highest frequency of 1145 kc to the lowest of 95 kc, a ratio of more than 12 to 1, but most LC tuning combinations have a maximum tuning ratio of only about 3 to 1. However, if the oscillator operates above the carrier, its range of frequencies must be from 550 + 455 or 1005 kc to 1600 + 455 or 2055 kc. In this case, the oscillator tank circuit tunes easily over its required range, 2055 kc to 1005 kc, as the ratio is only slightly greater than 2 to 1.



Frequency modulation and standard broadcast receiver.
The Hallicrafters Company

At the higher carrier frequencies used in f-m broadcasting, 88 mc to 108 mc, this tuning ratio problem is of slight importance.

For example, with the 10.7 mc i-f commonly employed at present, an oscillator working below the carrier will tune from 77.3 to 97.3 mc, while one operating above the carrier will tune from 98.7 to 118.7 mc. For each case, the required tuning ratio is much less than 2 to 1.

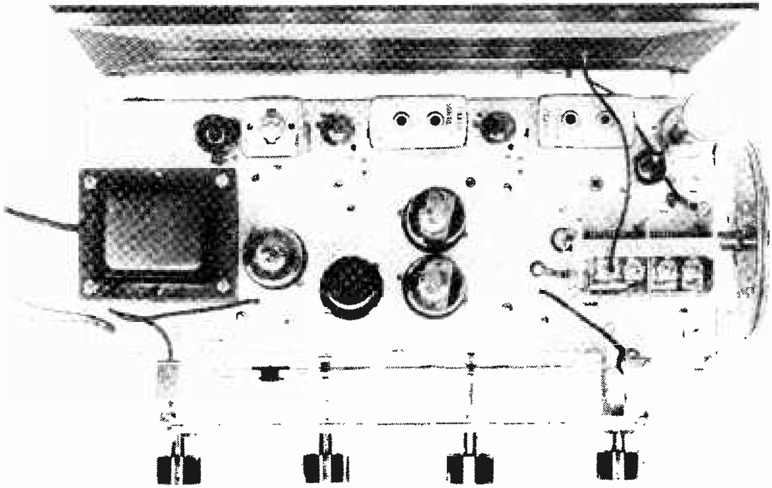
With the oscillator frequency higher than the carrier, it is easier to obtain good tracking over the tuning range. By this is meant that the various tuned-circuit LC values can be chosen so that, at all settings of the tuning dial, the difference between the oscillator frequency and the resonant frequency of the input tuned circuit, is equal to or very closely approximates the exact i-f of the receiver. The deviation from perfect tracking is likely to be somewhat greater when the oscillator works below the carrier frequency. On the other hand, the oscillator will have greater stability at the lower frequencies, therefore favoring operation below the carrier frequency. The maximum acceptable amount of oscillator drift, after warm up, has been found to be 10 kc. At an oscillator frequency of 97.3 mc, this represents a percentage drift of 0.0102%, whereas at 118.7 mc, 10 kc represents a maximum drift of 0.0084%. Though the difference in these percentages is slight it amounts to 22% of the lower value and is important in the practical design of high-frequency oscillator circuits. Still another factor which influences the choice between oscillator frequencies, higher or lower than the carrier, is the problem of image frequencies.

F-M RECEIVER INPUT CIRCUIT

A typical f-m receiver input circuit, including antenna, r-f amplifier, oscillator, and mixer stages, is shown in the simplified schematic diagram of Figure 7. A transmission line connects the dipole antenna to the untuned primary of input transformer T_1 the secondary of which, tuned by C_4, is connected across the control grid circuit of the r-f amplifier V_1. Condenser C_1, with negligible reactance at the carrier frequency, prevents the avc voltage from being grounded through the secondary.

The tuned circuit L_2-C_5 is shunt fed through the plate choke, L_1 and condenser C_2 and the amplified carrier voltage developed across it is applied to the control grid of the mixer tube V_3. The d-c grounding of the plate of V_1 and the grid of V_3, through L_2, is prevented by condensers C_2 and C_3 respectively.

Tube V_2 operates as an electron-coupled Hartley oscillator with the tank circuit L_3-C_6 and the high-frequency output at the plate is coupled through condenser C_7 to the control grid of mixer tube V_3. Thus, the mixer grid voltage varies in accordance with both the carrier and oscillator frequencies, and the intermediate frequency, equal to their difference, is developed across the tuned primary and secondary of transformer T_2.



Top view of chassis shown in previous illustration.

The Hallicrafters Company

Considering T_2 as the first i-f transformer, the circuits of Figure 7 compare very closely with comparable stages of an a-m broadcast type of superheterodyne receiver. However, the f-m receiver signal circuits not only operate at much higher frequencies but must provide good response over a much wider band. The a-m standard broadcast band is centered approximately at 1000 kc or 1 mc and each station has a 10 kc channel. The f-m broadcast band is centered approximately at 100 mc and each station has a 200 kc channel. These differences are not apparent in a schematic circuit diagram but keep them in mind as you study the following explanations.

INTERMEDIATE FREQUENCY

In the earlier Superheterodyne Receivers Lesson, it was stated that the main advantages of an i-f amplifier are; 1. designed to operate at a fixed resonant frequency, the tuned circuits provide maximum efficiency, 2, at the lower intermediate frequency, the operation is more stable and a given type of tube can provide higher gain. Thus, in both receivers of Figure 1, the i-f amplifier provides the major part of the voltage gain.

Another important advantage of the superheterodyne circuit is that the i-f provides what is known as arithmetical selectivity. For example, in the 540-1600 kc standard broadcast band with 10 kc channels, at 540 kc the frequency difference between adjacent carriers is 1.85% of the carrier frequency. At 1600 kc, the frequency difference between adjacent carriers is but 0.625% of the carrier frequency. This is one reason why the selectivity of a trf type receiver decreases as the carrier frequency increases.

In the 455 kc i-f amplifier of an a-m broadcast superheterodyne, the frequency difference between adjacent carriers remains constant over the entire broadcast band at approximately 2.2% of the intermediate frequency. Thus, the carrier frequency has but negligible effect on the receiver selectivity.

In the 80 mc-108 mc f-m broadcast band with 200 kc or .2 mc channels, at 88 mc the frequency difference between adjacent carriers is 0.227% of the carrier frequency while at 108 mc, the frequency difference between adjacent carriers is but 0.185% of the carrier frequency. Under these conditions, it requires an i-f of 10 mc to provide a frequency difference, between adjacent carriers, equal to 2.0% of the intermediate frequency.

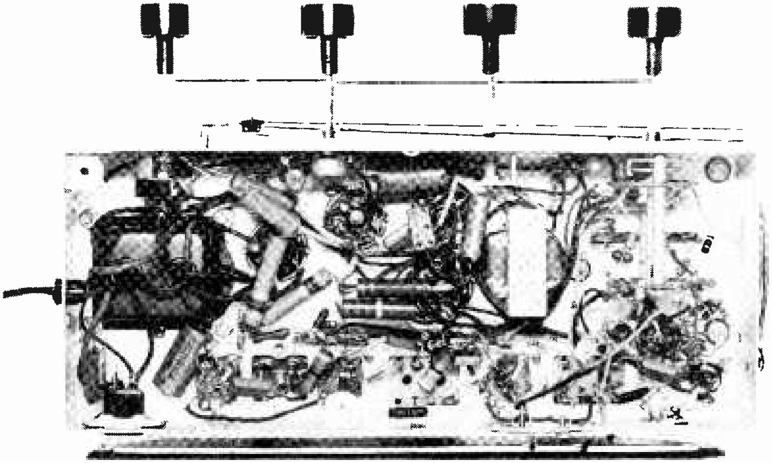
From the standpoint of high gain and good selectivity, a relatively low value of intermediate frequency is desirable, but to minimize image frequency interference, a comparatively high value of i-f is needed. As explained previously, the image frequency differs from that of tuned carrier by twice the i-f which, when sufficiently high, will cause the image to be so far removed in frequency, from that to which the r-f and mixer circuits are tuned, that it is attenuated to a negligible level.

In the common types of a-m broadcast receivers with an i-f of 455 kc, the image frequency is 2 x 455 = 910 kc above the tuned carrier. When the input circuits are tuned to 540 kc, the image frequency is 540 + (2 x 455) = 1450 kc and for tuned carriers above 690 kc, the image frequency lies outside the broadcast band. The commercial f-m broadcast band extends from 88 mc to 108 mc for a bandwidth of 20 mc and with an i-f of more than 10 mc, the image frequency will differ from the tuned carrier by more than 2 x 10 = 20 mc and thus fall outside the band.

Another form of interference occurs with the reception of two carriers which differ in frequency by an amount equal to the i-f. These carriers heterodyne to produce a beat note at the intermediate frequency and thus may be heard over the entire tuning range of the receiver. Here again, if the i-f is sufficiently high, the separation between the two carriers will be so great that the tuned input circuits will suppress the undesired carrier.

A more complete solution of this problem is to employ an i-f, the value of which is greater than the entire bandwidth over which the receiver tunes. For the f-m commercial broadcast band, this would require an i-f of something over 20 mc; however as explained above, this high value would reduce the gain and selectivity advantages of the system.

At the present time, this type of interference is minimized by using an intermediate frequency of 10.7 mc which can not be equalled by the beat frequency of any two f-m broadcast carriers. In the f-m broadcast band, all carrier allocations are at odd tenths such as 90.1 mc, 90.3 mc and so on, and the difference between any two of them is an even number or value. For example, if the receiver is tuned to a 90.1 mc carrier, for a 10.7 mc beat note, the second carrier must have a frequency of 90.1 − 10.7 = 79.4 mc or 90.1 + 10.7 = 100.8 mc. The frequency of 79.4 mc is outside the band and the



Bottom view of f-m and a-m chassis shown in two previous illustrations.
The Hallicrafters Company

allocations closest to 100.8 mc are 100.7 mc and 100.9 mc. These could produce beat notes of 10.6 mc and 10.8 mc respectively either of which is removed by .1 mc or 100 kc from the 10.7 mc i-f.

The i-f of 10.7 mc is slightly greater than half the band therefore any images will be removed from the tuned carrier by 2 x 10.7 = 21.4 mc and thus lie outside the band.

LIMITER

In an f-m system, any amplitude variation of the r-f or i-f wave constitutes distortion which, if permitted to affect the detector, will appear in the audio output. Even though the transmitted f-m wave may be of constant amplitude, a certain amount of a-m will be introduced in the tuned circuits of the receiver itself. This is due to the fact that, in order to respond to the frequencies of the 200 kc channel, the response curve of the tuned circuits must resemble that of Figure 8. Here the response is flat to about 50 kc each side of resonance, after which there is a sharp drop off, and at ± 75 kc, the response is down to 50% of maximum. Therefore, as the f-m wave deviates over its range, there is a variation in the output amplitude of these circuits. As some types of f-m detectors are susceptible to amplitude fluctuations, any such variations must be eliminated before the f-m signal is applied to the detector input. This is accomplished in a circuit known as a limiter, which prevents the amplitude of the f-m wave from exceeding a definite maximum value.

In the typical limiter circuit of Figure 9, the i-f amplifier output appears across the tuned secondary of transformer T and is applied to the control grid circuit of tube V through coupling condenser C and grid resistor R. As there is no source of d-c bias voltage, positive peaks of the input signal voltage will cause grid current which will charge condenser C to the indicated polarity.

During the remaining portion of each input cycle, C discharges slightly through R, but the discharge period is very short compared to the time constant of R and C, and therefore the charge on C, which is the bias on the control grid of tube V, remains essentially constant.

Although the cathode or self-bias method can be used in a limiter circuit, the grid leak bias, which automatically varies in magnitude with changes in carrier level, permits the employment of somewhat higher plate and screen grid voltages, and therefore results in a higher output from this stage.

Operating with comparatively low values of plate and screen voltage, the action of a limiter tube is shown by the I_pE_g characteristic curve of Figure 10. Here, the input signal, represented by curve e_i, indicates changes in amplitude as well as the desired frequency modulation. However, at some predetermined value of amplitude, as indicated by the vertical broken lines, the input voltage on the grid will vary the plate current from saturation to cutoff. Higher amplitudes of input voltage can not cause greater changes of plate current and therefore, as shown at the right, it has a waveform of constant amplitude. Although it is constant in amplitude, the limiter output retains the frequency variations, which represent the transmitted intelligence, and is applied to the input of the detector.

In order that complete limiting action take place, the lowest amplitudes of the input voltage must overdrive the limiter tube, because if they do not, some amplitude variations will appear in the output. Therefore, to insure a limiter output of uniform amplitude, the preceding stages must have sufficient gain to bring the signal up to a level which will cause the plate current to vary from saturation to cutoff.

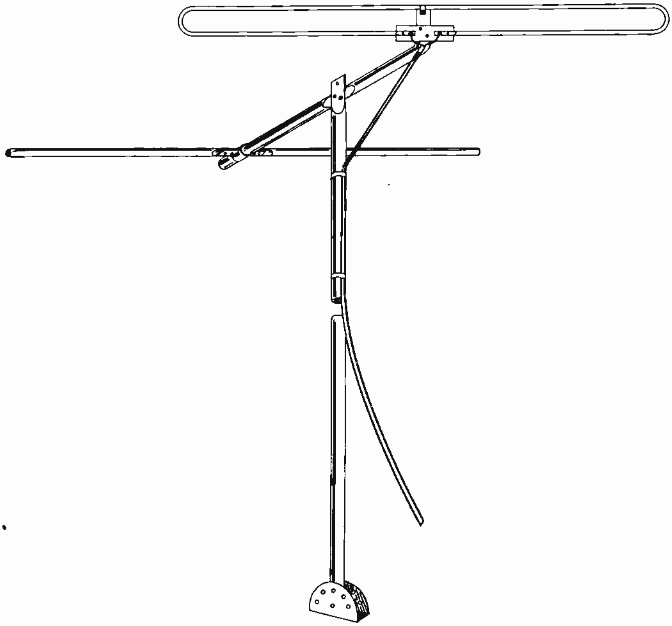
F-M RECEIVER I-F SECTION

A simplified circuit of a typical f-m receiver i-f section, including the limiter stage, is shown in Figure 11 where the 1st and 2nd i-f amplifier stages have about the same appearance as the corresponding circuits of an a-m receiver. However, the coils of the transformers, as well as their tuning condensers, have considerably lower values of inductance and capacitance, respectively, than those employed in a-m stages. Also, the f-m circuits are tuned to pass the comparatively wide band, indicated by the response curve of Figure 8.

This broad tuning is accomplished by shunting the LC circuits with resistors as shown in the diagram in Figure 11. When connected in this manner, a resistor acts to lower the Q of the tuned circuit and the lower the resistance value, the lower the Q and the broader the tuning. However, the gain of a stage varies with the Q therefore a compromise between gain and bandwidth must be made. This is the reason the curve of Figure 8 does not show the response of the typical f-m tuned circuit to be uniform over the maximum range of ± 75 kc.

Referring again to Figure 11, the diagram symbols indicate that the i-f transformers are permeability tuned. For the i-f tubes, each plate and screen grid supply circuit includes a resistance-capacitance decoupling filter while the control grid bias is developed across the usual arrangement of a bypassed cathode resistor. For the limiter tube, the lower operating voltages are obtained by the 470,000 ohm dropping resistor in series with the plate and the connection of the screen grid to the voltage divider made up of a 33,000 ohm resistor and a 100,000 ohm resistor. The control grid bias is developed across the parallel combination of R and C as explained for the circuit of Figure 9.

The limiter output consists of a constant amplitude, frequency modulated wave which, as indicated at the right of Figure 11, is coupled to the detector. In the description of Figure 1-B, it was stated that the function of the f-m detector is to convert variation of input signal frequency to corresponding variations of output amplitude. As the operation of the f-m detector is of great importance in the proper operation of an f-m receiver, the explanations of the entire following lesson will be devoted to this subject. Therefore, for the balance of this lesson, we will continue the comparison with a-m and describe the important advantages of f-m.



Folded dipole antenna with reflector.
Courtesy The Insuline Corporation of America

ADVANTAGES OF F-M

In regard to economies in transmitter design and operation, various advantages of the f-m system have been outlined in a preceding lesson. As far as the receiver is concerned, perhaps the greatest advantage of wide band f-m broadcast reception is the reduction in noise and other interference with high fidelity reproduction of program material.

In radio reception, the major forms of interference can be classified as: 1. those resulting from the reception of signals from stations other than that desired; 2. Noise voltages, man-made or otherwise, produced inside or outside the receiver, and 3. hum modulation due to a-c in the tube heaters, or to an a-c component in the output of the d-c power supply.

The effect of receiving an interfering carrier along with the desired one is shown in Figure 12 where curve A represents an unwanted carrier, which has one-half the amplitude and a slightly lower frequency than the desired carrier of curve B. The resultant voltage at the grid of the receiver input tube is the algebraic sum of the two carriers, A and B, as represented by curve C.

This resultant curve is amplitude modulated at a frequency equal to the difference between the frequencies of carriers A and B. If this difference frequency lies in the audio band, in an a-m receiver it will be demodulated and heard as a definite note or whistle in the output. However, in an f-m receiver, this amplitude modulation is removed by means of the limiter stage, as explained by the curves of Figure 10.

In the total period of time represented, the resultant curve C contains as many complete cycles as the desired carrier of curve B, therefore, its average frequency is equal to that of the desired carrier. However, curve C does not intercept its axis at equal time intervals as indicated by the light vertical lines extending toward curve B.

Starting at the left, curve C shifts gradually from its in-phase relationship with respect to the desired wave to a lagging angle, then back to zero phase angle, to a leading angle, and finally returns to zero phase angle again. This complete cycle of phase shift occurs at a rate equal to the difference between the frequencies of the desired and undesired carriers A and B.

Thus, the phase shift of the resultant wave results in frequency modulation as explained for the Armstrong f-m system in the lesson on F-M Transmitters. This resultant wave is applied to the second detector of the receiver, and if the frequency modulation lies in the audio band it can cause an audible note, or whistle, in the output of an f-m receiver. On the other hand, the frequency modulation will not affect the output of an a-m receiver.

The reception of the undesired carrier, curve A, causes the resultant wave of curve C to have a supplementary frequency deviation which adds to the desired deviation due to modulation at the transmitter. To give satisfactory results, the f-m transmitter and receiver systems must operate so that the f-m, due to the reception of an interfering carrier, is insignificant compared to that produced by the desired modulation voltage at the transmitter.

In the wide band f-m system employed in commercial practice, the maximum allowable deviation due to modulation is 75 kc. However, this represents the case of maximum amplitude of a particular modulating frequency, but at lower modulation amplitudes, the deviation will more likely be on the order of 40,000 cycles or less.

The frequency modulation due to an interfering signal is directly proportional to the amount of phase modulation produced, and also directly proportional to the difference between the interfering and desired signal frequencies. Expressed as an equation:

$$\Delta F = \frac{f \, \Delta \theta}{57.3} \qquad (3)$$

when:

ΔF = frequency deviation in cps
f = difference frequency in cps
$\Delta \theta$ = phase deviation in degrees

For example, if an interfering signal is separated in frequency from the desired one by 1000 cycles and causes a phase deviation of 14.32°, the resulting frequency deviation will be:

$$\Delta F = \frac{1000 \times 14.32}{57.3} = 250 \text{ cycles}$$

which is but a small fraction of an initial average deviation of 40,000 cycles caused by modulation. Thus, the 1000 cycle difference frequency caused by the interfering wave will be overridden easily by the desired signal, the ratio of their respective amplitudes being 1 to 160.

For a second example, suppose that the interfering signal differs in frequency from the desired one by 10,000 cycles, or ten times as much as before. If it causes the same amount of phase deviation, 14.32°, the resulting frequency deviation will be:

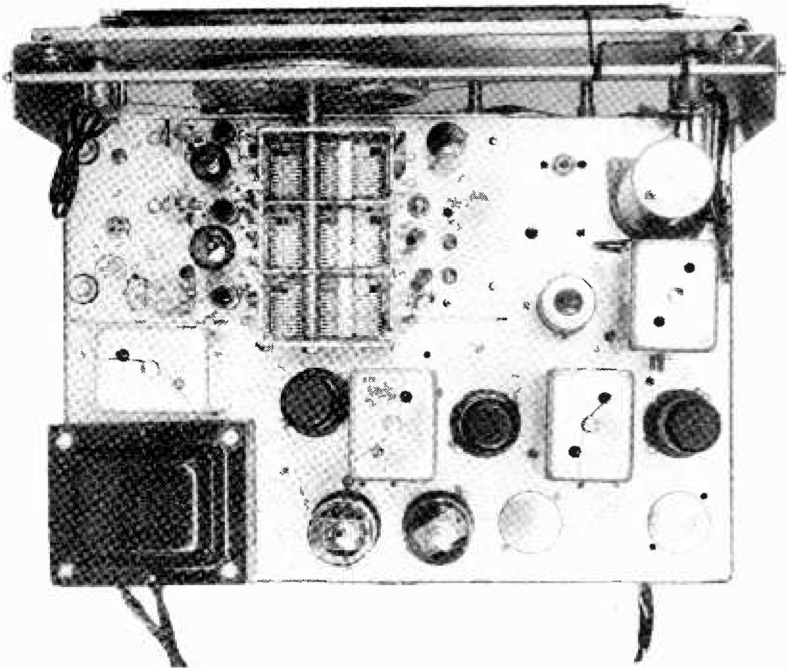
$$\Delta F = \frac{10{,}000 \times 14.32}{57.3} = 2{,}500 \text{ cycles}$$

In this case, the ratio between the amplitude of the desired signal, and that of the 10,000 cycle difference frequency, is 40,000 to

2,500, or 16 to 1. Thus, the greater the frequency separation between the desired and the interfering carriers, the greater the value of ΔF, and the louder the interfering tone in comparison with the volume of the desired signal.

Also, as mentioned above, ΔF is directly proportional to the amount of phase deviation caused by the interfering carrier. This phase deviation, $\Delta\theta$, is determined by the ratio of the amplitudes of the desired and interfering carriers and in order to prevent the ΔF, due to interference, from being too large, $\Delta\theta$ must not be greater than about 30°.

If $\Delta\theta$ is to be held to a maximum of 30°, the ratio of the amplitude of the desired to the interfering carrier must not be less than 2 to 1 as indicated by the vector diagrams in Figure 13. Here vector m represents the desired carrier that has twice the amplitude of an undesired carrier represented by vector n which, in this case, has a slightly higher frequency than the desired carrier. Vector R represents the resultant voltage produced at the grid of the input tube of the re-



9-tube F-M, A-M chassis.
Farnsworth Television and Radio Corporation

ceiver. As all these vectors represent high-frequency a-c voltages, they are assumed to be rotating at constant speeds in a counter-clockwise direction around their origin, point O. The eight diagrams show the relative positions of m, n, and R, at eight particular instants during the time interval T = 1/f, when f is the difference, in cycles per second, between the respective frequencies of the desired and undesired carriers.

At the first instant, Figure 13-A, m and n are in phase and the resultant voltage R, in phase with both, is equal to their sum. At the second instant, Figure 13-B, vector n, which is rotating faster, leads m by 60°, and the resultant R also leads m, but by a smaller angle of 19.8°. At the third instant, Figure 13-C, n leads m by 90° and R leads m by 26.6°.

In Figure 13-D, n has increased its lead to 120°, and R leads m by 30°. In the next instant, Figure 13-E, n leads m by 180°, but the phase difference between R and m has decreased to zero. However, due to the 180° phase difference between vectors m and n, the amplitude or length of R is equal to the difference of their lengths instead of the sum as indicated in Figure 13-A.

Continuing the cycle, at the next instant, Figure 13-F, n leads m by 240° but R lags m by 30°. In Figure 13-G, n leads m by 270° and R lags m by 26.6°. In Figure 13-H, the lead of n has increased to 300° and R lags m by 19.8°. Finally, at the completion of the time period T, the lead of n has increased to 360° and therefore it is again in phase with m as shown in Figure 13-A.

During the complete cycle, the maximum angle of lead or lag, between vectors R and m, occurs at the instants n and m are 120° and 240° out of phase as indicated by Figures 13-D and 13-F. In order to prevent this maximum angle of deviation from exceeding 30°, the amplitude of the interfering carrier, vector n, must not be greater than one-half of that of the desired carrier, vector m.

To summarize the action, the reception of an interfering carrier results in undesired amplitude and frequency modulation of the resultant input voltage of a receiver. In the case of an f-m receiver, the unwanted a-m is removed by the limiter stage. The f-m cannot be removed, but it will be of negligible magnitude, although the ratio of the amplitudes of the desired to that of the undesired carriers may be as low as 2 to 1. In the case of an a-m receiver, the frequency modulation of the input voltage is unimportant. However, its a-m cannot be removed, and will appear as a disturbance in the receiver output unless the ratio of the desired to undesired carrier amplitudes is at least 100 to 1.

NOISE VOLTAGES

In addition to the carriers, both desired and interfering, in any radio receiver the input includes various "noise" voltages. If the voltage peaks are infrequent and sharply defined, with successive peaks clearly separated, the noise is said to be of the "impulse" type. However, if the peaks follow one another in such rapid succession that a continuous sound is produced in the receiver output, the noise is considered to be of the "random" type. Typical sources of impulse noises are automobile ignition systems, sparking brushes of electric motors, faulty power lines, etc., while random noise is caused by various atmospheric disturbances, and also includes the irregular voltages generated within the receiver itself. These include the tube noises, described earlier in this lesson, and another known as "thermal-agitation".

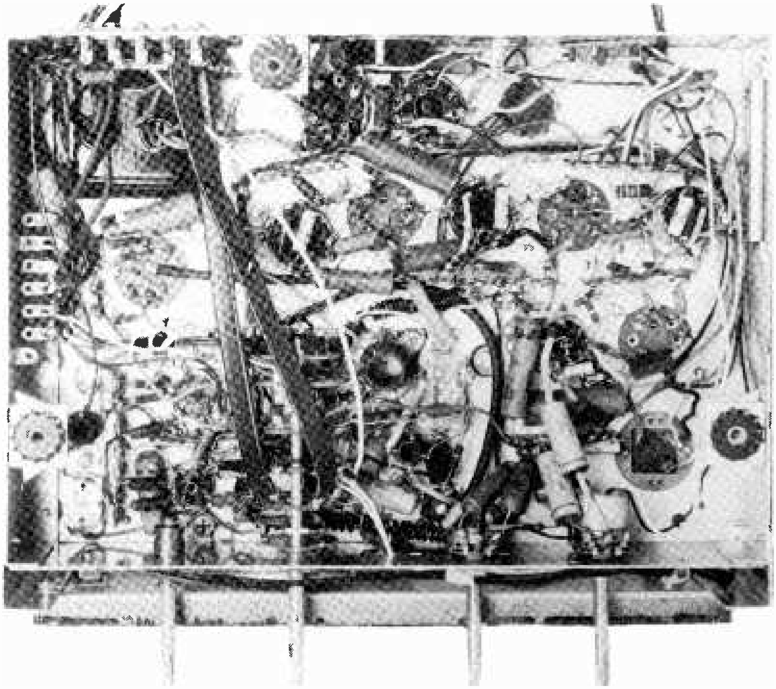
Thermal agitation noise voltages are developed as a result of the haphazard motion of free electrons in conductors. At any instant that more free electrons in a conductor happen to be moving in one direction than another, a difference of potential is developed, the magnitude of which depends upon the resistance and temperature of the conductor. Although thermal agitation occurs in all the conductors of a receiver, only that present in the input circuit is of importance, because it is here that the signal voltage is at its lowest level.

It has been found that in the high-frequency commercial f-m broadcast region of the spectrum, both impulse and random type noises are distributed evenly over the entire receiver response band. In the case of impulse noises, the various frequency components have harmonic relationships with the fundamental; while random noise voltages can be regarded as consisting of an infinite number of components at different frequencies, each one differing from the next higher or lower frequency by an infinitesimal amount.

In the earlier explanations of a-c it was stated that when two or more voltage components are present in a circuit, the rms value of the resultant is equal to the square root of the sum of the squares of their rms values. If the components are of equal amplitude, such as those of the noise voltages, then the rms value of their resultant is proportional to the square root of the number of components present. Thus, the rms values of random and impulse noises are proportional to the square root of the frequency bandwidth to which the tuned circuits of an a-m or f-m receiver are responsive at any particular dial setting.

It has been explained also that when an interfering signal is added to a desired signal, the resultant wave is both amplitude and frequency modulated. The a-m of this resultant wave causes undesirable disturbances in the output of an a-m receiver, but the unwanted a-m is removed by the limiter of an f-m receiver and the f-m is negligible, compared to the deviation due to modulation, providing the strength of the desired carrier is at least twice that of the undesired carrier.

Similar results occur in an f-m receiver when two or more interfering carriers are received, provided the amplitude of the desired carrier is equal to at least twice the peak value of the resultant of all the various inter-



Bottom view of F-M and A-M chassis shown in previous illustration.
Farnsworth Television and Radio Corporation

fering carriers. As noise voltages have been described as consisting of a series of components at different frequencies, they can be considered as a large number of interfering carriers, and their resultant will be suppressed by the f-m receiver in the same way as explained for a single interfering carrier.

Also, it has been mentioned that the frequency deviation, due to an interfering carrier, increases as the frequency difference between it and the desired carrier is increased. That is, the amplitude of the disturbance in an f-m receiver output will be higher the farther the interfering frequency is removed from that of the desired carrier.

To illustrate this action, the graph of Figure 14-A shows how the r-f noise components at the receiver input determine the amplitude of the a-f noise components at the receiver output. The output noise, due to r-f components at and near the desired carrier frequency, f_o, is minimum, and rises at a linear rate to maximum at the receiver resonance band limits, $f_o - 75$ kc and $f_o +$ 75 kc. The commercial f-m broadcast system employs wideband ± 75 kc frequency deviation, so that any deviation, caused by interfering carriers, is insignificant compared to that due to modulation. Thus the graph of Figure 14-A represents the total noise energy present at the output of the detector of an f-m receiver.

However, only a part of this noise energy is passed through the audio amplifier of an f-m receiver, which normally has a frequency response flat up to about 15 kc. This fraction of the total noise, represented by the shaded triangles in the graph of Figure 14-B, in proportion to the areas of the graph is only one twenty-fifth of what it would be if the a-f amplifier circuits had flat response up to 75 kc.

Since 15 kc is about the upper limit of the frequency band to which the human ear will respond, but little increase in fidelity would be obtained by increasing the audio amplifier range. However, a sharp cutoff of the response, above 15 kc, prevents noise components, differing by more than 15 kc from the tuned carrier, from reaching the receiver output. Although these high frequency noise components could not be heard individually, their energy would add to that of the lower frequency noise components, thus increasing the peak value of the resultant of all of them.

In an a-m receiver, all r-f noise components, differing from the carrier frequency by less than the highest modulation frequency, are amplified equally as well as the tuned carrier. If the a-m broadcast system were operated so as to reproduce audio frequencies up to 15 kc, the amount of noise present in the output would be as represented by the shaded rectangle of Figure 14-C. Comparing the areas, this noise rectangle is ten times as large as the corresponding shaded triangles for the f-m system, Figure 14-B.

Actually, this amount of noise is not reproduced in the output of an a-m receiver, since the upper audio-frequency limit is only 5 kc. Therefore, the graph of Figure 14-D illustrates the noise volume in a commercial broadcast band a-m receiver, relative to that of Figure 14-B for an f-m receiver. A later lesson will explain how the employment of certain circuits provides a reduction in the already small amount of noise in an f-m receiver output.

The ratio of the a-m to f-m receiver "noise areas", shown in the various graphs of Figure 14, is called the "improvement ratio", and is a direct comparison of the signal-to-noise ratios obtained with the respective systems. This improvement ratio varies somewhat with the type of noise, or amount of each type present, and for peak impulse noise only, is equal to twice the deviation ratio of the f-m system. For example, with a deviation ratio of 5, the improvement ratio is 2 × 5 = 10. Thus, for impulse noise, the signal-to-noise ratio of an f-m receiver is ten times as great as that of a corresponding a-m receiver, assuming equal carrier and noise voltage input to both.

For peak random noise only, the improvement ratio is approximately equal to 1.73 times the deviation ratio. With the deviation ratio of the above example for random noise, the improvement ratio is 1.73 × 5 = 8.65, therefore, the signal-to-noise ratio of the f-m receiver is 8.65 times as great as that of the a-m receiver.

The above values are given only as a general means of comparison, because in actual practice, the improvement ratios are determined by the quality of the design, components, construction, etc. of the various f-m and a-m receivers on the market. Due to these factors, considerable variation in improvement ratios is to be found for individual cases. In f-m communications, where a narrow audio channel is sufficient, the deviation ratio may be as high as 10 or more to permit improvement ratios in the neighborhood of 20 to 1, and explains why f-m communication is possible under severe interference conditions.

The third type of interference listed above, hum modulation, has the greatest effect upon the output when it exists in the early stages of the receiver where the signal is at a low level. Any a-c hum volage will cause amplitude modulation of the f-m wave, and unless suppressed, will cause a low-frequency tone in the speaker. However, this 60 or 120 cycle amplitude modulation is normally removed by the limiter stage of an f-m receiver in the same way as the a-m due to interfering signals or noise voltages.

The explanations of the following lesson will describe the actions and circuits by which the deviations of the f-m carrier are converted to a voltage with corresponding variations in frequency and amplitude.

IMPORTANT WORDS USED IN THIS LESSON

COAXIAL CABLE—A twin-conductor cable consisting of a small solid conductor supported by means of insulators at the center of a cylindrical tubular conductor. The center conductor forms one side of the circuit, while the cylindrical sheath is the other side and acts also as a shield.

CONVERSION TRANSCONDUCTANCE—A measure of the effectiveness of a tube to function as a mixer or frequency changer. Numerically, it is equal to the ratio of the i-f current in the plate circuit to the r-f voltage input to the signal grid.

DIPOLE—A half wave antenna usually consisting of two metal rods placed end to end but separated by a short distance.

DIRECTOR—A metal rod, mounted a fraction of a wavelength in front of a dipole, to increase further the effectiveness of the antenna in the forward direction.

LIMITER—The final i-f stage in an f-m receiver. Its function is to clip all signal amplitudes exceeding a certain value, so that no amplitude variations will reach the 2nd detector.

MATCHING SECTION—A portion of a transmission line, usually one-fourth wave in length, used to match the impedance of a line to that of the antenna.

ENT—To rotate or adjust the direction of an antenna or other object.

REFLECTOR—A metal rod, mounted a fraction of a wavelength behind a dipole, to increase the effectiveness of the antenna in the forward direction.

SHOT EFFECT—The small variations in plate current resulting from the slightly irregular manner in which the electrons are emitted from the cathode.

THERMAL AGITATION NOISE—Noise resulting in a radio receiver due to the random movements of the free electrons in a conductor. The resulting minute variations in current set up voltages which are amplified in the tubes and which manifest themselves as noises in the speaker.

TUBE NOISE—Noise originating in an electron tube due to thermol agitation, the shot effect, and related causes.

STUDENT NOTES

STUDENT NOTES

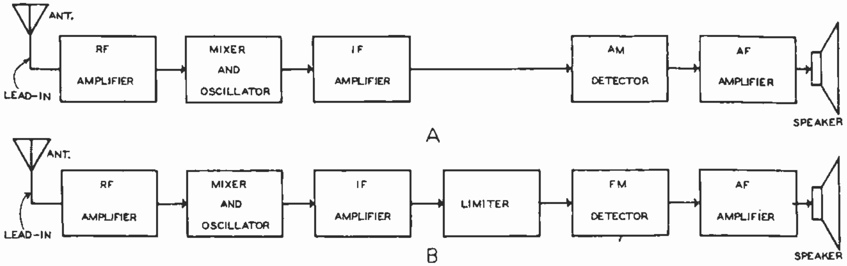


FIGURE 1

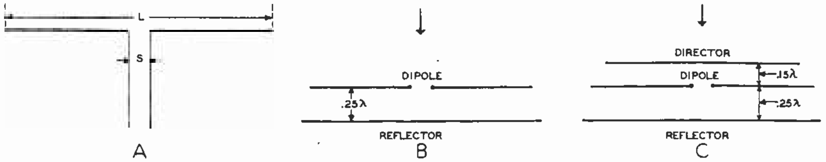


FIGURE 2

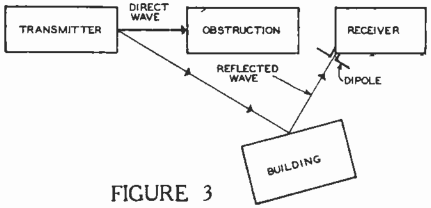


FIGURE 3

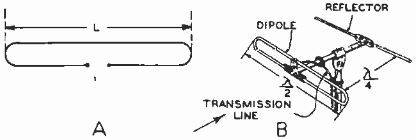


FIGURE 4

FIGURE 5

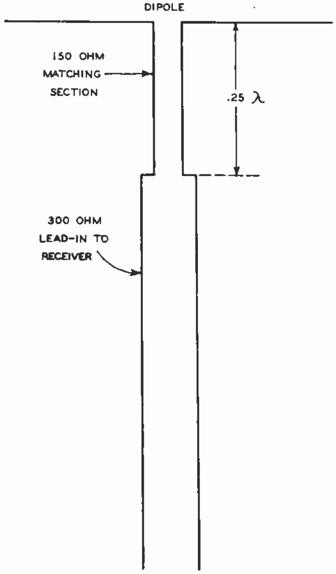


FIGURE 6

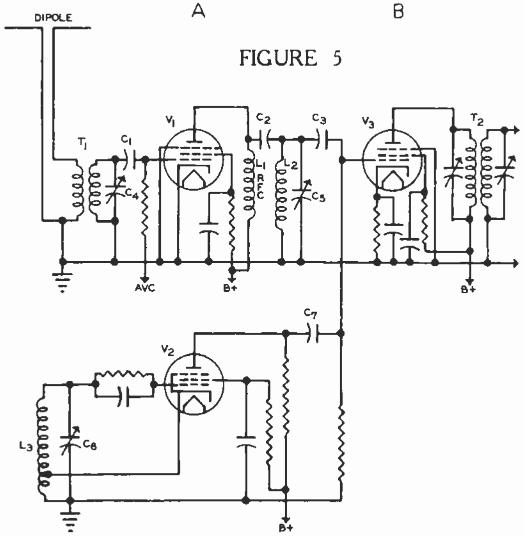


FIGURE 7

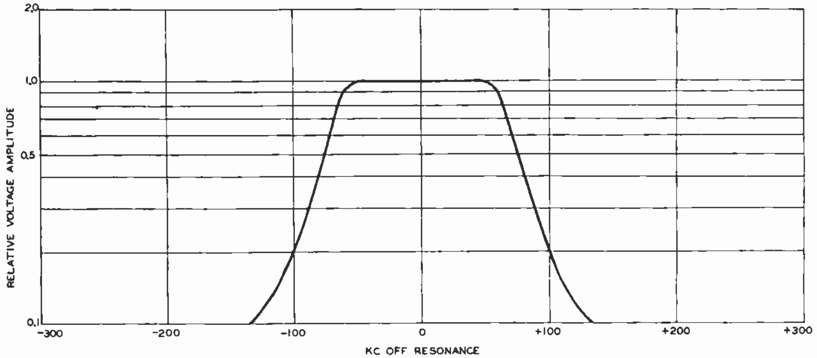


FIGURE 8

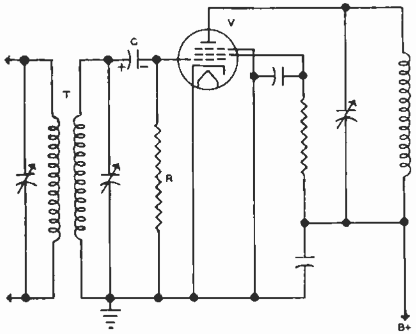


FIGURE 9

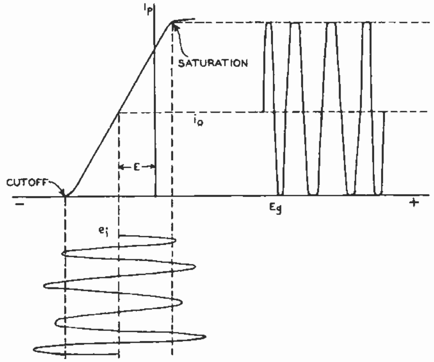


FIGURE 10

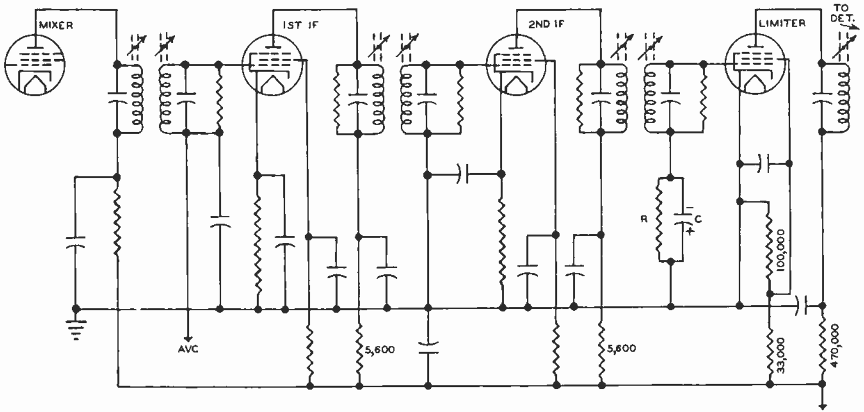


FIGURE 11

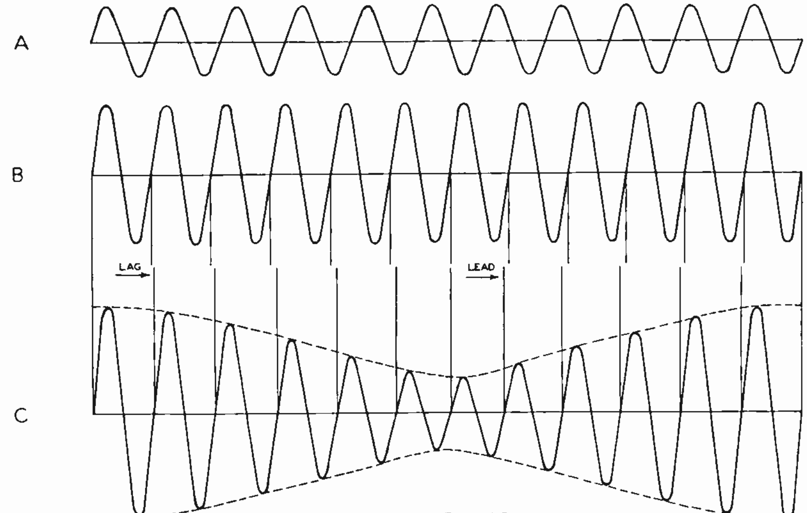


FIGURE 12

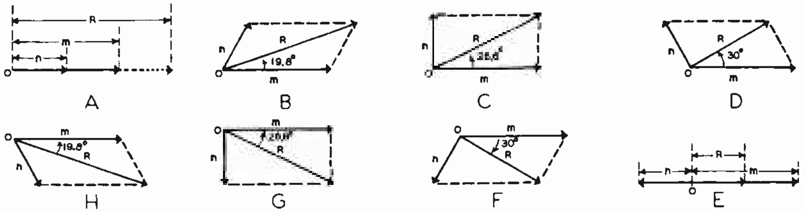


FIGURE 13

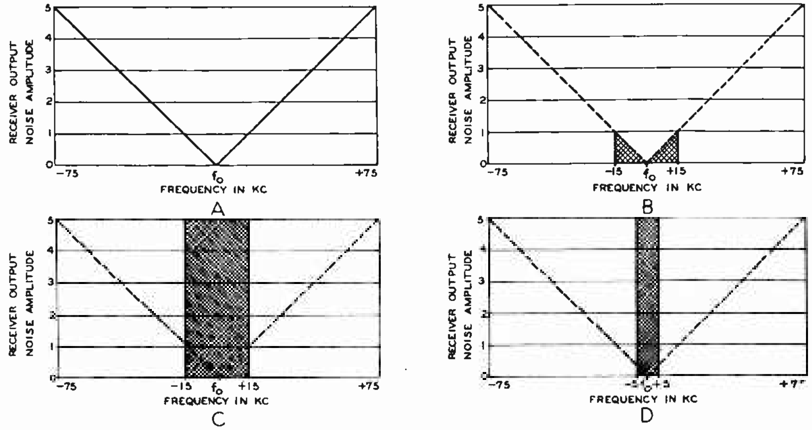


FIGURE 14

FROM OUR *President's* NOTEBOOK

PERSEVERANCE CONQUERS ALL

Genius, that power which dazzles mortal eyes,
Is oft but perseverance in disguise;
Continuous effort, of itself, implies
In spite of countless falls the power to rise.
'Twixt failure and success the point's so fine,
Men sometimes know not when they touch the line.

Just when the pearl was waiting one more plunge,
How many a struggler has thrown up the sponge!
As the tide goes out, it comes clear in;
In business 'tis at turns the wisest win.
And oh! how true when shades of doubt dismay,
" 'Tis often darkest just before the day."

A little more persistance, courage, vim!
Success will down o'er fortune's cloudy rim.
Then take this honey from the bitterest cup;
"There is no failure save in giving up,
No real fall as long as one still tries,
For seeming setbacks make the strong men wise.
There's no defeat, in truth, save from within;
Unless you're beaten there, you're bound to win."

Yours for success,

E. B. DeVry
PRESIDENT

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