F-M DETECTORS

Lesson RRT-17

DE FOREST'S TRAINING, INC.
2533 N. Ashland Ave., Chicago 14, Illinois

Radio Reception
and Transmission

LESSON RRT-17

F-M DETECTORS

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1929—Commercial ship-to-shore telephone service established by A. T. and T. with the largest American ship, the S. S. Leviathan.

1934—The Federal Radio Commission of seven members was created to regulate communication by wire and radio.

1934—Mobile two-way radio was developed and put into operation for the Boston Police Department.

1936—The first ultra-high-frequency automatic relay circuit was opened by RCA between New York and Philadelphia, simultaneously transmitting facsimile and multiple radio-telegraph messages.

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INDEX

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WHAT LIFE MEANS

It does not consist in being happy, but in making others happy.

It does not consist in seeking satisfaction, but in finding satisfaction in what satisfies others.

It does not consist in what we do, but in how and why we do it.

It does not consist in what we seem to be, but in what we are.

F-M DETECTORS

The explanations of the preceding lesson included comparisons of a-m and f-m and traced the path of a modulated carrier from the antenna through the r-f, mixer, i-f and limiter stages of an f-m receiver. Reviewing briefly, the output of the limiter is of constant amplitude and its modulation is in the form of frequency variations or deviations. The amount of deviation, above and below a mean frequency, is proportional to the amplitude of the modulation while the rate of deviation is equal to the frequency of the modulation.

In both a-m and f-m systems, at the transmitter the carrier is modulated by the same type of audio signals and in the receiver, the carrier must be removed to obtain voltages which duplicate those of the original modulation. Therefore, the f-m detector must convert the frequency deviations of its input to an output of the same waveform and frequency as the original modulation.

Commercial broadcast f-m receiver with chassis partially removed from cabinet.
Courtesy Radio Engineering Laboratories, Inc.

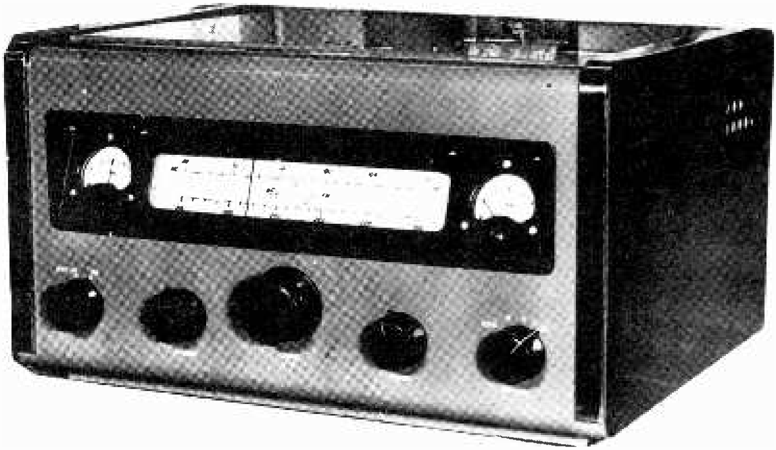
One of the first and perhaps simplest methods of f-m detection is by means of "de-tuned" triode detector, shown in the diagram of Figure 1. Here, secondary L of the i-f transformer T is tuned by condenser C to a frequency F_R somewhat below that of the mean intermediate frequency, F_C. These frequency relations are indicated in the response curve of Figure 2A which shows the variations in voltage which appear across the tuned circuit LC through its frequency response range. That is, if a voltage of constant amplitude and varying frequency is induced in circuit LC of Figure 1, the output voltage, plotted against frequency, will provide the response curve of Figure 2A.

When the mean i-f, F_C, is applied to the input of the circuit of Figure 1, the voltage across LC is approximately half the value developed at resonance, F_R, as indicated in Figure 2A by the intersection of the broken F_C ordinate and the solid line response curve. The sine wave at the upper right of the curve indicates the variations of frequency above and below F_C during one cycle of the modulating voltage. As shown by the vertical dotted lines, the frequency variations result in corresponding changes of the voltage across LC. This voltage variation, shown between points X and Y, will be linear if the frequency swing is confined to the straight portion of the response curve.

With a decrease of intermediate frequency, the voltage across LC increases in amplitude and causes an increase of the grid leak bias voltage developed across the parallel components R_1C_1 in Figure 1. The higher grid bias reduces the plate current of tube V, and causes its plate voltage to rise. When the i-f increases, the grid bias decreases, the plate current increases and the plate voltage is lowered. These variations in plate voltage constitute the a-f output, as indicated in Figure 1, and by the dotted lines drawn from the response curve of Figure 2A to the sine curve of Figure 2B.

In this example, the resonant frequency F_R of the tuned circuit is lower than the mean i-f, F_C, but the same results can be obtained by tuning LC to a frequency somewhat higher than F_C. Thus, a tuned circuit, resonant to a frequency somewhat higher or lower than the mean intermediate frequency, has the property of converting frequency variations of input voltage into amplitude variations of output voltage. Following this plan, any of the conventional a-m detector circuits can be used to obtain an output voltage, the frequency and amplitude of which corresponds to the frequency variations of the input voltage.

The simple f-m detector circuit of Figure 1 is exactly like that of a non-regenerative grid-leak detector used in a-m superheterodyne receivers except that for a-m, the LC circuit is tuned to exact resonance at the intermediate frequency F_c. In fact, the operation of the circuit of Figure 1 was explained primarily to illustrate a means of detecting f-m signals in terms of familiar circuit actions. It also explains why a-m communication receivers, covering frequencies in the f-m band, can be tuned to provide intelligible reception of f-m signals. In effect, the output voltage slides up and down the sides of the response curve of Figure 2A therefore, this method of detuning the resonant LC circuit, to convert changes of frequency to corresponding changes of amplitude, is known as "Slope Detection".



F-M receiver of previous illustration, as it appears housed in metal cabinet.
Radio Engineering Laboratories, Inc.

DISCRIMINATORS

One group of f-m detectors, known as "discriminators", has the ability to discriminate between frequencies above and below a mean or resting frequency, but the output varies with changes of input amplitude as well as frequency. However, if all amplitude changes are removed by a preceding limiter stage, the discriminator output is proportional to the frequency variations only. The two general types of discriminators employed in f-m receiver design, are the "de-tuned circuit", and the "center-tuned" or Foster-Seeley.

DE-TUNED CIRCUIT DISCRIMINATOR

A schematic diagram of the de-tuned circuit type, used in early models of f-m receivers, is shown in Figure 3. The circuit is built around the discriminator transformer, which includes the primary coil L_1 and the two secondary coils, L_2 and L_3. Diode V_2 is in series with the tuned circuit L_2C_2 and the load resistor R_2, while diode V_3 is in series with the tuned circuit L_3C_3 and the load resistor R_3. Resistors R_2 and R_3 are connected in series, and the output voltage e_0 is developed across both.

In operation, primary L_1 is tuned by condenser C_1 to resonance at the mean intermediate frequency, while L_3C_3 and L_2C_2 are tuned, respectively, to resonance at frequencies above and below the i-f. Since the i-f in the primary L_1 periodically varies above and below its mean value, it approaches the resonant frequency of each of the secondaries during every complete swing. During the interval that the i-f is at or near the resonant value of L_2C_2, the voltage across this tuned circuit rises to a higher value which causes an increase of current in V_2 and a larger voltage drop across the load resistor R_2. Likewise, when the i-f is at or near the resonant value of L_3C_3, a higher voltage drop is developed across load resistor R_3.

Referring to Figure 3, the polarities of the voltage drops across R_2 and R_3 are in opposition, with respect to each other. Therefore, at any instant, the output voltage e_0, between the cathodes of V_2 and V_3, will be equal to the algebraic sum or arithmetical difference of the voltage drops across R_2 and R_3. With respect to the grounded cathode of V_3, the voltage drop across R_2 is positive while that across R_3 is negative.

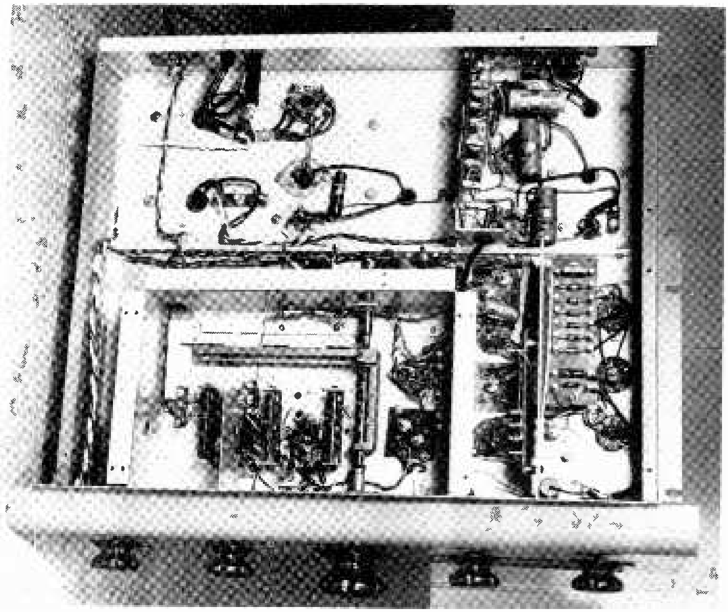
The complete action is illustrated in Figure 4A where the amplitudes of the voltages across R_2 and R_3 are plotted against frequency. Because of their opposite polarities, the drop across R_2, indicated as E_{R2} is drawn above the "0" or base line while the drop across R_3, indicated as E_{R3}, is drawn below the base line. The central broken line section of the curve indicates the sum or e_0 voltage during the interval of drops across both resistors.

To illustrate with definite values, assume the mean i-f is 10.7 mc, that L_2C_2 is tuned to 10.6 mc, while L_3C_3 is tuned to 10.8 mc and, at frequencies 100 kc or .1 mc off resonance, the tuned circuit outputs are approaching zero.

Starting at the left of Figure 4A and following the curve, at 10.5 mc voltage E_{R2} is low and voltage E_{R3} is negligible. As the frequency increases, E_{R2} increases also and reaches maximum at 10.6 mc, the resonant frequency of L_2C_2. As the frequency continues to increase, E_{R2} decreases and E_{R3} increases so that the total voltage e_0, indicated by the broken line section of the curve, drops to zero at the mean i-f of 10.7 mc.

As the frequency increases further, E_{R2} continues to decrease while E_{R3} continues to increase, reaching maximum at 10.8 mc, the resonant frequency of L_3C_3. For still further increases of frequency, E_{R3} decreases and reaches a low value at 10.9 mc. When the frequency reduces from 10.9 mc to 10.5 mc, the amplitude and polarity of the output voltage will retrace the sine wave curve.

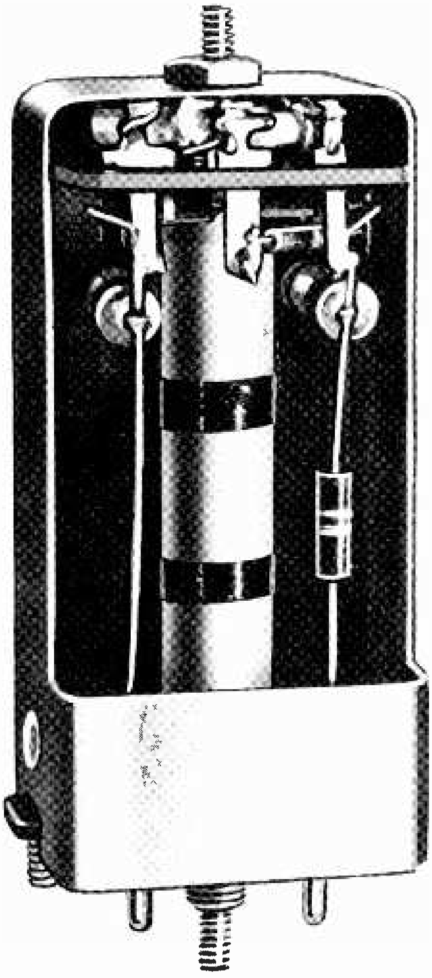
Thus, each complete cycle of input frequency swing, from 10.5 mc to 10.9 mc and back to 10.5 mc, will develop two cycles of output voltage. However, the f-m broadcast channels are limited to 200 kc with a maximum deviation of ± 75 kc, therefore the useful range of the output voltage covers only 150 kc as shown in Figure 4B. Here the lower frequency



Bottom view of f-m receiver shown in two previous illustrations. Here the cover plates are removed, and the component layout and wiring can be seen.

Radio Engineering Laboratories, Inc.

limit is 10.7 — .075 mc = 10.625 mc and the upper limit is 10.7 + .075 = 10,775 mc. Remember, the frequency swing is twice the deviation and here, 10.775 — 10.625 = .150 mc = 150 kc.



Perco f-m discriminator transformer assembly. Courtesy Linell Engineering Corporation

The characteristic "S" type discriminator output curve of Figure 4B is redrawn in Figure 5A to represent an exactly linear relationship between input frequency and output voltage. Here, f_r represents the mean frequency which provides zero output as indicated by the "0" intersection of the curve and the base line. During each complete cycle of modulation, the frequency will deviate from f_r down through f_1 to f_2, then back through f_1, f_r, f_5, f_6 and back through f_5 to f_r. The corresponding values of output voltage are indicated on the curve by the intersections numbered 0, 1, 2, 3, 4, 5, 6, 7 and 8.

The time interval between these successive values of frequency and output depends upon the waveform of the modulation and when it is sinusoidal, as in Figure 5A, the elapsed time between each adjacent pair of numbered intersections or frequencies is the same. To plot a conventional curve of the output voltage, amplitude vs time, in Figure 5B the base line, which represents time, is divided into eight equal parts. These are numbered to correspond with the successive intersections on the curve of Figure 5A. The points of the curve are plotted by projecting the numbered points on curve 5A over to their intersection with the corresponding ordinate of Figure 5B. Thus, each sinusoidal swing cycle of input frequency provides one cycle of sine wave output voltage.

The frequency swing is proportional to the amplitude of the modulating voltage and, for proper reproduction of the signals, this relationship must be carried over to the discriminator output. This action is illustrated in Figure 5A where, if the input frequency swings only from f_1 to f_5, the amplitude of the output voltage will be reduced as indicated by the broken line curve of Figure 5B. Thus, the frequency of the output voltage is equal to the rate of input frequency swing and its amplitude is proportional to the amount or range of input frequency swing.

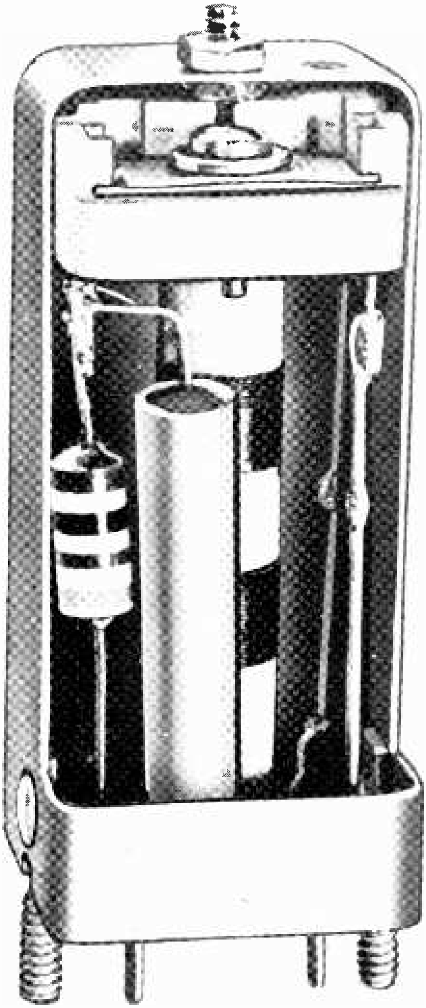
THE FOSTER-SEELEY DISCRIMINATOR

The foregoing explanations of the original discriminator circuit of Figure 3 were given for the purpose of showing the common method by which frequency changes of the f-m input are made to appear as corresponding changes of amplitude in the output. Later types of discriminator circuits are somewhat more compact, requiring the use of but two tuned circuits in place of the original three.

As the operation of the popular Foster-Seeley discriminator is based upon the phase relationships of voltages and currents in tuned circuits, the explanation of its action will be simplified through the use of vector diagrams. The vector addition of currents differing in phase by 90 was explained in connection with phase modulation in the lesson on Frequency Modulation Transmitters; and as an example of problems involving vectors at angles other than 90°, assume the following conditions for the circuit of Figure 6A.

Here, a-c sources E_1 and E_2, both operating at the same frequency, are connected in series across resistor R. The 25 volt maximum output of E_2 leads the 40 volt maximum output of E_1 by 60° and it is desired to determine the relative amplitude and phase of the resulting voltage drop across resistor R. The vector addition of these voltages is illustrated in Figure 6B where vector ob is drawn horizontally as a reference line and of a length to represent the 40 volts of E_1. Vector oa is then drawn at a leading angle of 60° and, as indicated by the 5 volt divisions, of a length proportional to the 25 volts of E_2.

A parallelogram is completed by drawing line am equal in length and parallel to ob, and line bm equal in length and parallel to oa. The diagonal, which represents the resultant voltage E_R, is then drawn in and marked off into 5 volt divisions. The magnitude of E_R is found to be approximately 57 volts and measured with a protractor, the leading angle of E_R is found to be about 23°.



Perco output i-f transformer with built in resistance-capacitance filter.
Courtesy Linell Engineering Corporation

In the basic arrangement of the Foster-Seeley type discriminator circuit, shown in Figure 7A, the input transformer consists of the primary L_1, and the center-tapped secondary L_2L_3. Primary L_1 is tuned by condenser C_1 to the normal or mean i-f and condenser C_2 tunes secondary coil L_2L_3 to this same frequency. In addition to the inductive coupling provided by the transformer, there is capacitive coupling direct from the plate of the final limiter tube to the secondary center tap through condenser C_C.

The discriminator contains the two diodes, V_1 and V_2, and the output voltage e_0 is developed across the two load resistors, R_1 and R_2. The upper diode circuit is from the plate of tube V_1, through the L_2 section of the secondary to the center tap, through the choke L, the load resistor R_1, and back to the cathode. The other diode circuit is from the plate of V_2, through the L_3 half of the secondary to the center tap, through choke L and resistor R_2 to the cathode. Condensers C_3 and C_4 serve to bypass the i-f so that only the audio variations appear across the load resistors.

Also a bypass condenser (not shown) between B+ and ground, has negligible reactance at the intermediate frequency. Therefore, in the simplified circuit of Figure 7B, the i-f voltage across primary L_1 is impressed across choke coil L through condenser C_C. As far as the coupling action is concerned, choke coil L could be replaced with resistor R, shown in broken lines, but the choke is preferred since it offers high impedance to the i-f without causing a high I^2R loss due to the diode currents it carries.

The remainder of the diagram represents either one of the diode circuits. At the intermediate frequencies, the reactance of condensers C_3 and C_4 in Figure 7A is negligible therefore, in Figure 7B, end X of choke L and the cathodes of the diodes are shown at i-f ground potential. Here, the circuit of V_1 is from the plate of the diode, through L_2, choke L to ground, and back up to the cathode. The other diode circuit can be traced in the same way through V_2, L_3 and L therefore the complete discriminator circuit is symmetrical.

Notice here, each diode circuit includes one half of secondary L_2L_3 but choke coil L is in series with both. Voltages are induced in secondary L_2L_3 by its inductive coupling with primary L_1 but voltages across choke coil L are caused by its capacitive coupling to the plate of the limiter tube. Thus, each diode circuit includes two independent sources, 1: the voltage across half the secondary L_2L_3 and 2: the voltage across choke coil L.

Equivalent circuits for each diode are shown in Figure 8A where the applied voltages are represented as a-c generators in series with the load resistor, which includes the diode, in an arrangement identical to that of Figure 6A. Since the discriminator circuit includes but one choke coil L, a more exact representation of the equivalent circuits is given by the arrangement of Figure 8B in which the two sections of Figure 8A have been combined. Once more, notice carefully, each diode circuit includes two sources of signal voltage, E_L and E_{L2} for V_1 with E_L and E_{L3} for V_2.

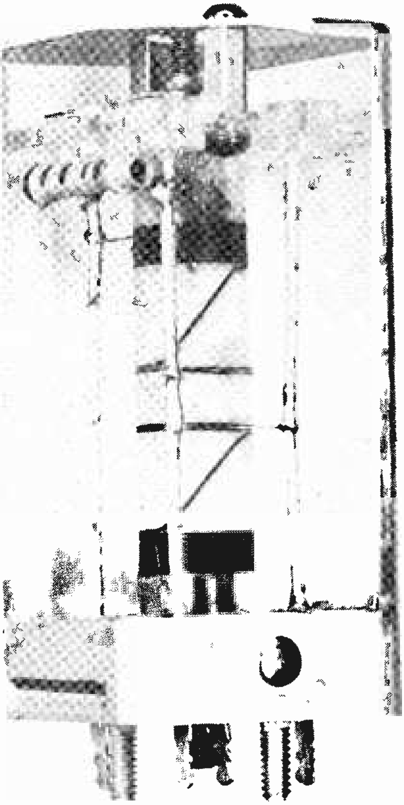
The proper operation of the discriminator depends upon the phase relationships between these voltage sources and can be explained best by means of vectors therefore, the diagrams of Figure 9 are drawn with reference to the circuit of Figure 7A.

Starting with Figure 9A, the voltage across the tuned primary L, is represented by vector E_{L1}. Since the inductance of L_1 is much greater than its resistance, the primary current, represented by vector I_{L1} lags the voltage E_{L1} by approximately 90°. The magnetic field set up around primary L_1 varies with the current therefore vector I_{L1} can be considered as representing the magnetic flux also. These flux lines extend through the secondary L_2L_3 and induce a voltage E_i, the amplitude of which is proportional to the rate of cutting. Since the rate of cutting is greatest when the value of the primary current I_{L1} is passing through zero, and lowest when I_{L1} is maximum, the induced voltage E_i lags the flux and I_{L1} by 90°. Thus as shown in Figure 9A, the induced voltage E_i in the transformer secondary lags I_{L1} by 90° and is 180° out of phase with E_{L1}.

This induced voltage causes a secondary current I_S, with a phase relationship, to E_i, that depends upon the nature of the secondary impedance, which, in turn, depends upon the frequency of the signal at any instant. With an input at the "mean" frequency, at which the tuned circuit $L_2L_3C_2$ is resonant, the inductive and capacitive reactances are equal, their effects are neutralized, and the circuit is purely resistive. As shown in Figure 9B, under these conditions the current I_S is in phase with E_i.

At frequencies above resonance, the inductive reactance increases while the capacitive reactance decreases, therefore the circuit becomes inductive and the current I_S lags the voltage E_i by some angle θ, as shown in Figure 9F. At frequencies below resonance, the inductive reactance decreases while the capacitive reactance increases, therefore the circuit becomes capacitive and I_S leads E_i as indicated in Figure 9H.

To follow the action through the secondary circuits, in Figure 10A the induced voltage E_i is indicated as an external source in series with coil L_2L_3 connected across tuning condenser C_2. The circulating current caused by this voltage is represented by the circular arrow I_S and the phase relationships between E_i and I_S of Figure 10A are indicated by



A typical high frequency shielded coil used in FM receivers.

Courtesy The National Company

the corresponding vectors of Figure 9.

The secondary current I_S, produces a voltage drop E_S across coil L_2L_3 and since the coil offers a practically pure inductive reactance, E_S will lead I_S by very nearly 90°, whether or not the circuit is resonant at the frequency of the input voltage.

As indicated in Figure 10B, the center tap of the coil divides voltage E_S into E_{L2} and E_{L3} but with E_S across the entire coil, the relative phase of the voltages across terminals A-B, A-C and B-C is the same. Therefore, as E_S lags I_S by 90°, E_{L2} and E_{L3} also lag I_S by 90° and in Figure 9, the E_{L2} and E_{L3} vectors must be drawn at right angles to vector I_S.

However, center tap B, Figure 10B, is common to both diode circuits and, with it as the reference point, voltage E_{L2} is of opposite polarity or 180° out of phase with respect to voltage E_{L3}. To indicate this condition, in Figure 9 vectors E_{L2} and E_{L3} are drawn at an angle of 90° with respect to vector I_S but at an angle of 180° with respect to each other.

Referring to the circuit of Figure 7B, voltage E_{L1} is coupled to the choke L through condenser C_C, and since the reactance of choke L is very high, compared to that of coil L_1, it has little effect on the total impedance of the tuned primary circuit. Consequently, voltage E_L across choke L can be considered as equal to, and in phase with, the primary voltage E_{L1}. Therefore, as indicated in the vector diagram of Figure 9A, E_L can be substituted for E_{L1}. With this substitution, the diagrams of Figure 9A and 9B are combined in Figure 9C, which indicates the phase relationships of the four voltages E_i, E_L, E_{L2} and E_{L3} and the current I_S. Since E_L is in phase with E_{L1} at all times, it is also always 180° out of phase with E_i, as shown in the diagrams of Figures 9C, 9F and 9H.

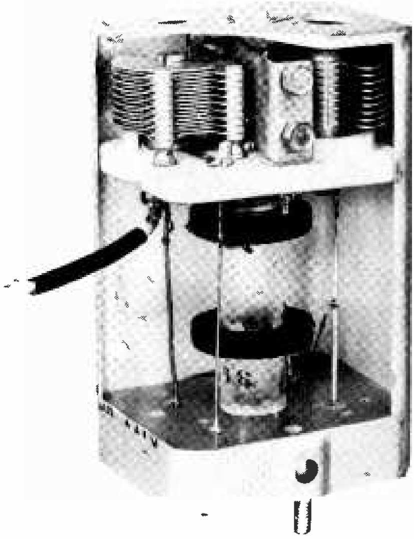
In the explanation of Figure 8 it was stated that the V_1 diode circuit contains the two voltage sources E_L and E_{L2} therefore, as explained for Figure 6, the total or resultant voltage which causes diode current in the V_1 circuit, is the vector sum of these two applied voltages. At the mean or resonant frequency, E_L and E_{L2} are 90° out of phase as in Figure 9C, and their resultant can be represented by the vector E_{V1} in Figure 9D. Similarly, the V_2 diode circuit contains the two voltage sources E_L and E_{L3}, and it is their vector sum which causes diode current in this circuit. At the resonant frequency of $L_2L_3C_2$, E_L and E_{L3} are 90° out of phase, and their resultant is represented by vector E_{V2} in Figure 9E.

The magnitude of the respective diode currents is determined by the amplitude of the corresponding resultant voltages, E_{V1} and E_{V2} which, as indicated in Figures 9D and 9E are equal at resonance. Equal voltages cause equal diode currents and, therefore equal voltage drops across load resistors R_1 and R_2 of Figure 7A. However, as the respective voltage drops are of opposite polarity, the total or effective output voltage e_0 has a value of zero.

When the input frequency swings above resonance, the respective phase relationships of E_L, E_{L2}, and E_{L3} are as shown in Figure 9F, and adding them vectorially, as in Figure 9G, the resultant E_{V2} is greater in magnitude than E_{V1}. Likewise, when the input frequency swings below the center frequency, E_L, E_{L2} and E_{L3} have the phase relationships shown in Figure 9H, and the vector addition of Figure 9-I shows the resultant E_{V1} is greater than E_{V2}.

Because of these variations in the respective amplitudes of E_{V1} and E_{V2}, the V_1 diode circuit current will be greater than that in the V_2 diode circuit when the input frequency is below resonance and less than that in the V_2 circuit when the input frequency is above resonance.

Since the voltage drops across load resistors R_1 and R_2 are of opposite polarity and proportional to their respective diode currents, the output e_0 will: 1: be zero when the i-f is at the mean or center frequency, 2: be positive with respect to ground when the i-f swings below the center frequency; and 3: be negative with respect to ground when the i-f swings above the center frequency. Thus, the circuit output voltage will vary in amplitude and polarity at a rate determined by the frequency modulated i-f input, and its output vs time curve will be the same as that shown in Figure 5B, which as stated previously, represents the audio output of the discriminator circuit.



Shielded i-f transformer with air-core trimmers shown mounted in upper section of the can.
Courtesy The National Company

Amplitude modulation of the input would vary the amplitudes of voltages E_L, E_{L2} and E_{L3} and thus the lengths of the corresponding vectors in Figure 9. For example, an increase of input amplitude would cause proportional increases in the length of vectors E_L, E_{L2} and E_{L3} in Figure 9G. As a result, vectors E_{V1} and E_{V2} would also increase proportionally although the phase angle between them would not change. However, the resulting proportional increases of voltage drops across resistors R_1 and R_2 of Figure 7A would cause an increase of output voltage e_o.

As a simple illustration, assume voltage E_{V1} of Figure 9G causes a 1 volt drop across resistor R_1 of Figure 7A and voltage E_{V2} causes a drop of 1.5 volts across R_2 for an output of $1.5 - 1 = .5$ volt. Then, if a change of input amplitude increases them both by 50%, the drop across R_1 will be 1.5 volts and that across R_2 will increase to 2.25 volts for an output of .75 volts. Thus a discriminator is responsive to changes of input amplitude as well as frequency.

MODIFIED DISCRIMINATOR CIRCUITS

Various modifications of the circuit of Figure 7A are used by different receiver manufacturers and one of these, shown in Figure 11, eliminates the choke coil L and filter condenser C_4.

Considering only the intermediate frequency, in the circuit of Figure 11 there is a path from the limiter plate through condenser C_C and resistor R_2 to ground. At this frequency, the reactance of condenser C_3 is negligible therefore there is a second path from the limiter plate through condenser C_C, resistor R_1 and condenser C_3 to ground. Although not shown, the B+ connection to the limiter plate circuit is bypassed to ground through a fairly large condenser of negligible reactance at the i-f. Thus, there is a third path from the limiter plate through coil L_1 to ground and, therefore at the intermediate frequency, R_1 and R_2 are in parallel with L_1.

With this arrangement, the voltage across L_1, impressed across R_1 and R_2, is applied to each diode circuit and the need for a choke coil, like L of Figure 7A, is eliminated. By substituting the voltage across the primary, E_{L1}, for E_L, the vector diagrams of Figures 9C to 9I inclusive may be applied to the modified discriminator circuit of Figure 11.

A second variation of the basic discriminator circuit is shown in Figure 12 where the plate end of primary coil L_1 is coupled through C_C to the junction between R_1 and R_2. This arrangement places primary voltage E_{L1} in series with the discriminator and permits the use of double diode tubes having only one common cathode. However, to provide the desired action a dual winding is needed for the discriminator transformer secondary.

A third arrangement, shown in Figure 13, applies the primary voltage E_{L1} to the discriminator circuit by means of the capacitive voltage divider, C_2C_3, which is connected in series across the secondary winding L_2. As the reactance of C_2 is equal to that of C_3, the voltage E_{L1} is applied in equal magnitude to both diode circuits the same as though it were applied at the center tap of L_2. This arrangement permits permeability tuning of the transformer coils but otherwise, the circuit is about the same as that of Figure 11.

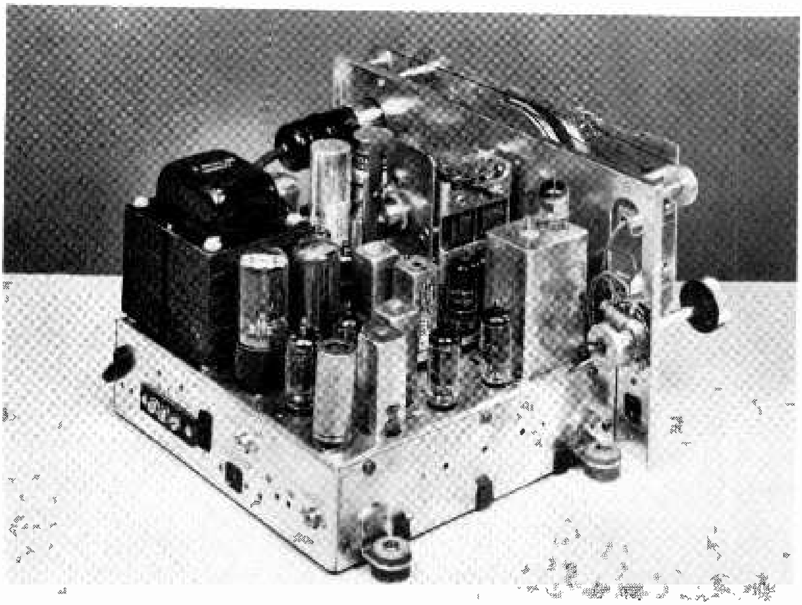
RATIO DETECTOR

Another more recently developed type is the f-m "Ratio Detector", the basic circuit of which is shown in Figure 14. Although similar to that of a discriminator, this circuit can be distinguished because the diodes are connected in series instead of push-pull. That is, in Figure 14, the plate of V_2 is connected to the L_3 end of the secondary coil, while the cathode of V_1 is connected to the L_2 end.

One advantage of this type of detector over the conventional discriminator is that it provides its own limiting action and thus permits the omission of the limiter stage. Furthermore, in receivers employing discriminators, the i-f voltages must be amplified to a level high enough to saturate the limiter, but with the ratio detector, this high level is not necessary and therefore fewer stages of i-f amplification are required.

Since the ratio detector performs both the functions of amplitude-limiting and detection, for simplicity, each of these actions will be explained separately. For the limiting action, the circuit of Figure 14 has been redrawn as Figure 15A where some of the components have been omitted, but no connections have been changed.

The i-f voltage developed across the transformer secondary L_2L_3 is applied to the circuit, and the diodes allow rectified current through V_1, R and V_2 therefore, condensers C_3, C_4 and C_5 charge to the indicated polarities. Usually, condenser C_5 has a capacitance of about 8 mfd and R has a resistance of abou 15,000 ohms or more, so that their time constant is .12 second or more, equivalent to a frequency of 8-1/3 cps or less. Therefore, as explained for the avc filter of an earlier lesson, no audio or i-f voltages will appear across resistor R. Instead, condenser C_5 will charge to a value, equal approximately to the voltage across L_2L_3, and will vary only with changes of input voltage which occur at frequencies of 8 cps or less. Thus, with the cathode of V_2 grounded, as in Figure 14, and the polarity of the voltage across C_5 as indicated, an avc voltage is available between the plate of V_1 and ground.



Modern receiver chassis for both a-m and f-m reception.
Courtesy Stromberg-Carlson Company

Because the filter action of C_5R does not permit any audio or intermediate frequency variations of input amplitude to cause a change of voltage, the circuit acts as a limiter. Notice here, condenser C_3 and C_4, connected in series with each other, are in parallel with C_5 and R. Therefore the total voltage of their combined charges must always be equal to that of C_5.

Comparing the circuits of Figures 7A and 14, the voltage sources in the diode circuits are identical and therefore will have the phase relationships and resultant amplitudes diagrammed in Figure 9. In this respect, the equivalent circuit of Figure 7A is shown in Figure 8 while the equivalent circuit of Figure 14 is shown in Figure 15B. In Figure 8, the resultant voltages are impressed across resistors R_{V1} and R_{V2} while in Figure 15B, the corresponding resultant voltages are impressed across condensers C_3 and C_4. Also, due to the diode connections, the voltage drops across R_{V1} and R_{V2} are series opposing while in Figure 15, the voltages across C_3 and C_4 are series aiding.

As explained for the circuit of Figure 15A, the total voltage across C_3 and C_4 does not vary at audio or intermediate frequencies but, as indicated by the diagrams of Figures 9G and 9I, the instantaneous voltages across each condenser will vary with changes of input frequency. As one resultant voltage increases the other decreases therefore, although the total voltage remains the same, there will be instantaneous changes in the ratio of the separate voltages across C_3 and C_4.

For example, assume that in Figure 15A the voltage E_{C3} across condenser C_3, has a value of 8 volts while E_{C4} across condenser C_4, has a value of 4 volts. Then the total voltage, across C_5 and R is $8 + 4 = 12$ volts. Expressed as a ratio,

$$\frac{E_{C3}}{E_{C4}} = \frac{8}{4} = 2$$

Assume further that in a following instant, a change of input frequency causes E_{C3} to increase to 9 volts and E_{C4} to decrease to 3 volts. Under these conditions, the total voltage is still $9 + 3 = 12$ volts but the ratio becomes,

$$\frac{E_{C3}}{E_{C4}} = \frac{9}{3} = 3$$

Thus the ratio of E_{C3} to E_{C4} varies in accordance with changes of input frequency and therefore the name "Ratio Detector".

In order to follow the variations in the respective voltages applied by L_2, L_3 and L, condensers C_3 and C_4 must be able to discharge as well as charge. The equivalent circuit of Figure 15B shows only the charging circuits, but the discharge paths can be followed in the schematic diagram of Figure 14. Assume that C_3 has been charged to 9 volts by electron flow from its lower plate through L, L_2, and V_1, to the upper plate, which then is negative with respect to the lower plate, as shown in Figure 15A. If the vector sum of E_{L2} and E_L diminishes to 8 volts, electrons can flow from the upper plate of C_3 in Figure 14, through R, V_2, L_3 and L to the lower plate of C_3 until its charge is reduced to 8 volts.

Similarly, when C_4 discharges to a lower potential, electrons can leave its upper plate and pass through L, L_2, V_1 and R to the lower plate of C_4. Because the capacitance of C_5 is so much greater than that of C_3 and C_4, the slight shift of electrons necessary to decrease the charge on these small condensers has practically no effect on the voltage across C_5. The charge and discharge actions of condensers C_3 and C_4 are very rapid, and therefore at all times, the voltage E_{C3} can be considered as exactly equal to the vector sum of E_L and E_{L2}, and the voltage E_{C4} equal to the vector sum of E_L and E_{L3}.

In Figure 14 the lower plate of C_4 is grounded, and its upper plate is negative with respect to ground. However, its charge E_{C4} varies in magnitude from instant to instant in accordance with the frequency variations of the f-m carrier signal. In other words, the negative d-c potential at the junction between C_3, C_4 and L fluctuates constantly with the frequency modulation of the i-f input voltage.

Although the d-c component of the voltage across condenser C_4 is blocked by the condenser C_0, the a-c component is coupled through it to the a-f amplifier input of the receiver. Thus at its a-f output terminals, the ratio detector in Figure 14 provides an a-c voltage variation with a frequency characteristic like that represented by the S curve of Figure 5A. Likewise, its output variation with time may be represented by a curve like that of Figure 5B.

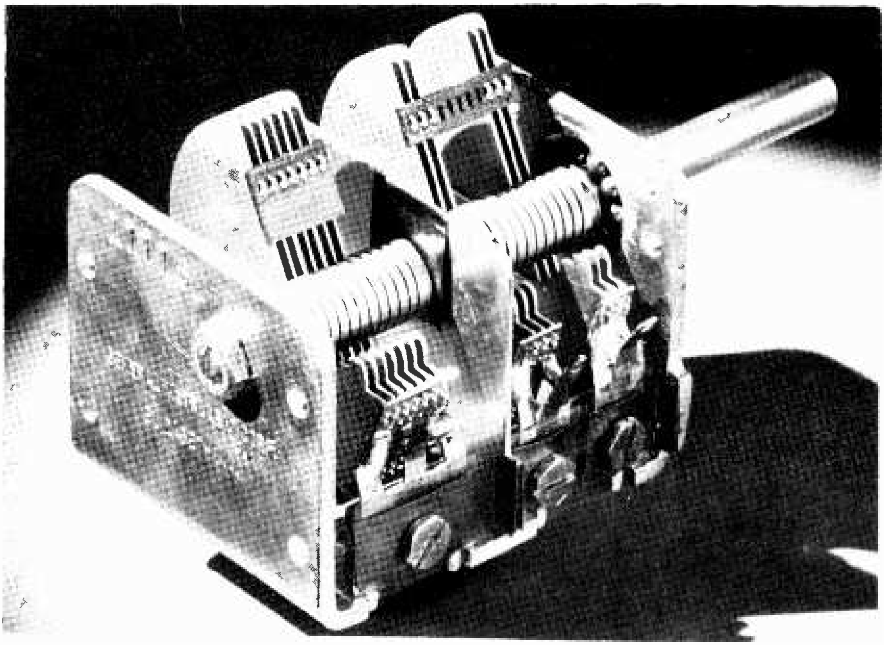
BALANCED RATIO DETECTOR

Like the discriminators, there are a number of variations of the basic ratio detector circuit, one of which is given in Figure 16. Here, the resistance across condenser C_5 is center tapped and considered as two separate components, R_1 and R_2, with the junction between them connected to ground. As explained previously, the large capacitance of C_5 maintains a fairly constant d-c voltage across them. With respect to the grounded center tap between them, the voltages at the outer ends of R_1 and R_2 will be equal and of opposite polarity therefore the arrangement is known as a "balanced" ratio detector.

As choke coil L is connected between ground and the center tap of secondary L_2L_3, the voltage across it is impressed on both diode circuits. For example, one i-f signal path can be traced from the plate of V_1, through L_2 to the center tap, through L to ground and through R_1 to the cathode. Because of the extremely low reactance of C_3 at the intermediate frequencies, R_3 can be considered in parallel with R_1.

The other i-f signal path can be traced from the plate of V_2 through R_3 and R_2 in parallel, to ground, through choke L and the L_3 section of the secondary to the cathode. Here again, the potential at the junction between condensers C_3 and C_4 continually varies in magnitude and frequency in accordance with the i-f modulation.

With respect to ground, in the detector of Figure 14 the voltage at the junction between C_3 and C_4 varies alternately above and below some average negative d-c value. In the "balanced" ratio detector of Figure 16, the voltage at the junction between C_3 and C_4 varies alternately above and below ground, because the center



Tuning condenser with special three-plate sections for tuning the high-frequency f-m range.

Courtesy General Instrument Corporation

point of the load resistance ($R_1 + R_2$) is at ground potential. Thus, this voltage which appears across potentiometer R_3 has no d-c component and can be connected directly to the input of the following a-f amplifier stage.

Another variation of the ratio detector circuit, shown in Figure 17, employs a transformer in which the tertiary winding L is wound on the same form as the primary L_1 and, therefore, is coupled inductively to it. This arrangement replaces the coupling condenser C_C and choke coil L in the circuits of Figures 14 and 16.

As in the preceding circuits, voltages E_{L2} and E_{L3} across the two halves of the tuned secondary, L_2L_3, have 90° phase relationships with the secondary current I_S, as shown in the vector diagrams in Figure 9. Here, the voltage across the untuned secondary L, is 180° out of phase with E_{L1}, and corresponds to vector E_i in Figure 9, therefore, as shown in Figure 18, the vector diagrams for the circuit of Figure 17 are reversed horizontally. The voltage across secondary L, will remain 180° out of phase with the voltage across the primary L_1 regardless of the input frequency but the relative phase of the secondary current and therefore that of voltages E_{L2} and E_{L3} will vary with changes of input frequency.

In Figure 17, the V_1 diode path is from the plate through C_3 to ground, from ground **up** through C_6 and L to the center tap of the secondary, and through L_2 to the cathode. The V_2 path is from the plate through L_3 to the center tap, **down** through L and C_6 to ground, and from ground through C_4 to the cathode. As in the other ratio detector circuits, the diode currents charge C_3 and C_4 to the respective polarities indicated in Figure 15A. Note, however, that through L and C_6 the direction of the V_1 current is opposite to that of the V_2 current.

Thus, as explained for the discriminator, in Figure 17 voltages E_L and E_{L2} are impressed across diode V_1 and the resultant voltage is equal to their vector sum. In the same way, the resultant voltage impressed across diode V_2 is the vector sum of voltages E_L and E_{L3}. Therefore the effect of changes of input frequency are shown by the vector diagrams of Figure 18.

At the mean i-f, or resonant frequency of the tuned circuits, E_{L2} and E_{L3} are 90° out of phase with E_{L1} and, as shown in Figure 18A, E_{V1} and E_{V2} are of equal magnitude. Under these conditions, equal voltages of opposite polarity will be applied across L and C_6 of Figure 17, therefore the net or effective voltage across them will be zero.

When there is an increase in the frequency of the input voltage, the secondary current lags voltage E_1, as shown in Figure 9F and therefore in the circuit of Figure 17, produces the conditions of Figure 18B. Here, the magnitude of E_{V1} is greater than that of E_{V2} and their algebraic sum, applied across L and C_6 causes the upper plate of C_6 to become positive with respect to ground.

When there is a decrease in the frequency of the input voltage, the secondary current leads voltage E_1, as shown in Figure 9H and therefore the circuit of Figure 17 produces the conditions of Figure 18C. Here, the magnitude of E_{V2} is greater than that of E_{V1} and their algebraic sum, applied across L and C_6, causes the upper plate of C_6 to become negative with respect to ground.

Thus, the frequency swing of the f-m carrier causes the junction point, between L and C_6 in Figure 17, to vary from positive to negative, with respect to ground, with values which duplicate the frequency, amplitude and waveform of the modulation imposed on the carrier at the transmitter. As indicated, the voltage which appears across C_6 is applied to the input of the a-f amplifier.

Because a-f amplitude variations in the received signal are filtered by the large condenser, C_5, in Figures 14, 16 and 17, a limiter stage is not needed when a ratio detector is employed. However, the output of a ratio detector will vary with slow signal strength changes, to provide an avc voltage, whereas, in receivers using the limiter-discriminator combinations, there can be no increase in output voltage after the limiter is saturated. Of course, it is possible to employ a limiter stage with a ratio detector, as is done sometimes, but this arrangement requires a much higher i-f voltage gain than is necessary when using a ratio detector alone.

THE LOCKED-IN OSCILLATOR

A single stage f-m demodulator, used in certain Philco models, is known as the Bradley or "Locked-In Oscillator" detector. As shown in Figure 19, in this circuit the cathode and first two grids of tube V form an electron coupled Colpitts oscillator with a tank circuit made up of L_3, C_{10} and C_{11} and trimmer C_3. The second grid acts as the oscillator anode and is connected to the supply through dropping resistor R_4. The class C bias is developed across the grid-leak and condenser combination R_1C_5, and the plate current, permitted by the oscillator section of the tube, exists in the form of fairly short duration pulses. The path of the plate current can be traced from B+, through R_3, through L_4 and R_2 in parallel, to the plate, through the tube to the cathode, through the RFC, and to ground (B−).

All four tuned circuits in Figure 19, are adjusted to resonance at the mean intermediate frequency but, due to the loading effect of resistor R_2, the response of the L_4C_4 circuit is broadened to about six times the width of the frequency swing of the incoming signal. With this arrangement, changes of plate current in L_4 will not affect the amplitude of the oscillator signal.

However, the reactive component of the impedance, reflected into the oscillator tank from the L_4-C_4 circuit, will vary with changes in plate current and cause the oscillator frequency to vary. The amplitude of the plate current pulses depends upon the instantaneous potential of input grid number 3 which in turn, depends upon the relative phase of the pulses and the input voltage from the i-f amplifier.

With an input signal of the mean i-f as shown in Figure 20A, the oscillator adjusts itself so that the plate current pulses I_p lead the input voltage e_s by 90°. Thus, at all except the zero amplitude points of its cycle, the input voltage will cause an increase or decrease in the amplitude of the plate current pulses. There are two zero points in each input cycle, but the only stable one is that illustrated in Figure 20A. In operation, automatic phase adjustment occurs until this condition is attained.

When frequency of the input voltage swings above the mean i-f, the phase difference between it and the I_p pulses is decreased, and, as shown in Figure 20B, the amplitude of the pulses increases. That is, the current in L_4 of Figure 19 is increased, and the decreased reactance reflected into the oscillator tank circuit causes an increase in oscillator frequency.

When the frequency of the input voltage swings below the mean i-f, as shown in Figure 20C, the plate current pulse amplitude is decreased because the input tends to become out of phase with the pulses. Thus the current in L_4 is decreased and the increase of reflected reactance causes a decrease in oscillator frequency. Therefore, the oscillator follows the frequency variations of the incoming signal, and this "lock-in" action will occur over a range of frequencies which depends upon circuit constants, the signal amplitude and frequency deviation values.

Over this operating range, the amplitude changes in the plate current, of tube V in Figure 19, are directly proportional to the frequency deviation and the rate of change is the same as that at which the input frequency varies. Thus the variations of the average plate current will correspond to the audio modulation imposed on the carrier at the transmitter. Since the plate current is carried by load resistor R_3, the audio voltage developed across it is coupled through condenser C_9 to the input of the a-f amplifier.

Although the variation in plate current is due to the f-m voltage input, the "lock-in" action of the oscillator is necessary to provide changes which vary linearly with frequency. If the incoming signal strength is too low, or the deviation too great, the oscillator will fall out of control, and no audio output will be obtained. The "Locked-In Oscillator" detector does not require the use of a limiter stage, because its response to amplitude modulation of the carrier is negligible. Excessive width of the plate current pulses results in some distortion therefore the pulse width must be made narrow by the use of a minimum amount of coupling between coils L_3 and L_4.

THE AUDIO AMPLIFIER

One great advantage of f-m transmission is the ability of the system to transmit and reproduce the full range of audio frequencies. If these capabilities are to be fully realized, the audio amplifier stage, as well as the loud speaker system, must be designed so as to be responsive over the desired range. As stated earlier, f-m transmitters have an audio frequency response up to 15 kc, and therefore, for the f-m receiver to have true high fidelity, its audio section also should be able to reproduce frequencies ranging up to 15 kc. However, the actual high frequency response characteristic of any particular receiver is determined by the quality of the components employed in the audio section; and these, in turn, depend to a large extent upon the allowable manufacturing cost

If the audio circuit coupling networks are designed to pass the wide a-f band with minimum attenuation of the lowest and highest frequencies, the obtainable amplification per stage will be relatively low. Thus, practically all f-m receiver audio sections, contain at least two amplifier stages. In some designs, a push-pull output stage is used to minimize distortion; however, in others, equal quality reproduction is obtained with single ended output circuits.

The transformer which couples the amplifier output to the speaker must also exhibit a response which is flat up to the maximum frequency passed by the audio amplifier. In other words, the overall response of the entire audio section can be only as good as that of its poorest component, and the output transformer is often one of the main causes of distortion in the output of a receiver.

Finally, but by no means the least important, the response characteristic possessed by the loud speaker also is frequently a limiting factor in the quality of obtainable sound reproduction. This is due to the fact that the cost of real high-fidelity speakers is so great that their employment in low or medium priced receivers is prohibitive. For this reason, many designers have had to reach a compromise between high quality reproduction and cost in order to keep the selling price of the f-m receiver within the range acceptable to the general public. Because of this fact alone, some relatively inexpensive commercial f-m receivers do not provide the highest quality of tone made possible by the f-m system, though they usually exceed that possessed by corresponding a-m receivers.

IMPORTANT WORDS USED IN THIS LESSON

CENTER FREQUENCY—The assigned operating or resonant frequency above and below which the f-m deviations occur.

DISCRIMINATOR—A form of f-m demodulator in which variations of input frequency appear as corresponding changes of total voltage across the load resistors of two push-pull connected diode circuits.

EQUIVALENT CIRCUIT—A simple arrangement of circuit elements used to illustrate the basic operation of a more complex circuit network.

LOCKED-IN OSCILLATOR—A form of single-stage f-m demodulator that employs an oscillator which locks in step with the frequency variations of the incoming signal.

NON-REGENERATIVE—A circuit that does not involve a regenerative action.

RATIO DETECTOR—A form of f-m demodulator in which variations of input frequency appear as corresponding changes in the ratio of the voltages across two series connected diode circuits.

REFLECTED REACTANCE—The reactance that appears to exist in one circuit due to coupling with another circuit in which it is located.

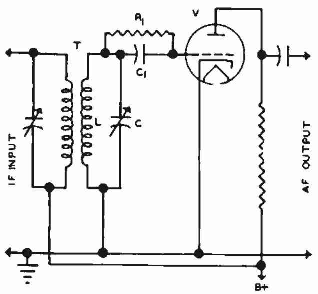


FIGURE 1

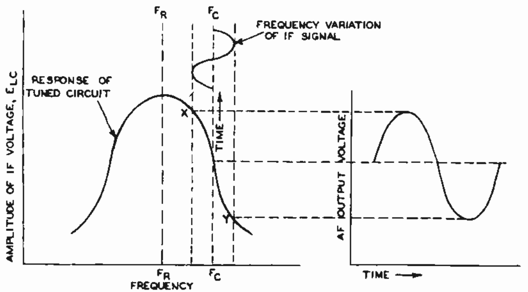


FIGURE 2

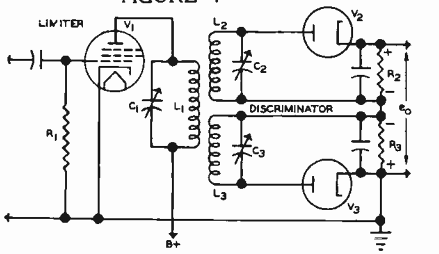


FIGURE 3

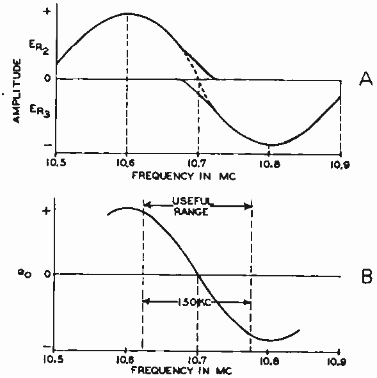


FIGURE 4

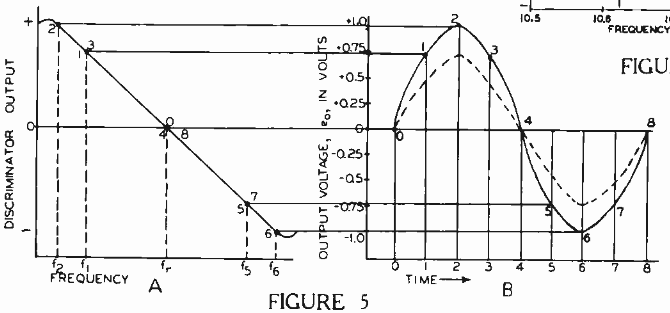


FIGURE 5

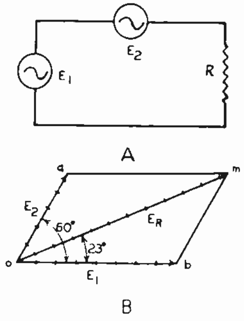


FIGURE 6

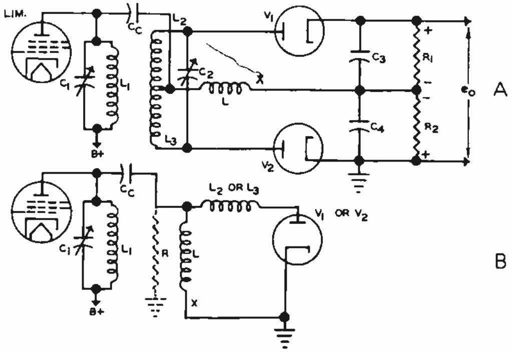


FIGURE 7

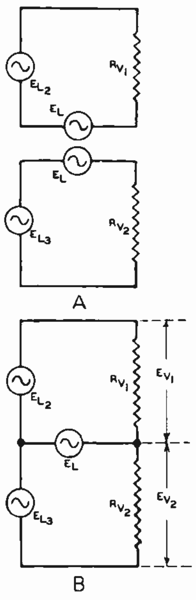


FIGURE 8

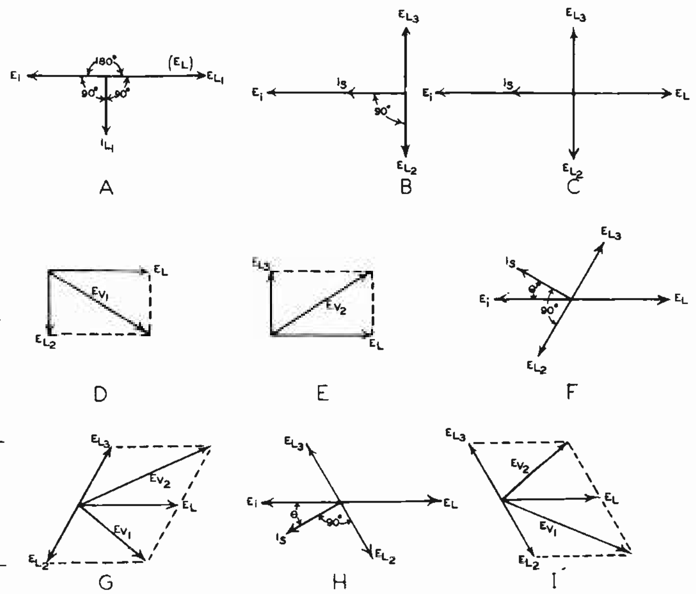


FIGURE 9

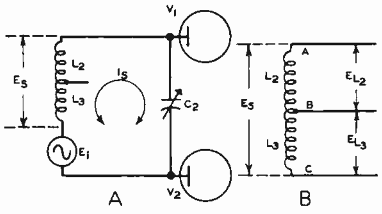


FIGURE 10

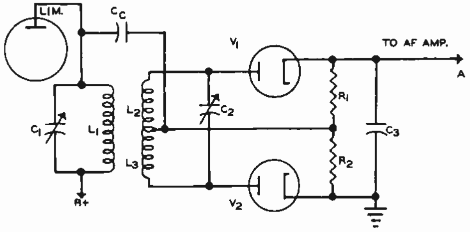


FIGURE 11

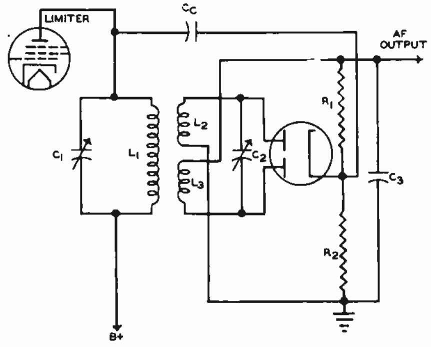


FIGURE 12

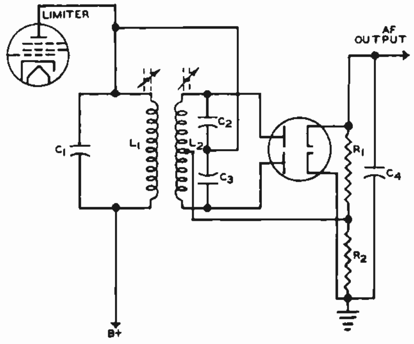


FIGURE 13

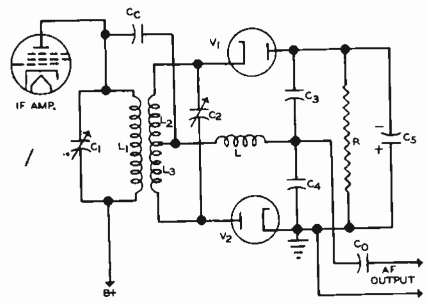


FIGURE 14

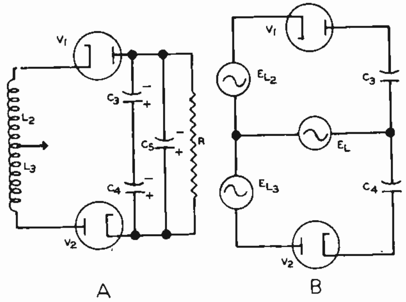


FIGURE 15

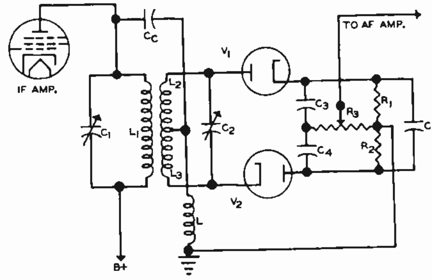


FIGURE 16

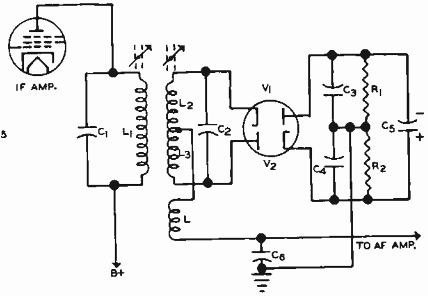


FIGURE 17

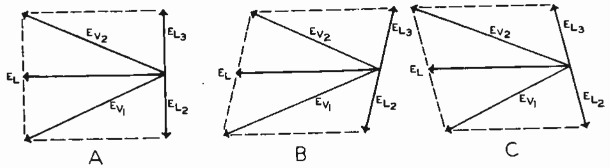


FIGURE 18

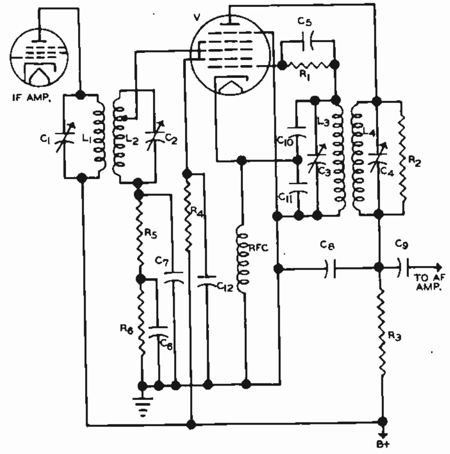


FIGURE 19

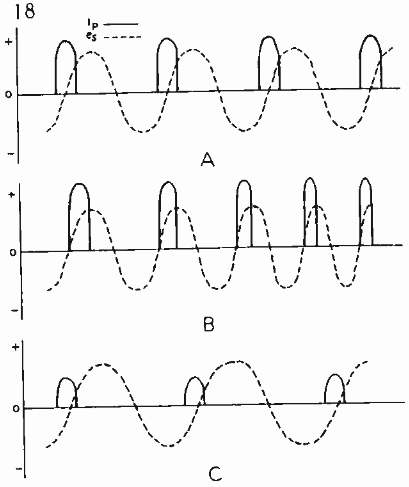


FIGURE 20

FROM OUR *President's* NOTEBOOK

THE MAN WHO WINS

The man who wins is an average man,
Not built on any peculiar plan.
Not blest with any peculiar luck,
Just steady and earnest and full of pluck.

When asked a question he does not "guess"—
He knows, and answers "no" or "yes".
When set a task that the rest can't do.
He buckles down 'til he's put it through.

Three things he's learned: That the man who tries
Finds favor in his employer's eyes;
That it pays to know more than one thing well;
That it doesn't pay all he knows to tell.

So he works and waits, 'til one fine day
There's a better job with bigger pay.
And the men who shirked whenever they could
Are bossed by the man whose work was good.

For the man who wins is the man who works,
Who neither labor nor trouble shirks,
Who uses his hands, his head, his eyes;
The man who wins is the man who tries.

—Charles R. Barrett

Yours for success,

E.B. DeVry

PRESIDENT

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