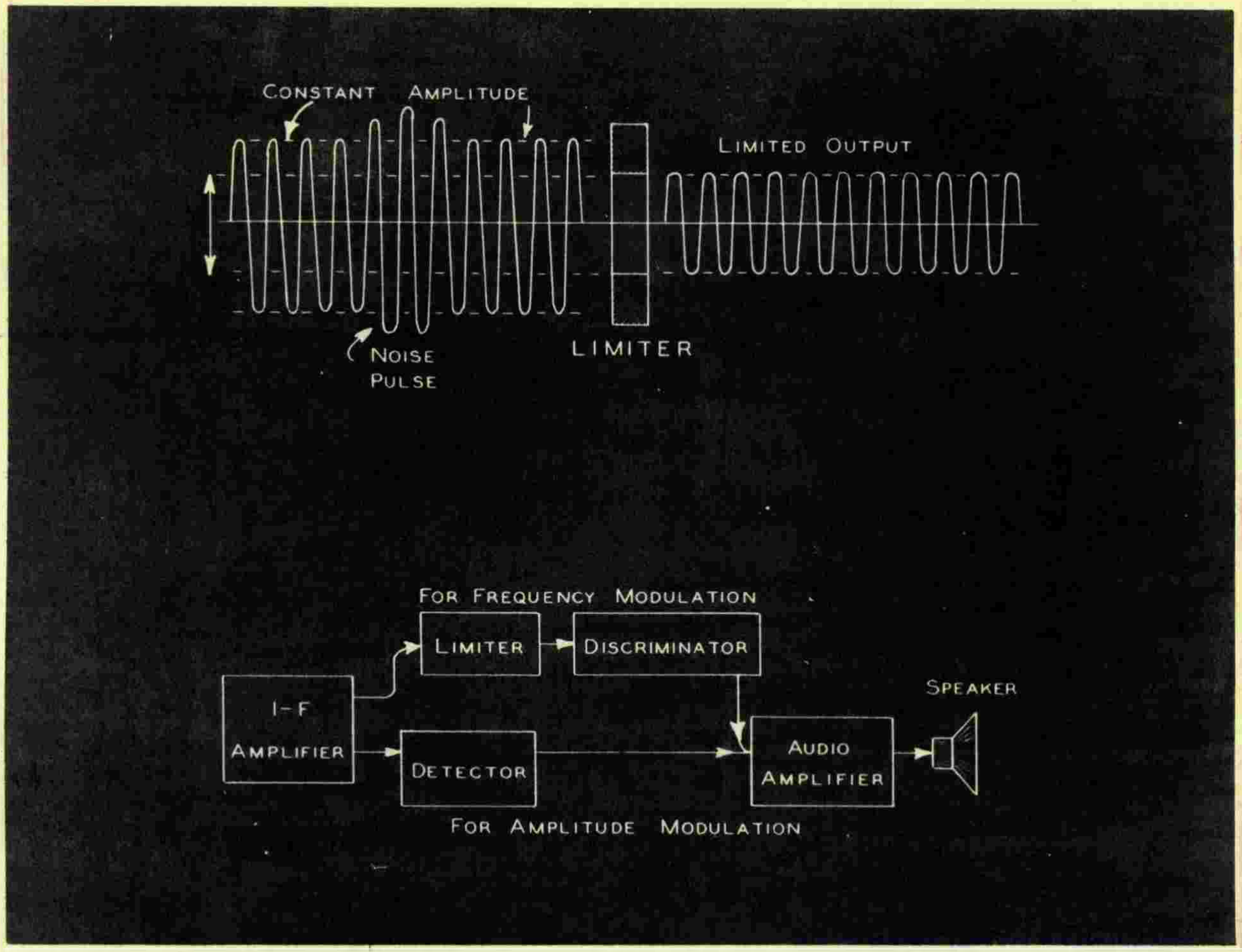

LESSON 71 RA

FREQUENCY MODULATION

RADIO-TELEVISION TRAINING SCHOOL, INC.

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From the beginning of broadcasting of music and voice until a few years ago there was only one method of radio transmission and reception in general use. Radio technicians and engineers understood that signals were being sent and received by means of a system called amplitude modulation. But the public, which included most of us before we took up radio, never thought of such things as modulation - radio was just plain radio.

Then came a new method of transmission and reception, a method employing frequency modulation rather than amplitude modulation. Everyone heard about this new method, called f-m radio or just FM. Because of the newness, the public assumes that f-m radio must be better than a-m (amplitude-modulation) radio, and, in some respects, the public is correct. As shown by Fig. 1, the frequency-modulation method requires having additional "stages" and some stages that are entirely different from

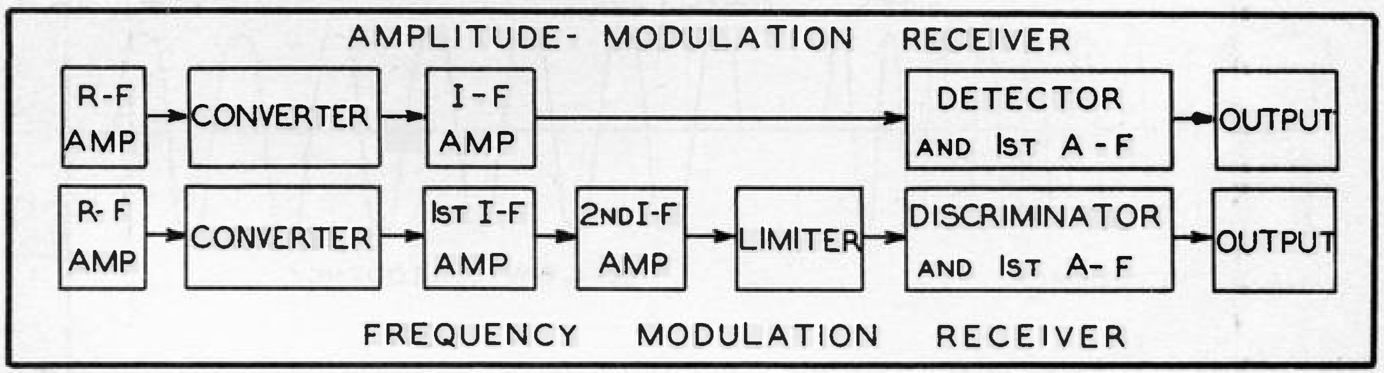

FIG. 1. The principal parts of receivers for amplitude - modulation and for frequency modulation.

those in a receiver for amplitude modulation. These additions and differences will be examined as we proceed.

Before comparing the two methods of transmission and reception it should be recalled that modulation refers to the manner in which voice, music, or other signals to be transmitted are added to the radio waves which travel through space. Modulation means a change or a variation. If the sound signals are made to vary the strength or amplitude of the radio wave from instant to instant we have amplitude modulation. If the signals are made to vary the frequency of the radio wave we have frequency modulation.

We might begin with exactly the same radio waves and use them for either method of transmission. These radio waves would have the two characteristics shown by Fig. 2. One characteristic is the frequency of the waves, the number of times per second that the electric and magnetic fields change their directions in the waves. The other characteristic is the strength of the waves, which we call their amplitude, and which represents the maximum values of electric and magnetic forces which compose the waves. As shown by upper diagram, the frequency may be changed with no change of amplitude, and as in the lower diagram, the amplitude may be changed with no variation of frequency.

Supposing that you and another person were going to signal each other by means of a rope whose opposite ends you are holding. If you swing your end of the rope up and

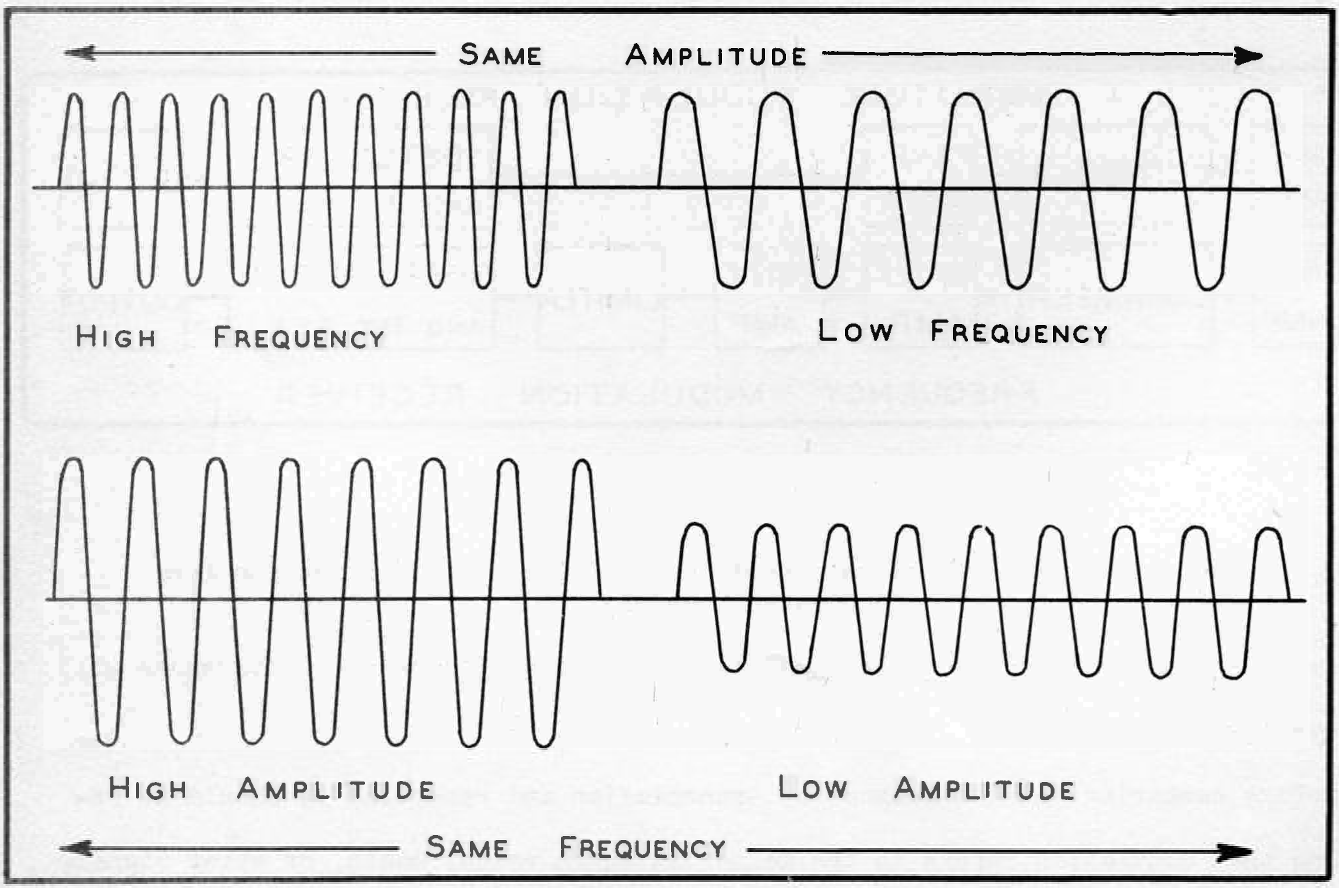

FIG. 2. Frequency may vary with no change of amplitude, and amplitude may vary with no change of frequency.

down, waves of motion travel along the rope from you to the other person. It might be agreed that an up-and-down motion at the rate of five times per second means one thing, while ten times per second means something else. Then you would be transmitting signals by frequency modulation. Or, you might agree that waving the rope hard, to get high waves onto the rope, would mean one thing, while a gentle waving to produce relatively low waves would mean something else. That would be transmission of signals by amplitude modulation. With either method you would be using rope waves, as in both kinds of radio transmission we use radio waves. The only difference is in the manner of varying the rope waves, just as the only difference between the two kinds of radio transmission is in the manner of varying or modulating the radio waves.

When a radio wave is sent from a transmitter with no sound signals added, the wave does not vary in either frequency or amplitude. The signal may be added by varying either of these characteristics. If the apparatus at the transmitter is such that sound signals cause variations of wave frequency there is frequency modulation. If the sound signals cause variations of strength or amplitude there is amplitude modulation.

The chief advantage in using frequency modulation rather than amplitude modulation is that reception may be relatively free from noises which result from atmospheric static and many other kinds of electrical interference. The reason for this relatively noise-free reception is quite simple. It is that most varieties of interference get mixed in with our radio signals between transmitter and receiver because the interfering electrical impulses are of kinds which vary or modulate the amplitude of the radio waves. The a-m receiver, which will reproduce any kind of amplitude modulation, does not distinguish between signals and noise, and so both come from the loud speaker at the same time. But the f-m receiver does distinguish between frequency modulation which brings the desired signal and amplitude modulation which carries the noise. The f-m receiver, when correctly designed, adjusted, and operated, rejects most of the noise and reproduces most of the desired signal.

It is true also that a well designed and constructed f-m receiver is capable of reproducing a greater range of sound frequencies than the a-m type, consequently gives truer musical rendition. The fact is that a receiver, no matter how good it is, can reproduce only the audio frequencies which come to it in the transmitted signal. In most of the present a-m carrier frequency channels each transmitter is permitted to use only enough frequencies to cover an audio range up to 5,000 cycles. But, for reasons which we shall discover shortly, the range of audio frequencies transmitted with frequency modulation is not directly related to the width of the channel of carrier frequencies which a transmitter is permitted to use. Consequently, with frequency modulation it is possible to transmit the highest audio frequencies. Present practice is to transmit audio frequencies up to about 15,000 cycles.

FREQUENCY MODULATION

Nowadays our radio education and experience commence with apparatus operating on amplitude-modulated signals, and our ideas become rather set or fixed along such lines. Then frequency-modulation seems somewhat confusing. Had we commenced with training and experience on frequency-modulated apparatus there is no doubt but what we should find amplitude modulation confusing. If we pause here long enough to examine similarities and differences of the two modulation systems, most of the possible confusion never will appear.

At the top of Fig. 2 is our frequency modulated wave. We must carry the audio signals solely by changes of frequency; we must not change the amplitude. At the bottom is our amplitude modulated wave. With it we must carry the audio signals by changes of amplitude, with the carrier wave remaining always of the same frequency.

Now let's look at Fig. 3, which represents the changes in quality or characteristics of sounds which are to become the transmitted signals. As shown at the top, we may vary the pitch, which means to vary the audio frequency, while retaining the same loudness, strength, or volume of sound. As shown below, we may vary the volume without changing the pitch. Volume corresponds to signal voltage or amplitude; more amplitude means more volume. Of course, there are conditions where pitch and volume change simultaneously, but for examination of what happens we may consider the two qualities separately.

Now we may state the problems of amplitude modulation and of frequency modulation quite simply. With amplitude modulation we must find two ways of varying the amplitude; such that one of the variations will correspond to changes of audio signal pitch or frequency, while the other variation will correspond to changes of audio signal

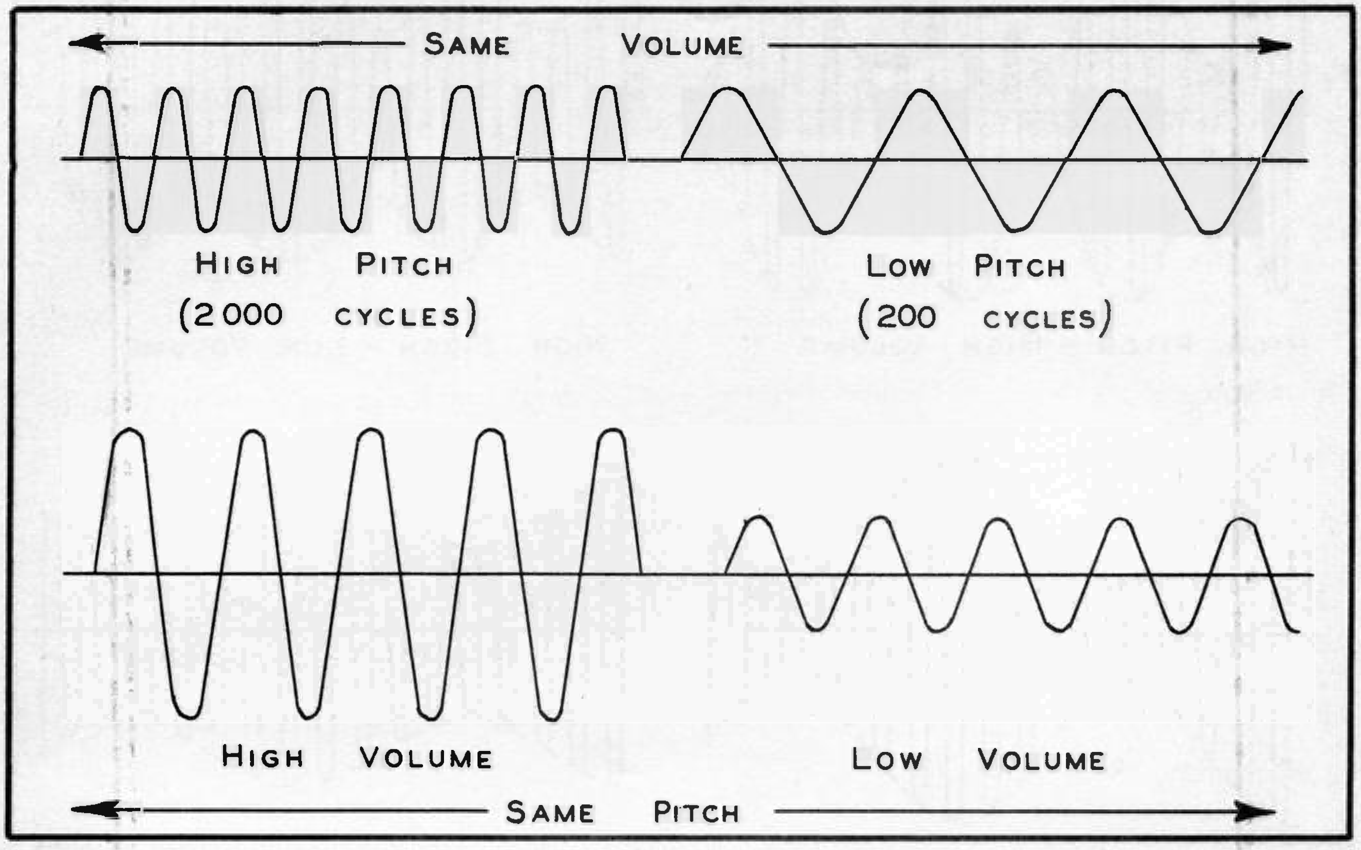

FIG. 3. Characteristics of sounds, as represented by frequency and amplitude.

loudness or amplitude. To keep matters straight, we shall refer to pitch and loudness of the audio signals, and shall refer to frequency and amplitude only with reference to the radio carriers.

For changes of audio signal loudness we increase and decrease the amplitude of the radio wave. We are changing only the amplitude, so have amplitude modulation. Such changes for volume are represented at the bottom of Fig. 3.

For changes of audio signal pitch we vary the lengths of times between changes of radio carrier amplitude. Again we are changing only the carrier amplitude, not the carrier frequency, so have amplitude modulation.

All of the changes of carrier amplitude for amplitude modulation are shown by Fig. 4. At the upper left is represented the signal for a high-pitched sound of

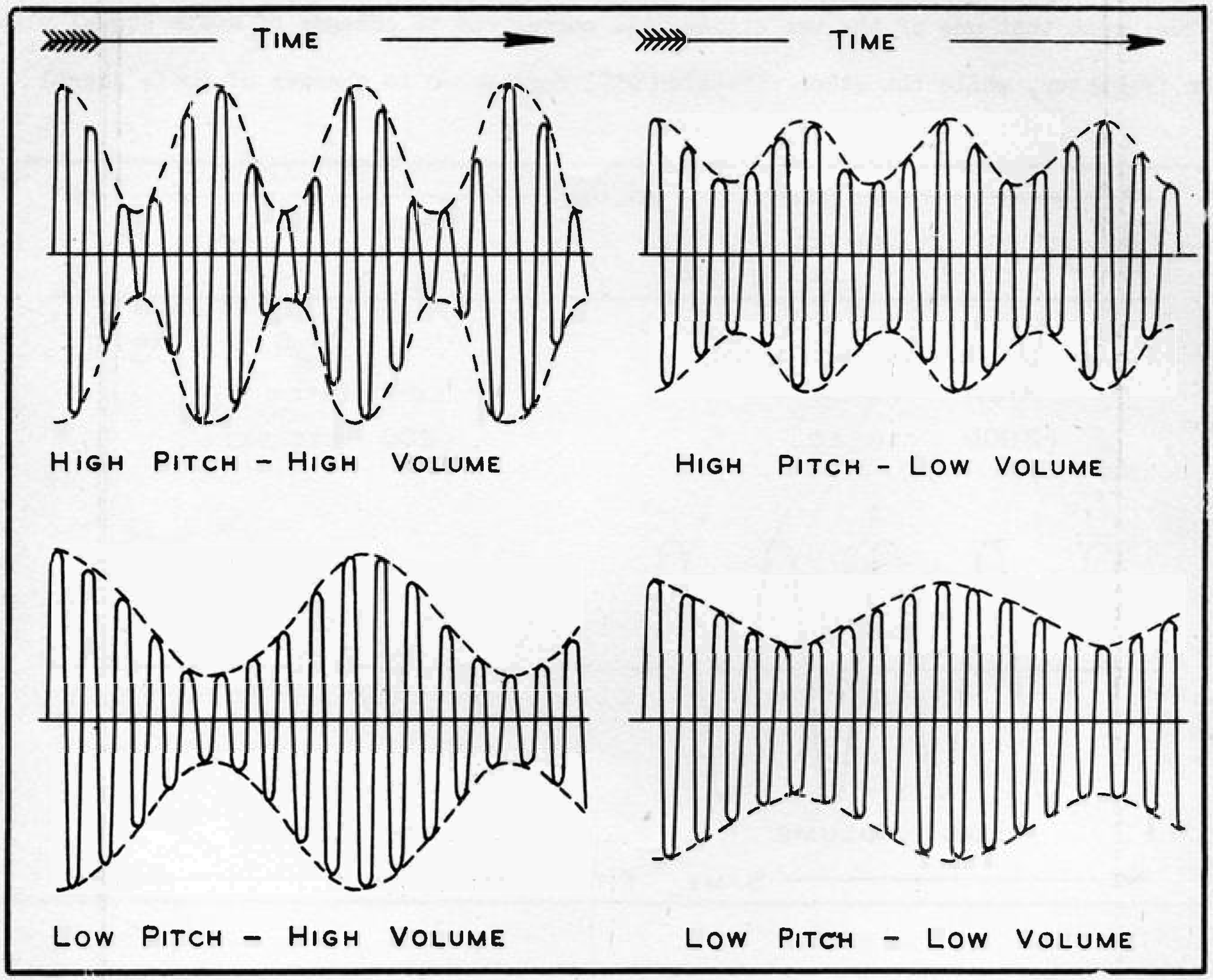

FIG. 4. How amplitude modulation of the carrier wave varies with changes of sound characteristics being transmitted.

high volume. The changes of carrier amplitude come close together, have short time intervals between them, and so they represent a high-pitched sound, which is a sound of high audio frequency. At the upper right is represented the same high pitch, but with lower volume. Here the lengths of time between changes of amplitude are the same as before, because the pitch is the same, but there is less change between minimum and maximum amplitudes, there is a smaller change of amplitude than before, and the volume or loudness of the audio sound is less. Note that the carrier frequency, represented by the closely spaced waves, is not changed. Only the amplitude is changed, yet we transmit a variation of sound volume.

At the lower left in Fig. 4 is represented a signal for a low-pitched sound of high volume. The time periods between changes of amplitude are longer than for the high-pitch signals shown above. Longer periods mean lower audio frequency, or a lower pitch. But the changes between minimum and maximum amplitudes are the same as for the high-volume sound represented immediately above, and so again we have high volume. At the lower right is represented a signal for a low-pitched sound of low volume. Time periods between changes of amplitude are the same as for the low-pitch signal shown immediately to the left of this one. And the changes of amplitude between minimum and maximum values are the same as for the low volume signal immediately above this one. Throughout all of these signal representations the carrier frequency is unchanged. Only the amplitude has been varied. Sound pitch is represented by how often the carrier amplitude changes. Sound volume is represented by how much the carrier amplitude changes.

Now we come to frequency modulation. We must vary the carrier frequency in two ways. One kind of variation must represent changes of sound pitch in the signal. The other kind of frequency variation must represent changes of sound loudness in the signal. We must transmit both kinds of sound variation by changes of only the carrier frequency; we must not change the carrier amplitude. We may discover the solution of our problem in the last three lines of the paragraph ahead of this one. All that we need do is change the word amplitude to the word frequency. Then we have two statements. First; sound pitch is represented by how often the carrier frequency changes. Second; sound volume is represented by how much the carrier frequency changes.

Fig. 5 shows variations of carrier frequency when employing frequency modulation for the same kinds of sound signals as shown by Fig. 4 with amplitude modulation. High frequencies are represented by waves close together; lower frequencies by waves farther apart. The more waves in a given space the higher is the frequency, and the fewer waves in the same distance the lower is the frequency. Changes of frequency are shown where the waves get farther apart or closer together.

At the top is represented a frequency-modulated signal for a sound of high-pitch at high volume. There are rapid changes of frequency, and since pitch is represented by how often the carrier frequency changes from high to low and back again, the many changes of this frequency in a given length of time mean a high-pitched sound. The changes are from very high to very low frequency, and since sound volume is represented by how much the carrier frequency changes, this means a loud sound.

The line of waves second from the top in Fig. 5 shows the carrier frequency changing at the same rate as above, so again we have the high-pitched sound which

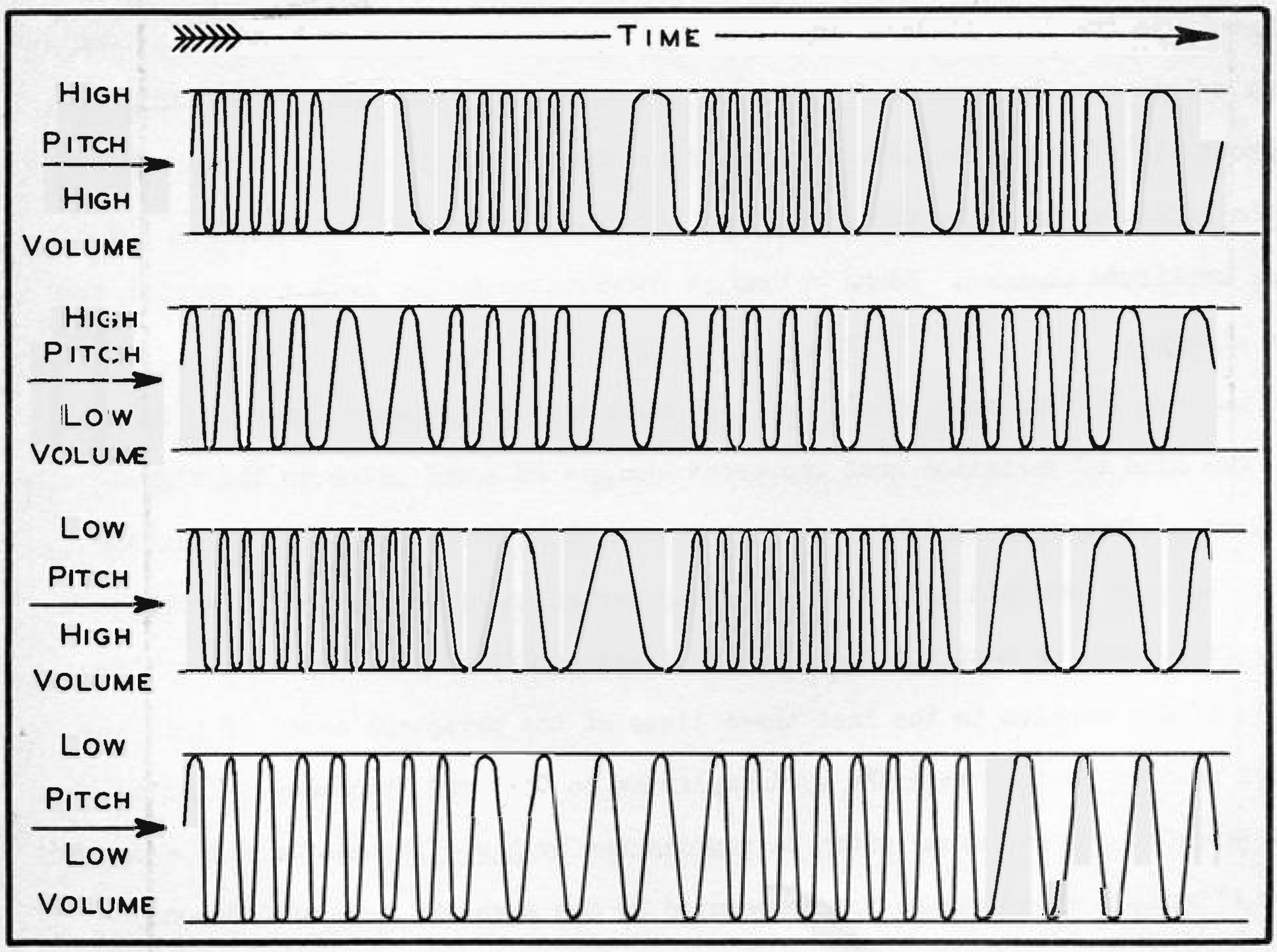

FIG. 5. How frequency modulation of the carrier wave varies with changes of sound signal characteristics.

corresponds to rapid changes of carrier frequency. But the difference between high and low frequencies is nowhere near as great as before, and this lessened change of frequency means lower volume in the sound signal.

The third line of Fig. 5 shows the changes from high to low frequency and back again occuring less often than in the upper lines. Remembering that sound pitch corresponds to how often the carrier frequency changes during a given length of time, such as a second, we see that now we have a lower pitched sound than before. The difference between the high frequency and the low frequency is very great, just as on the top line. This great change of carrier frequency means high volume of sound.

On the bottom line the frequency changes at the same rate, per second of time, as on the line immediately above. This slow rate of change per second means a low pitched sound, or a sound of low audio frequency. There is not a very great difference between the higher and lower frequencies, and so this lower signal represents a low volume of sound.

Throughout all of the changes of sound pitch and volume shown by Fig. 5 there has been no change of carrier amplitude. The only changes are of carrier frequency.

Looking back at Fig. 1 we find two stages in the f-m receiver which are not in the a-m receiver. One is the limiter, for which there is no counterpart in the a-m receiver. The other is the discriminator, which takes the place of the detector in the a-m receiver. To understand how and why the limiter and discriminator stages of the f-m receiver operate as they do it is essential that three facts be kept in mind. They are:

1. The f-m carrier amplitude is not changed by the sound signal.
2. Changes of loudness, volume, or amplitude of the sound signal cause the f-m carrier frequency to vary from its average value. The louder the sound, or the greater the sound amplitude, the farther the f-m carrier frequency is driven from its average value. When there is no sound signal, or zero sound amplitude, the f-m carrier frequency does not vary from that average value. This effect of sound signal volume on f-m carrier frequency may be shown as in Fig. 6.
3. Changes of pitch or of audio-frequency in the sound signal cause the f-m carrier frequency to vary between higher and lower values at a rate

which is the same number of times per second as the number of cycles per second of the sound frequency.

DEVIATION

The louder the sound represented by the signal the greater will be the shift of the f-m carrier frequency from its average value. It has been agreed that the shift of frequency for the loudest sounds handled shall be 75,000 cycles or 75 kilocycles. The shift of frequency away from the average value is called frequency deviation or just deviation. There is nothing about frequency modulation that makes it absolutely necessary to use a deviation of 75 kc for audio signals of maximum amplitude, but this maximum deviation happens to be a value which reduces noise interference to a low value when a wide range of audio frequencies is being transmitted.

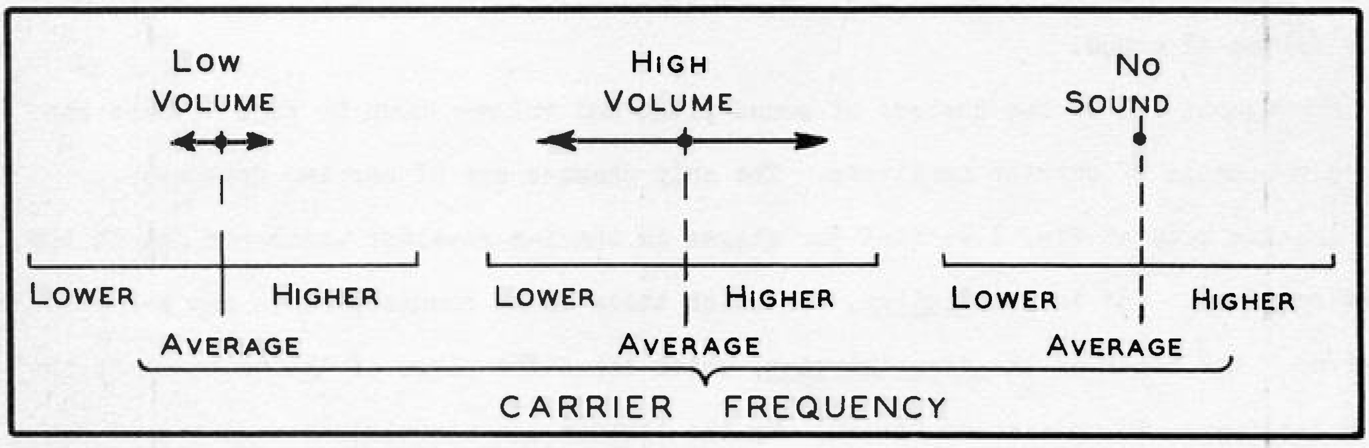

FIG. 6. Changes of carrier frequency correspond to changes of sound volume or loudness.

Fig. 7 shows the frequency distribution in a frequency channel used by a transmitter operating with frequency modulation. The average carrier frequency, at the center of the frequency channel, often is called the center frequency. The maximum deviation, for loudest sound signals, is 75 kc below the center frequency and 75 kc above that frequency. This makes a total maximum swing or change of carrier frequency which amounts to 150 kc. An additional 25 kc is allowed (for prevention of possible inter-station interference) below the lowest deviation and above the highest deviation. Thus the total range of frequencies used, or the total width of the f-m channel, becomes 200 kc.

You will occasionally hear the term "deviation ratio". This is the ratio of the maximum deviation to the maximum audio frequency transmitted in the signal. With a

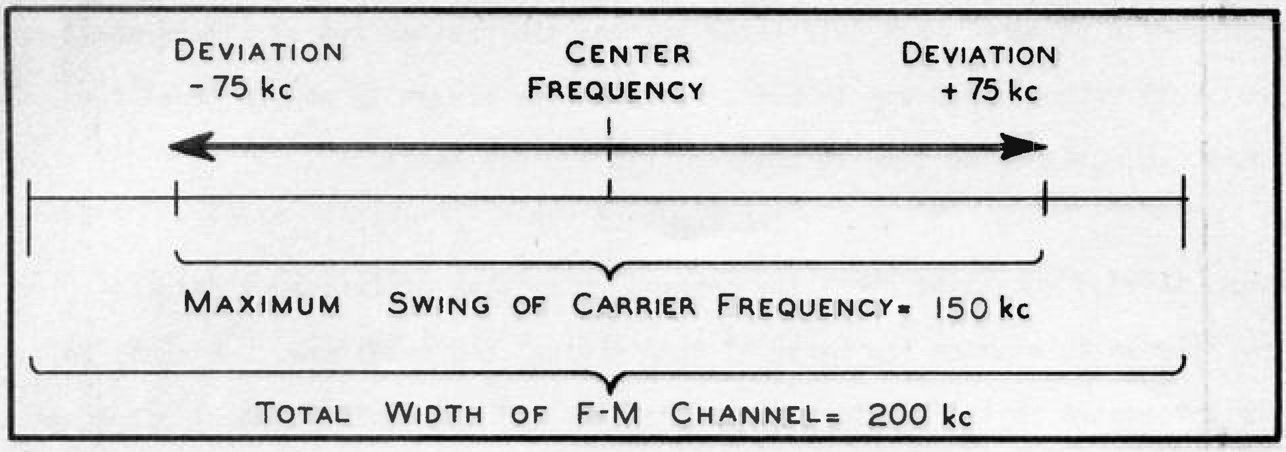

FIG. 7. Frequencies in a frequency-modulation channel when there is maximum deviation.

maximum deviation of 75 kc, and a maximum audio frequency of 15,000 cycles or 15 kc the deviation ratio is 75/15 or is 5. Were the maximum deviation 15 kc and the maxi- audio frequency 5,000 cycles or 5 kc the deviation ratio would be 15/5, or 3.

FREQUENCY BANDS

The present standard broadcast band of frequencies for a-m transmission extends from 550 to 1,600 kc, which is a total of 1,050 kc. Were f-m transmitting stations, with their 200-kc channels, to operate in this standard broadcast band there would be room for only five such f-m stations to operate simultaneously. To provide the necessary band width for the wide f-m channels this kind of transmission is carried on, for broadcasting, between the frequencies of 88 and 108 megacycles, which is the same as between 88,000 and 108,000 kilocycles. There is also an "emergency service" band extending from 152 to 162 megacycles.

The band extending from 88 to 108 mc, or from 88,000 to 108,000 kc, provides a total band width of 20 mc or 20,000 kc. This divides into 100 channels of 200 kc each. But many more than 100 f-m broadcasters may transmit at the same time, because the high-frequency signals have a useful distance range of less than 100 miles from the transmitter. Consequently, were they spaced apart by distances of 100 miles or somewhat less, any number of stations might be transmitting at the same time on each of the 100 channels.

The 88 to 108 mc f-m band sometimes is called the "new band", because in pre-war days the f-m band extended, for broadcasting, from 42 to 50 mc. Some transmission is continued in parts of this "old band" so that the pre-war f-m receivers won't be left entirely without programs to hear. Some of the presently manufactured f-m receivers are designed to tune in both the old and new bands.

THE F-M RECEIVER

Having learned something about the general principles of frequency modulation we now may proceed to examine the parts of some typical f-m receivers. We shall be chiefly interested in the workings of the limiter and the discriminator, which are parts found only in f-m receivers, but first it will be well to take a preliminary look at everything from antenna to loud speaker.

Our antenna circuit, or circuits, extending as far as the control grid of the radio-frequency amplifier tube, may employ the principles illustrated by Fig. 8. Here are shown three different kinds of antennas, all of which may be employed with the same receiver. At the left is shown an antenna especially well adapted for reception of the f-m radio frequencies in the band extending from 88 to 108 mc. This is a dipole antenna, consisting of two horizontal metallic rods, each a few feet long, extending outward in opposite directions. From the inner ends of the rods a twin-conductor transmission line runs to the f-m coupler A. In this coupler the primary winding, whose outer ends are connected to the line, has a center tap connected to ground. Across the secondary winding is a trimmer capacitor for tuning the secondary. The upper end of this tuned circuit is connected to the FM position on the selector switch.

For short-wave reception in bands from 6 to 26 megacycles (49 to 12 meters wavelength) there is shown a capacitance type of antenna, or Marconi type antenna, which usually consists of an elevated conductor at one end, and of the earth as a ground at the other end. This is the ordinary outdoor or indoor antenna with which most of us have long been familiar. For standard broadcast reception there is shown a loop antenna, which ordinarily is built into the receiver cabinet. The connection from the external antenna makes one or more turns around the loop so that, when desired, standard broadcast reception may be through this external antenna with the loop acting as the secondary winding of a coupler whose primary consists of the turns in the external antenna circuit. The loop is tuned by trimmer capacitor B. A connection runs

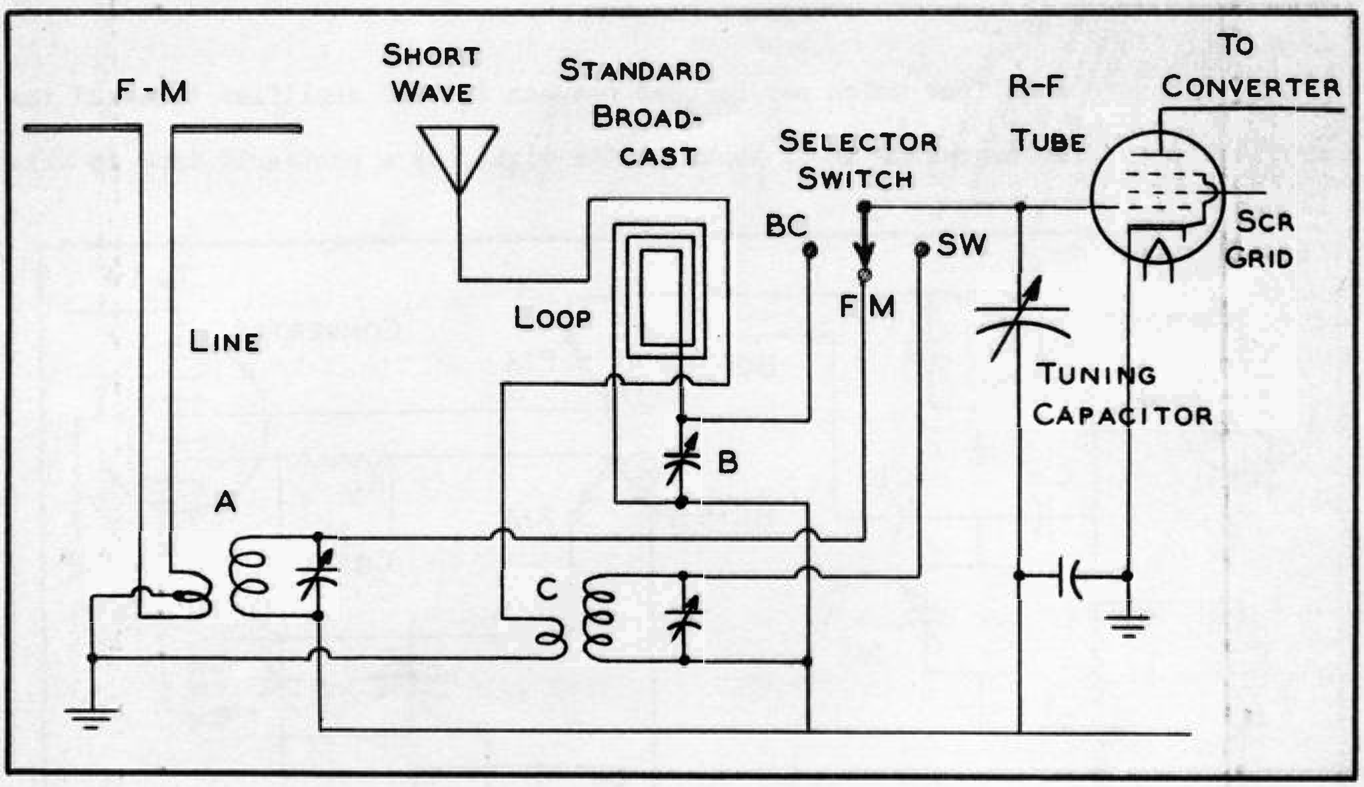

FIG. 8. Circuits between the antennas and the r-f amplifier tube.

from the tuned loop circuit to the BC contact of the selector switch.

Between the loop and ground the line from the external antenna goes through the primary of the short-wave coupler C, whose secondary is tuned by a trimmer capacitor, and from whose tuned secondary a connection is taken to selector switch contact SW.

The rotor of the selector switch is connected to the control grid of the r-f tube and to the main tuning capacitor in the control grid circuit. Turning this switch to one of its three positions connects into the grid circuit either the f-m coupler, the short-wave coupler, or the loop, and places the trimmer capacitor of the selected coupler in parallel with the main tuning capacitor. Separate adjustment of the trimmers allows each of the couplers to be tuned through its band or bands by operating the variable main tuning capacitor by means of the tuning control of the receiver.

The plate of the r-f tube is coupled to the signal grid of the following converter tube.

It should be kept in mind that in these diagrams we are illustrating general principles rather than the connections used in any particular make and model of receiver. However, the principles are those actually in use, and with minor modifications will be found in common use.

Fig. 9 shows connections which may be used between the r-f amplifier tube and the converter tube. The converter tube, shown at the right, is a pentagrid type in which

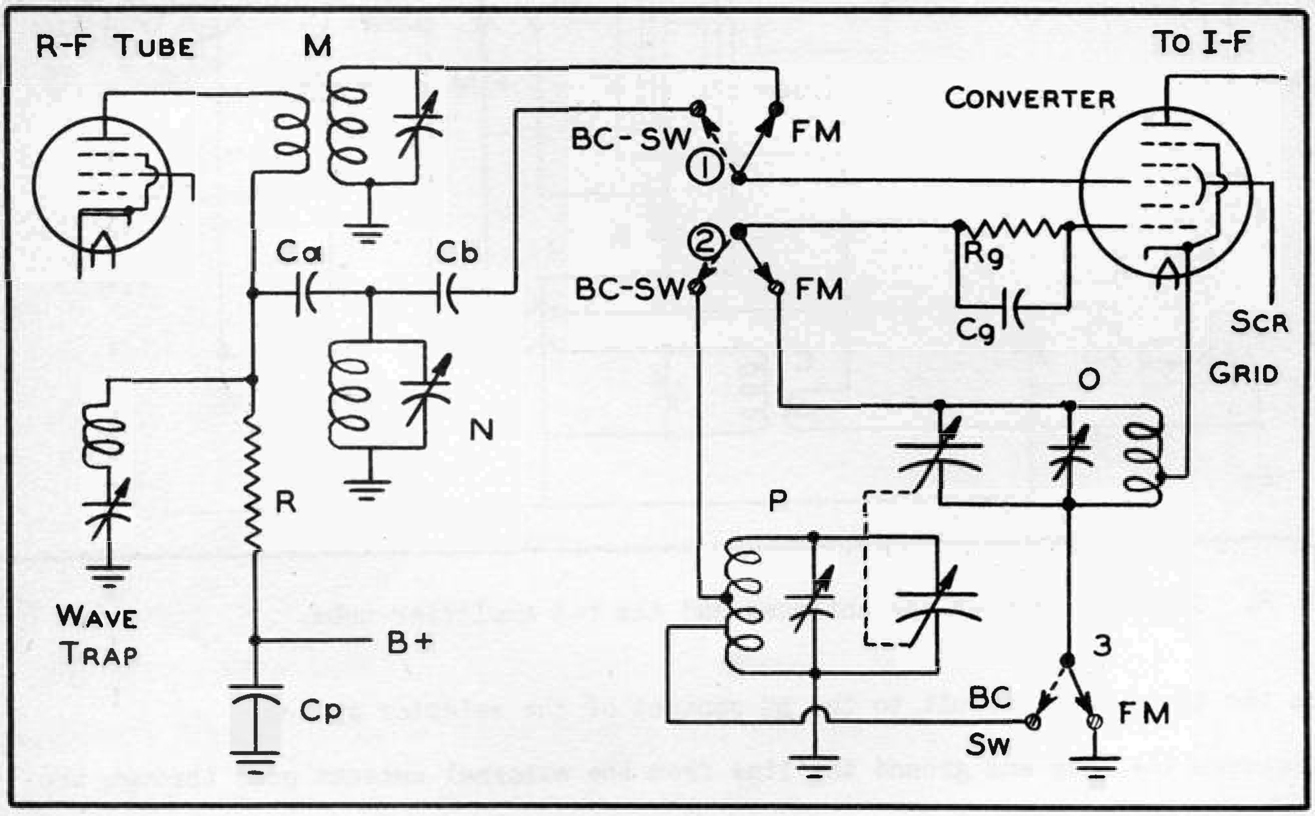

FIG. 9. Circuits between the r-f amplifier and the converter tube.

the grid immediately above the cathode is the oscillator grid, the next one is part of the screen grid, the third one is the signal grid, the fourth is part of the screen grid, and the fifth is the suppressor grid.

There are three selector switches; 1, 2 and 3, all shown in the positions forf-m reception. Switch 1 connects the converter signal grid to either the f-m couplerM or else the standard broadcast and short-wave couplerN. Switch 2 connects the converter oscillator grid, through a grid resistor and capacitor Rg and Cg, to either the tuned oscillator circuit O for f-m reception or else the tuned oscillator circuit P for standard broadcast and short-wave reception. Switch 3, for f-m reception, grounds the lower end of tuned circuit O while opening the output lead from tuned circuit P. For broadcast and short-wave reception this switch removes the ground from circuit O and connects the output of circuit P through part of the coil in O to the converter cathode. Various other types and arrangements of oscillator circuits might be used.

The variable tuning capacitors connected across the coils of circuits O and P are ganged together and operated from the panel tuning control. The smaller adjustable capacitors are trimmers.

Couplings M and N between the r-f tube plate and the converter signal grid are broadly tuned types. The small capacitors across the coils are trimmers. For f-m reception there is inductive coupling between the primary of M, in series with the r-f plate circuit, and the secondary. The primary is of small inductance, but its inductive reactance at the high frequencies of the f-m radio signals is high, and permits ample transfer of signal energy to the secondary.

At the relatively low radio frequencies of standard broadcast and short-wave reception the small inductance of the primary in coupler M has but little inductive reactance, and the signal passes through this primary and through resistor R and bypass capacitor Cp to ground. Potential differences in R, which accompany the signal currents in this resistor, are applied through coupling capacitor Ca to the tuned circuit of coupler N. This coupler is tuned to have high parallel impedance, and the signal is forced on through coupling capacitor Cb and switch 1 to the converter signal grid.

Connected between ground and a point just above coupling resistor R is a wave trap circuit consisting of a coil and adjustable capacitor in series. This trap circuit is tuned to resonance at the intermediate frequency being used for standard broadcast and short-wave reception. When so tuned, the trap circuit has minimum impedance at this frequency, and any signals at the intermediate frequency which may come through the antenna and r-f circuits are bypassed to ground and thus kept out of the converter signal-grid circuit.

Up to this point we are tuning and amplifying f-m radio frequencies in the very high range between 88 and 108 megacycles, and are tuning and amplifying standard broadcast and short-wave signals at much lower radio frequencies. The radio frequencies have been applied to the signal grid of the converter. Simultaneously there have been applied other frequencies from the tuned oscillator circuits O and P to the oscillator grid of the converter. The r-f and oscillator frequencies act together on the electron stream in the converter and produce either of two intermediate frequencies; one for f-m reception, and another for reception of standard broadcast and short-wave signals.

Tuning indudtances and capacitances used in f-m radio-frequency circuits are much smaller than those which we have been used to using for standard broadcast, or even for short-wave tuning. Fig. 10 illustrates an example of f-m tuning. The circuit includes a coil having an inductance of 0.10 or 1/10 of one microhenry. The

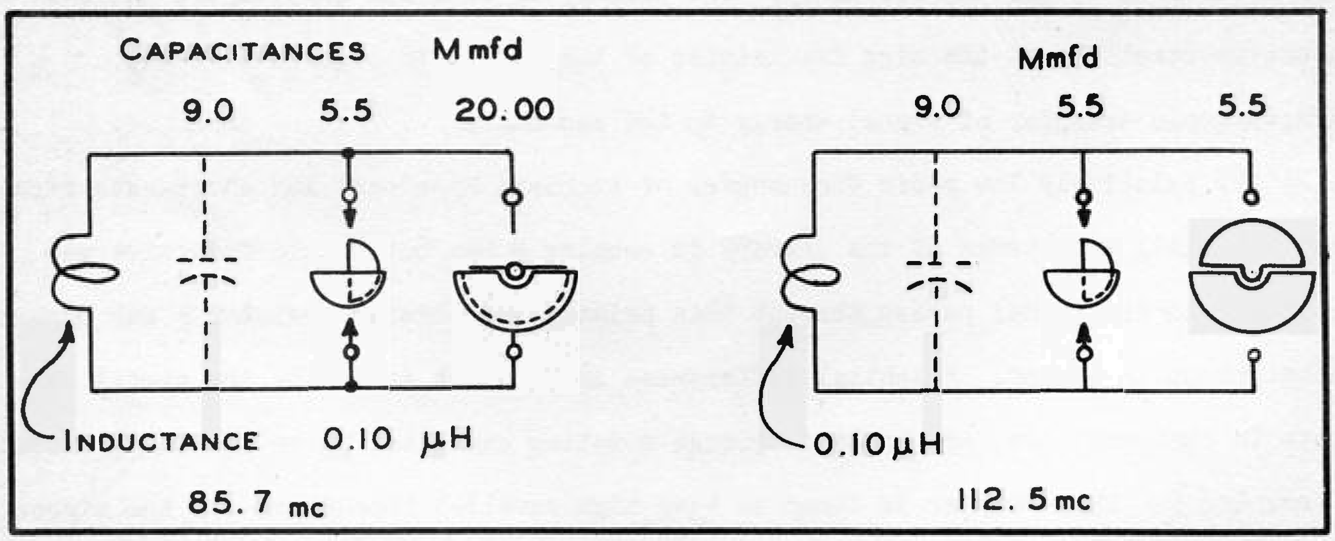

FIG. 10. The small tuning inductance and capacitances for high frequencies.

distributed capacitance of the coil and all the conductors in the circuit is represented by a broken-line symbol, and is assumed to have a fixed value of 9.0 mmfd (micro-microfarads). Next is represented a small trimmer capacitor, shown as adjusted to a mid-position and as having capacitance of 5.5 mmfd. At the right is the tuning capacitor, set for its maximum capacitance of 20.0 mmfd at the left and fc its minimum capacitance of 5.5 mmfd at the right.

With the maximum adjustable tuning capacitance of 20.0 mmfd this circuit will be resonant at a frequency of 85.7 mc, which is 2.3 mc below the low end of the f-m band. With minimum tuning capacitance the circuit will be resonant at 112.5 mc, which is 4.5 mc above the high end of the f-m band. An inductance of 0.10 microhenry would be provided by somewhat less than one and one-half turns of wire on a diameter of one-half inch when spfead out to occupy a length of one-quarter inch.

The intermediate-frequency amplifier which follows the converter is shown by Fig. 11. There are two stages of i-f amplification instead of the single stage usually found in superheterodyne receivers for the standard broadcast and short-wave bands. Two stages afe used for f-m reception because we require strong signals at the input to the following limiter stage if the limiter is to do its appointed work, and we have only rather small amplification per stage. The amplification per stage is less than in standafd broadcast and shoft-wave receivers because for f-m reception we employ an intermediate frequency on the order of 10 megacycles or higher instead of the 455 or 456 kilocycles generally used for standard broadcast i-f amplification. Amplification or gain pef stage always is less in high-frequency amplifiers than in those wofking at lower frequencies.

In Fig. 11 there are i-f transfofmers between the convertef and first i-f tube, between the two i-f tubes, and following the second i-f tube. Each transfofmer consists of two sections, each a complete transformer in itself. The upper section in each unit is tuned to the f-m intermediate frequency, while each lower section is tuned to the intermediate frequency used for standard broadcast and short-wave reception. Connected to the first i-f transformef is a selector switch that short-circuits the broadcast section (as shown) when f-m signals are to be received, and which short-cifcuits the f-m section when broadcast or short-wave signals are to be received. Such a selector switch is shown on only the first i-f transformer, although there might be similar switches on other i-f transformers also.

All of the primaries and secondaries of all the i-f transformers are parallel resonant circuits, which have high impedance at their tuned frequency, but have low impedance at all other frequencies. Consequently, the f-m frequencies meet high impedance in the upper sections of the transformers, but pass through the lower sections

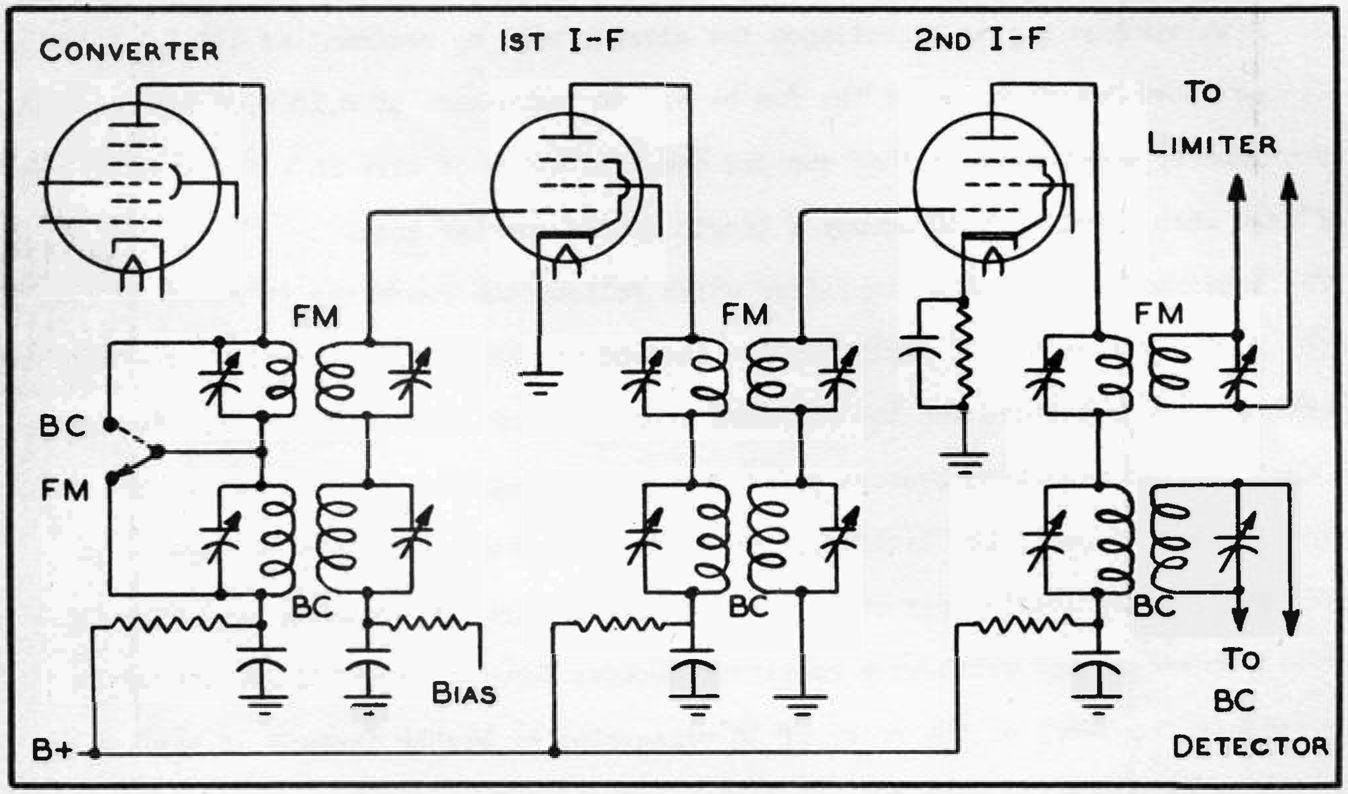

FIG. 11. The intermediate-frequency amplifier between the converter tube and outputs to the limiter and detector.

with little opposition. The standard broadcast or short-wave intermediate frequencies meet little opposition in the f-m sections of the transformers, but in the lower sections there is high impedance to these frequencies. Consequently, with the transformer sections connected in series, each section transfers energy from primary to secondary at the frequency to which it is tuned.

As we may see in Fig. 9, when the selector switches are set for f-m reception the converter receives f-m radio frequencies st its signal grid, and at its oscillstor grid receives an oscillator frequency such as combines with the radio frequency to produce the intermediate frequency required forf-m amplification. With the selector switches set for standard broadcast and short-wave reception, the two frequencies fed to the converter grids are such as to combine for production of the lower intermediate frequency used for these bands. Then whichever intermediate frequency is being produced in the converter is picked off by its particular section of the i-f transformers.

The secondaries of the last i-f transformer of Fig. 11 are not in series with each other. The upper secondary, tuned for the f-m intermediate frequency, connects to the input of the following limiter stage, which acts only when the reception is of f-m signals. The lower section, which is tuned for the standard broadcast and short-wave intermediate frequency, connects to the broadcast detector. This detector will be one of the diode types commonly used in superheterodyne receivers designed for reception of standard broadcast and short-wave bands.

THE LIMITER

The purpose of the limiter stage is to remove any amplitude modulation which gets into the frequency-modulated signal at any point between the transmitter and the input to the limiter stage in the receiver. The frequency-modulated signal which is supposed to remain at constant amplitude may have its amplitude varied at some instants by electrical interference reaching the receiver antenna circuit or by certain conditions which arise in the receiver circuits between the antenna and the limiter.

Although we shall examine the performance of the limiter stage in some detail a little later on it is well at this point to understand the kind of performance to be expected. At the upper left in Fig. 12 is represented a signal whose frequency may be modulated, but whose amplitude is supposed to remain at the constant value equivalent to the arrows. However, during the instant of time from A to B the amplitude has been varied by some effect inside or outside of the receiver, and this momentary variation of amplitude has come through the i-f amplifier to the limiter input. In passing through the limiter stage the amplitude peaks which exceed the desired constant value have been cut off, as shown at the upper right. The frequency or frequencies in the signal have not been altered, but the amplitude has been made of constant value. Were the amplitude not reduced to a constant value, any pulses such as the one between A and B would go on through to the discriminator and be reproduced from the loud speaker as noise.

At the lower left in Fig. 12 is represented a weaker signal than the one above.

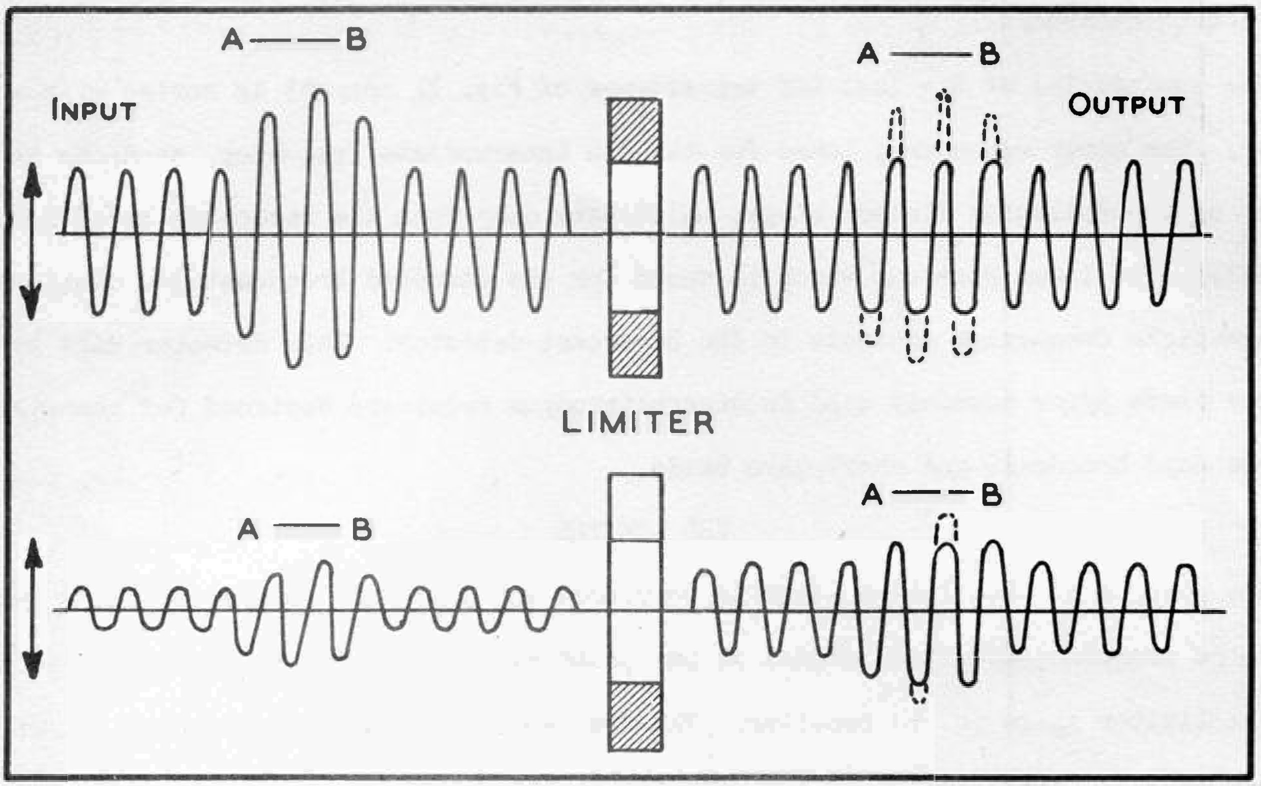

FIG. 12. How the limiter should act, and how it acts on very weak signals.

From the extreme left to point A, and from B toward the right, this weak signal is of constant amplitude and might be a frequency-modulated signal. But between A and B there is a variation of amplitude similar to the variation in the stronger signal up above. This weak signal is amplified by the limiter stage, and it issues from the output of the limiter as shown toward the right. All of the amplitudes have been increased by the amplification, and between A and B we have the amplified noise pulse which is the variation of amplitude from its desired constant value. Some of the noise peaks have been cut off, hut not all of them, and the noise will go through to the following discriminator and issue from the loud speaker.

The limiter stage really is an amplifier stage of a very special kind. Its output amplitude remains practically constant with all input amplitudes which are equal to, or in excess of, some certain value, which is the value represented by the arrows at the left in Fig. 12. Any input amplitudes which exceed this limit are not amplified but, on the other hand, are effectively reduced so far as the output is concerned. But input amplitudes which are less than the certain value mentioned will be amplified as shown by the lower diagram. If the input is very weak it will not be amplified up to the maximum output amplitude which can come from the limiter, although instantaneous input amplitudes of greater value may cause instantaneous maximum outputs from the limiter, as between A and B at the lower left.

In order that the output from the limiter stage may be of constant amplitude, or may be without amplitude modulation, it is necessary that the input amplitudes never fall below the value represented by the arrows in Fig. 12. This is the reason for providing high amplification in the preceding i-f amplifier. Even then, some signals reaching the antenna may be so weak that all of the amplification provided cannot raise their amplitude to the minimum required at the limiter input. If such signals are accompanied by noise pulses in the form of amplitude modulation, the noise will come through the loud speaker. Fortunately, the "service range" in miles of distance from an f-m transmitter within which signals may be received at all is such that the received signals are fairly strong. Beyond this range of fairly strong signals there can be no reception. The reason for this restricted service range will be discussed in following pages.

Before leaving the limiter stage we should look at Fig. 13, where is shown the behavior of this stage when the input from the i-f amplifier is of greater amplitude than the required minimum for limiter action. The output amplitude from the limiter is of the same value as at the top of Fig. 12. Everything, including any noise pulses of varying amplitude, has been brought to this output level, which is the maximum that can be delivered from the limiter. For most satisfactory operation, the constant-amplitude frequency-modulated input to the limiter should have amplitude greater than the minimum which makes the limiter cut off the peaks. That is, the input amplitude should be as represented in Fig. 13 rather than as in Fig. 12.

From the right-hand side of Fig. 14, a frequency-modulated signal at the f-m intermediate frequency passed from the i-f amplifier to the limiter, and an amplitude-modulated signal at the standard broadcast intermediate frequency passed to the broadcast

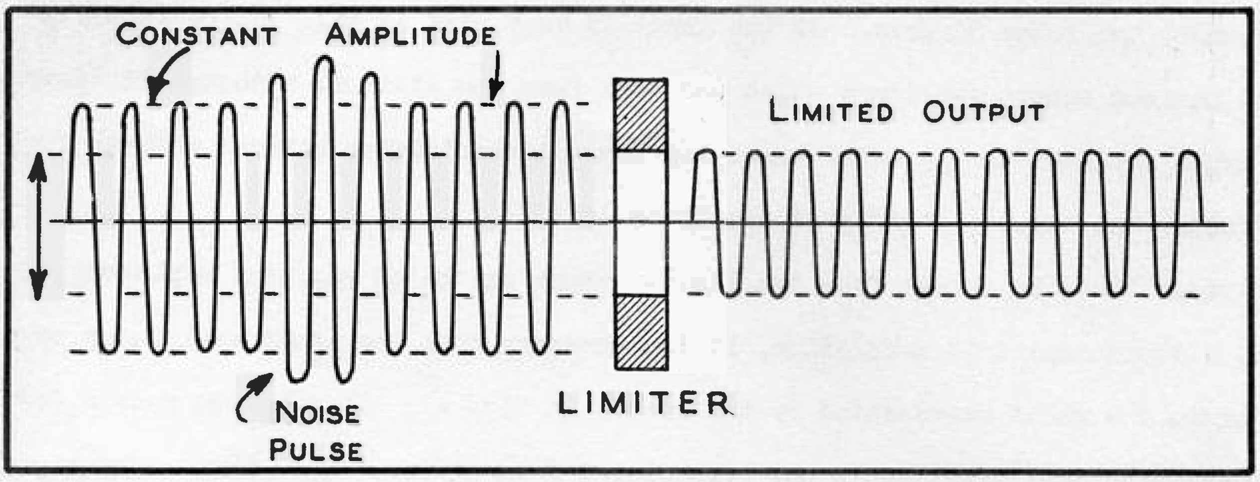

FIG. 13. How the limiter performs on a strong input signal.

detector. The two signal paths from the i-f amplifier are shown at the left in Fig. 14. The frequency-modulated signal goes to the limiter, where unwanted amplitude modulation is removed. From the limiter the frequency-modulated signal of constant amplitude goes to the discriminator, which changes this frequency-modulated signal

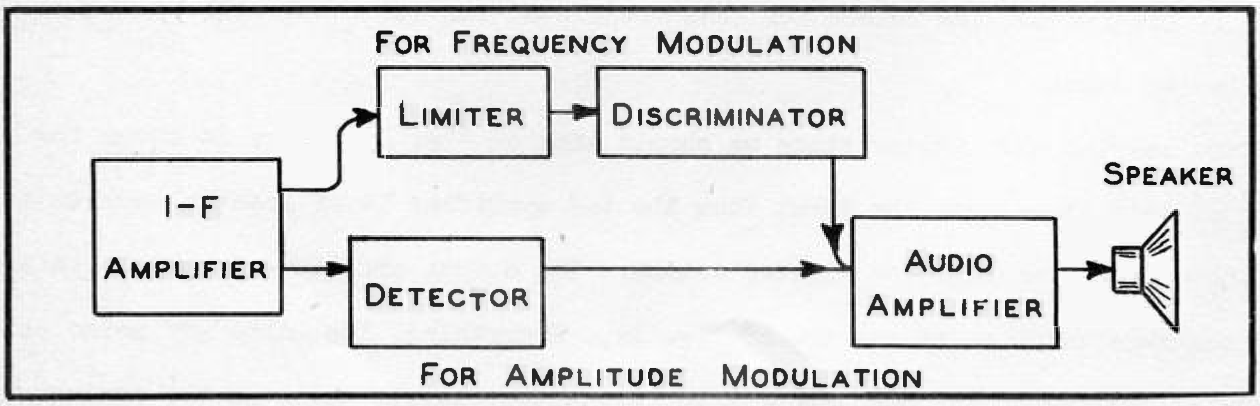

FIG. 14. For frequency modulation we use the limiter and discriminator stages.

(which is at intermediate frequency) into an amplitude-modulated signal at audio frequency. The audio-frequency signal then goes through the audio amplifier to the loud speaker.

From the i-f amplifier the amplitude-modulated signal goes to the detector used f amplitude modulation. This a-m detector is of the diode rectifier type such as used in practically all standard superheterodyne receivers. The detector changes the a-m signal, which is at the intermediate frequency used for standard broadcast, into an a-m signal at audio frequency. This signal goes through the same audio amplifier that is used for the f-m band, and goes to the same loud speaker.

The a-m detector changes only the signal frequency, from intermediate frequency to audio frequency, and does not have to change the kind of modulation. But the discriminator not only has to change the frequency from intermediate to audio, but has also to change the kind of modulation from frequency-modulation into amplitude-modulation.

The changes which have to be made by the discriminator may be shown as in Fig. 15. At the top is represented the input to the discriminator. This input is of constant amplitude, but of varying frequency. That is, the input potentials are frequency-modulated. The frequency varies from high to low and back again, over and over as the signal continues. When the frequency is highest we say that there is maximum deviation in one direction, and when the frequency is lowest there is maximum deviation in the opposite direction. Midway between its highest and lowest values, the input frequency goes through its average value, which we call the center frequency. If this constant-amplitude signal were not modulated with a sound signal, its frequency would remain at the center or average value. It is modulation by sound signals at the transmitter which causes the frequency to vary, or to deviate.

Down below in Fig. 15 is shown the output potential from the discriminator. At every instant in which the input goes through its center-frequency value the output potential is of zero value. This means that while the incoming signal is not modulated, or while no sound is being put onto the transmitted signal, the output from the discriminator will be of zero potential, which means no output at all.

At every instant in which the input frequency increases to a value higher than the center value, the discriminator output potential increases in a direction shown as positive in the diagram. And when the input frequency drops below the center value, the discriminator output potential increases in a direction opposite to that for opposite deviation, or increases in a negative direction as shown on the diagram.

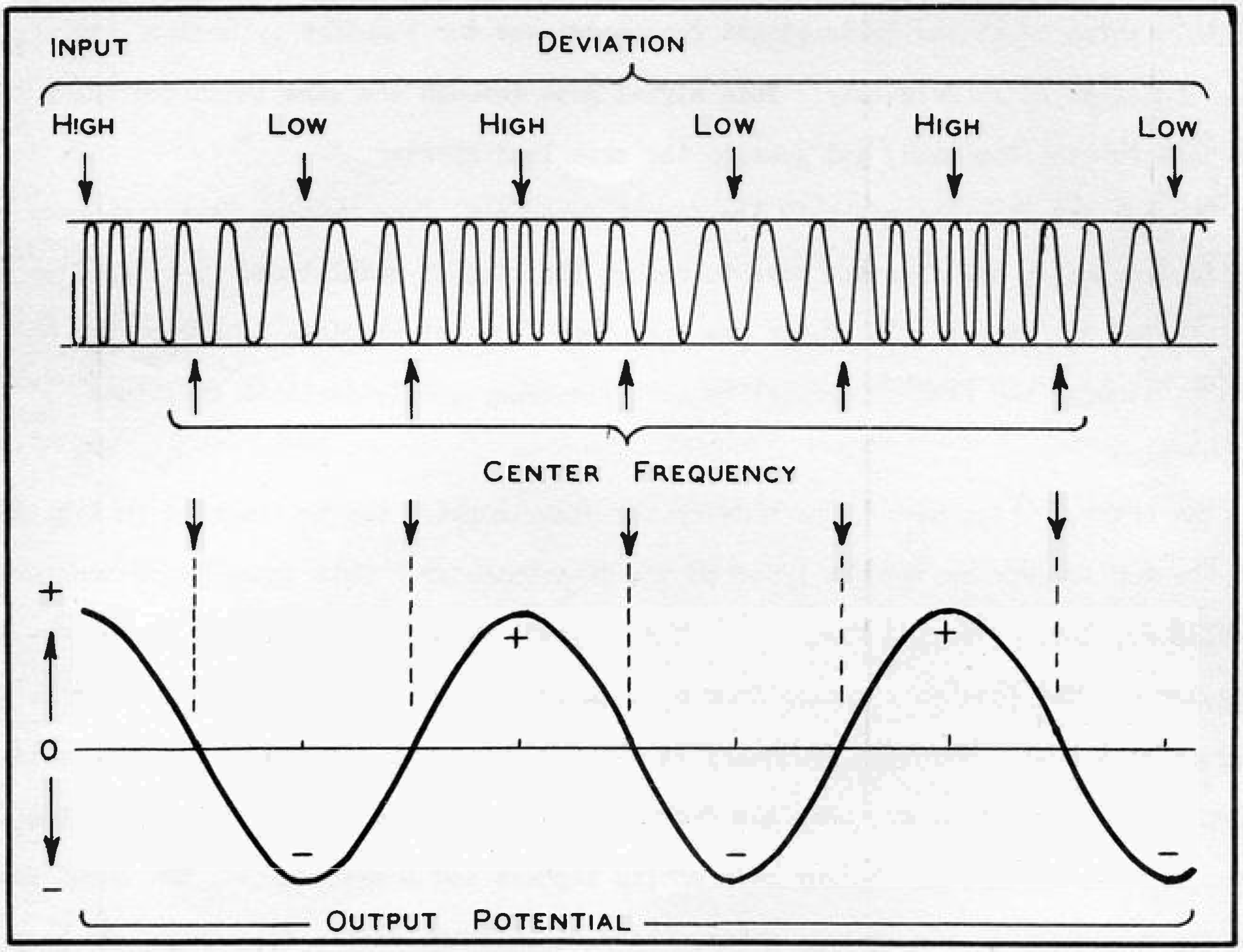

FIG. 15. The change from frequency modulation at intermediate frequency into amplitude modulation at audio frequency that occurs in the discriminator.

The greater the deviations of frequency in the input the greater will be the corresponding positive and negative peaks of output potential.

Here we have an output potential whose strength (amplitude) varies directly with frequency deviation of the incoming signal, the greater the deviation the stronger is the output. And we have output potentials which vary their direction or polarity at the same rate per second as the rate of changes of frequency in the input. Changes of frequency in the input occur at sound frequency or audio frequency, and so changes of potential in the output likewise occur at audio frequency. Changes of potential are changes of amplitude, and so we have changed frequency modulation of the input into amplitude modulation of the output of the discriminator.

Back near the beginning of this lesson there were two statements; one, that sound pitch (audio frequency) is represented by <u>how often</u> the carrier frequency changes, and the other, that sound volume is represented by <u>how much</u> the carrier frequency changes. These statements describe the discriminator performance shown by Fig. 15. The rate of change or the frequency of change in output potential is the same as the rate of change of frequency in the input. Thus we recover the original audio frequency in the form of amplitude changes or potential changes which will actuate the control grid of the audio-frequency amplifier tube.

The extent of the changes of output potential, or the volts values reached by the potentials in their positive and negative polarities, correspond exactly to how much the input frequency varies. The greater the variation (deviation) of input frequency, the greater are the output potentials and the louder are the sounds from the speaker.