PHILCO SERVICE

PHILCO Factory-Supervised Service

New Product News

COMBINED WITH

Shop Practices and Service Techniques

RADIO

OCTOBER, 1951

FREQUENCY MODULATION

Because of the many requests we have had for a discussion of FREQUENCY MODULATION and in order to give the subject full and thorough treatment it was necessary for us to combine the October NEW PRODUCT NEWS and SHOP PRACTICES AND SERVICE TECHNIQUES.

We believe you will find this article of exceptional interest and that you will want to file it as an important reference in your technical library.

A radio-frequency signal may have intelligence impressed upon it in various ways. The most familiar method is to vary the amplitude of the radio-frequency signal in accordance with the information to be transmitted. A receiver may then convert the amplitude variations into a replica of the original intelligence.

Amplitude modulation of a carrier actually produces new side-band frequencies which are the sum and difference of the carrier and modulating frequency. Detection or demodulation of an amplitude-modulated signal combines the carrier and side-band frequencies to recover the modulating frequency, which is the difference between the carrier and side-band frequencies.

The amplitude-modulation method of transmitting intelligence has a number of limitations. Atmospheric noise, as well as circuit noise at both transmitter and receiver, cause a high minimum noise level. This limits the range of volume variation permissible for AM (amplitude modulation).

Another method of modulation is wide-band frequency modulation. In this system, the frequency of the carrier is varied by the modulating frequency. This method has the advantage of being unaffected by amplitude variations, such as noise pulses.

Frequency modulation of a carrier produces many side-band frequencies. These side-band frequencies are spaced at intervals which are the carrier frequency, F_o, plus and minus the modulating frequency, F_m, $F_o \pm 2 F_m$, $F_o \pm 3 F_m$, $F_o \pm 4 F_m$, etc. To reproduce the modulating frequency at the receiver, without noticeable distortion, a certain significant number of the side-band frequencies must be accepted by the receiver. Low frequencies require reproducing a greater *number* of side-band frequencies than do high frequencies, but high-frequency side bands are spaced at greater intervals and it so happens that the highest significant side band is produced by high modulating frequencies of high amplitude.

Present-day frequency-modulation systems are designed to faithfully reproduce something less than 15 kc with a modulation index $\frac{(\triangle F_o)}{F_m}$ equal to five (5). (The modulation index corresponds to the modulation percentage of AM). A maximum frequency deviation of approximately 150 kc occurs in this system.

Radio-frequency amplifier stages of an FM receiver must pass a band of 150 kc, to reproduce the signal without distortion. Radio-frequency amplifiers should be understood to mean both the variable-tuned stages and the fixed-tuned i-f amplifiers. The wide pass band and the high gain required in FM receivers present the principle problems to the radio serviceman. The general theory of radio-frequency amplifiers applies to those used in FM receivers.

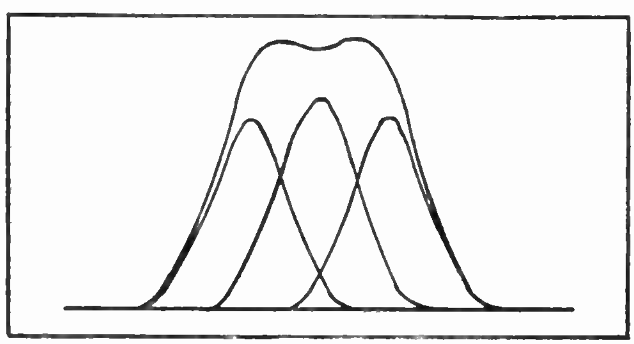

Figure 1

An adequate pass band in the r-f and i-f amplifiers of an FM receiver may be obtained by various means. The most common methods are:

1. "Stagger-tuning" of the stages.
2. Use of "overcoupled" transformers between stages.
3. Low "Q" tuned circuits between stages.

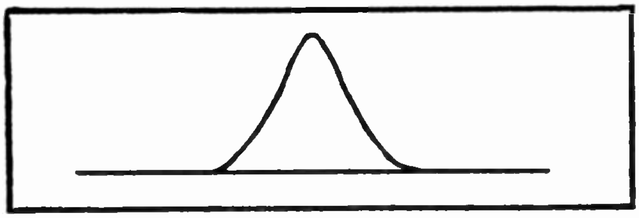

Figure 2

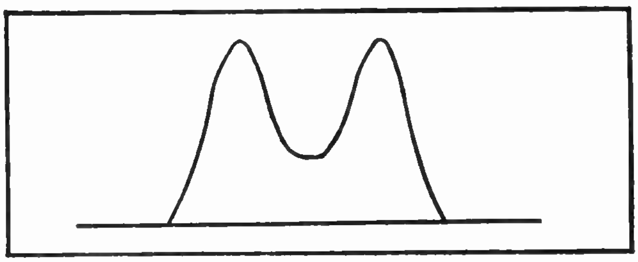

Figure 3

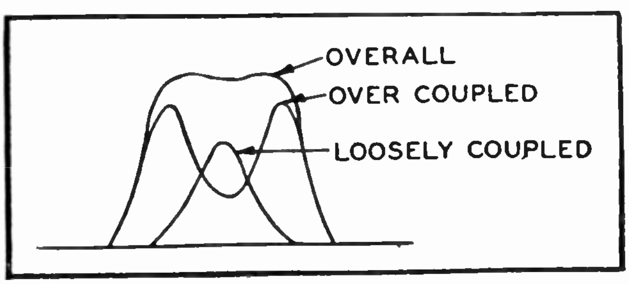

Figure 4

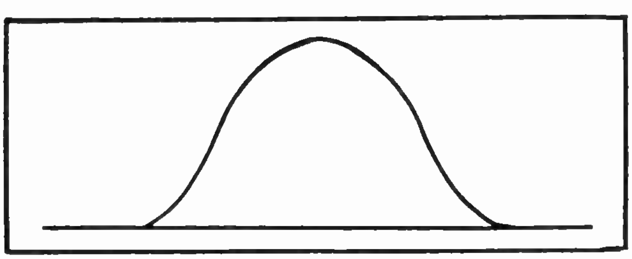

Figure 5

"Stagger-tuning" means tuning successive stages for maximum gain at slightly different frequencies in the overall band of frequencies to be amplified, so that nearly uniform amplification is obtained over this band. See figure 1.

"Overcoupled" transformers have a flat-topped or double-peaked response, depending upon the degree of overcoupling. Slightly more than critical coupling causes the response shown in figure 2; greater coupling produces the response in figure 3. Overcoupled and loosely coupled circuits may be used in cascade to produce an ideal overall response, as shown in figure 4.

Low "Q" circuits produce an overall response as shown in figure 5.

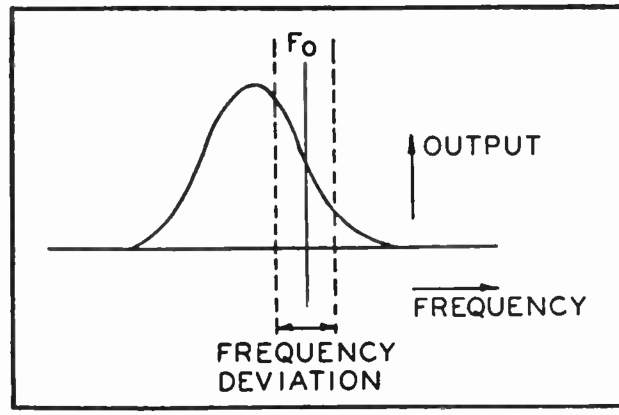

Figure 6

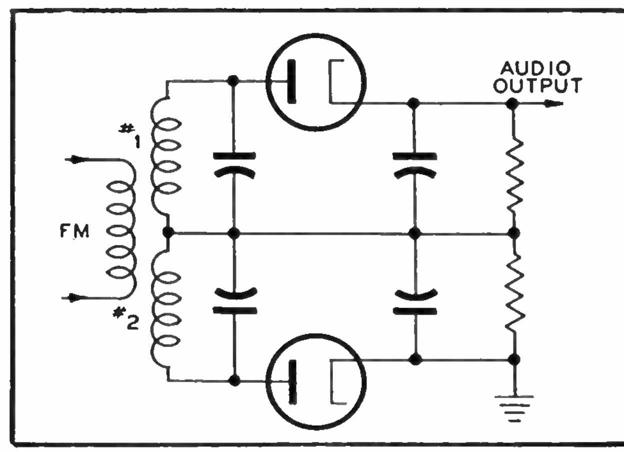

Figure 7

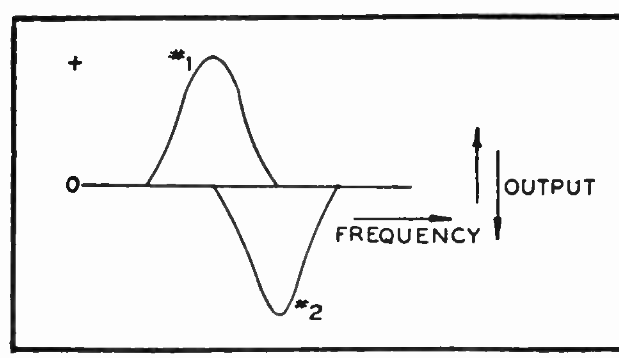

Figure 8

Recovery of the modulating frequency from a frequency-modulated signal requires a circuit which responds to a frequency change. A tuned circuit followed by a detector answers this requirement; this combination may be used to demodulate an FM signal by tuning the circuit so that the frequency varies along one slope of the response curve, as shown in figure 6.

This simple system is unsatisfactory because the response is non-linear, producing a distorted output. To improve linearity, two tuned circuits may be used in a circuit, such as shown in figure 7.

By proper design, the non-linearity of one circuit may be used to cancel the non-linearity of the other and vice versa due to the differential connection of the output

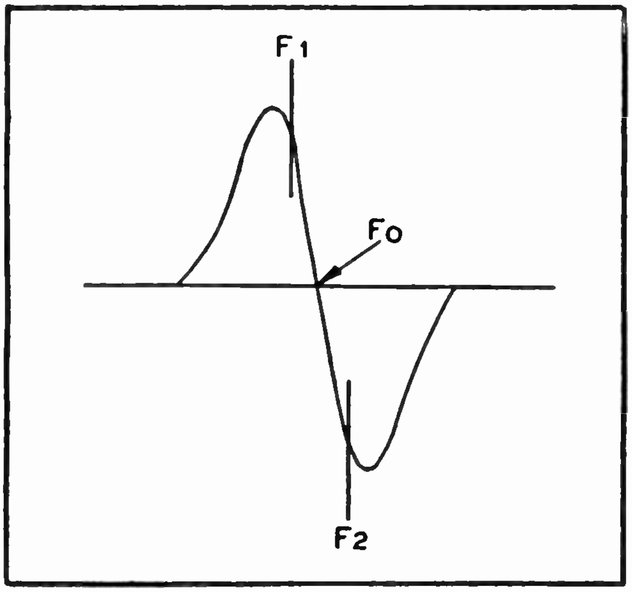

Figure 9

circuits. The outputs of circuits #1 and #2 with respect to frequency are shown in figure 8.

The output across the two circuits is shown in figure 9. Output varies linearly with frequency from F_1 to F_2.

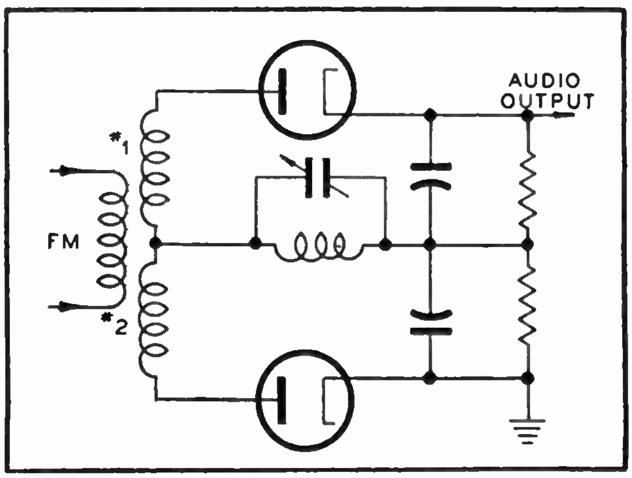

Figure 10

Proper FM demodulation requires that F_1 and F_2 be at least 150 kc apart and symmetrically spaced with respect to the carrier frequency.

Figure 10 shows, in simplified form, a variation of the system just described as used in 1942 Philco FM radios. This circuit responds, to a noticeable extent, to amplitude modulation as well as frequency modulation except at the carrier frequency; for this reason it has limited noise-reducing action.

Noise-reducing qualities may be added to the circuit shown in figure 7 by an amazingly simple expedient, conceived by Mr. Stuart Seeley and illustrated in figure 11.

One of the diodes is reversed and a large condenser C, shunted with a resistor R, is connected across the two diodes which are now in series. The currents of both diodes flow through the common resistor R_1, (to be more exact, the difference in current through the diodes flows through R_1), so the voltage across R_1 resembles that shown for figure 8. Because diode #1 has a constant voltage opposing current flow in series with R_1, the

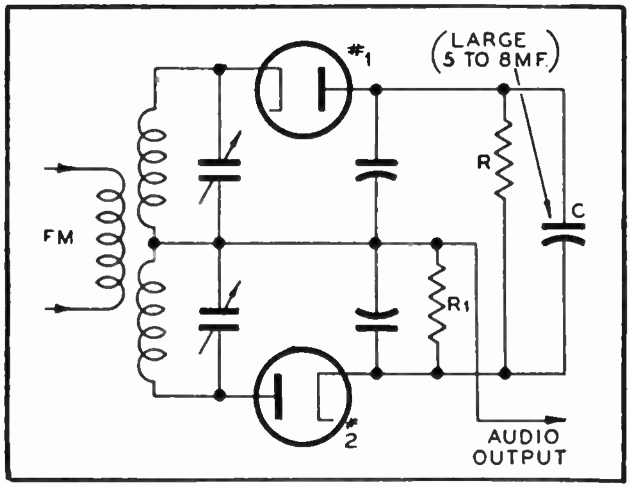

Figure 11

response curve is not as symmetrical as for the circuit in figure 7.

Noise reduction is provided by the circuit in figure 11 due to C, which charges up through the diodes to the average carrier level. If a sudden change in carrier

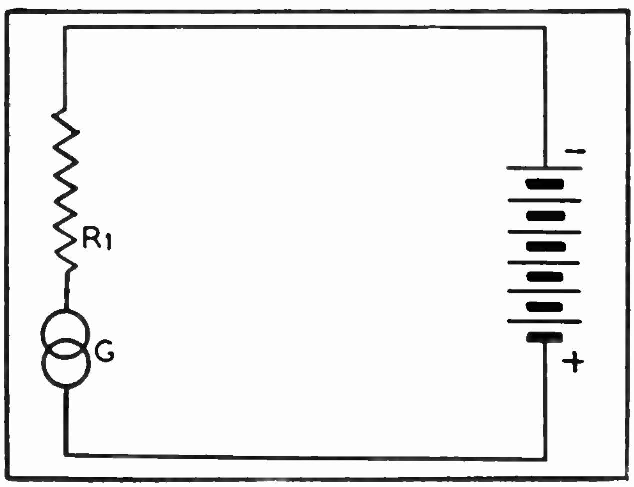

Figure 11A

amplitude occurs (due to noise, for example) the increased voltage developed in the two tuned circuits will be lost in charging the condenser C. Because of its large capacity (5 to 8 μf) the voltage across C will change a negligible amount.

The action of the circuit in eliminating amplitude variations is equivalent to the effect of a low-impedance battery shunted across a high-impedance voltage source, as shown in figure 11A.

The high-impedance voltage source is the generator G whose internal resistance is R_1. There will be no voltage variation across the output terminals of the generator even though the generator voltage changes. Voltage variations will be lost across the internal resistance

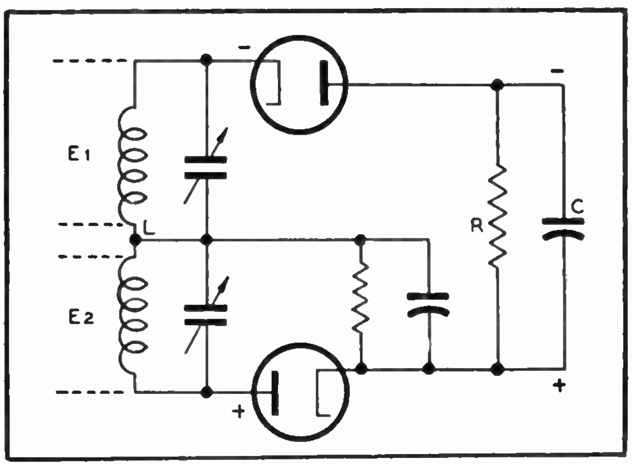

Figure 11B

of the generator. These conditions are duplicated in the Seeley circuit when the diodes are conducting, connecting the high-impedance winding L across the large condenser C, which acts like a battery. See figure 11B. As a result, any increase in voltage developed in the winding is lost across the internal resistance of the winding. Although this action to eliminate amplitude variations is limited to the conducting periods of the diodes, it is remarkably effective. The circuit just described is called a ratio detector because the output voltage is proportional to the ratio of the voltages E_1 and E_2.

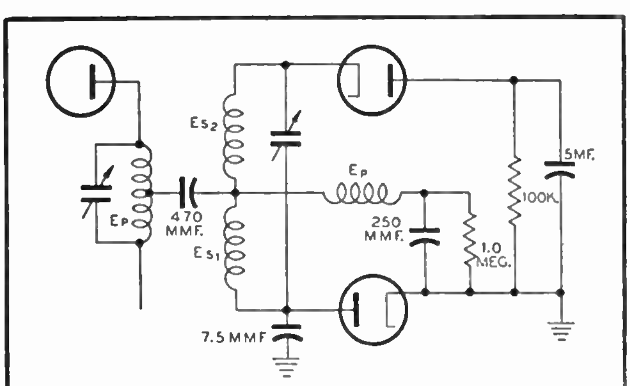

Figure 12

Figure 12 is a simplified schematic of the circuit actually used in several 1946 Philco FM radios.

There is no magnetic coupling between the primary and secondary of the input circuit. The FM signal is first converted to an AM signal. Conversion to an AM signal in this circuit is accomplished by combining the primary voltage E_p with each half of the secondary voltage E_{s1} and E_{s2}. At resonance, the voltages E_{s1} and E_{s2} are each 90° out of phase with the primary voltage E_p, one lagging and the other leading. This may be explained by remembering that, at resonance, the impedance of a resonant circuit is resistive in character. Tapping the circuit is nearly equivalent to tapping a voltage divider so far as the magnitude and character of the im-

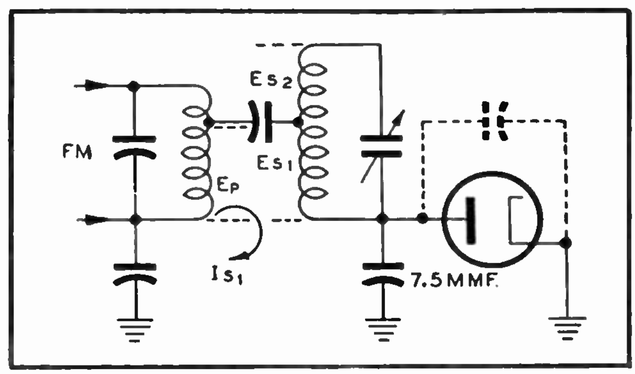

Figure 12A

pedance is concerned. Referring to figure 12A, this means that the primary voltage E_p forces a current I_{s1} through the circuit made up of the tapped secondary winding and the capacity C (actual condenser in parallel with diode plate to cathode capacity).

I_{s1} is in phase with E_p because the tapped winding is a high *resistance* while the capacity C has a low reactance at the operating frequency. Since the current I_{s1} flows through an inductance (one half of the secondary), it will produce a voltage drop (counterelectromotive force, if you prefer) leading the current by 90°. This is the voltage E_{s1} which is, therefore, 90° out of phase with E_p since E_p is in phase with I_{s1}. Because

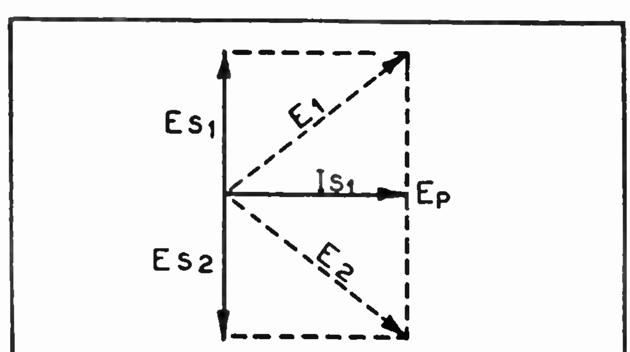

Figure 12B

of the magnetic coupling between the two halves of the secondary, a voltage E_{s2}, also 90° out of phase with I_{s1}, will be induced in the other half of the secondary winding. The relationships are shown vectorially in figure 12B; it should be noticed that the resultant voltages E_1 and E_2 are equal.

If the input voltage, in figure 12A, is higher in frequency than the resonant frequency of the secondary, the

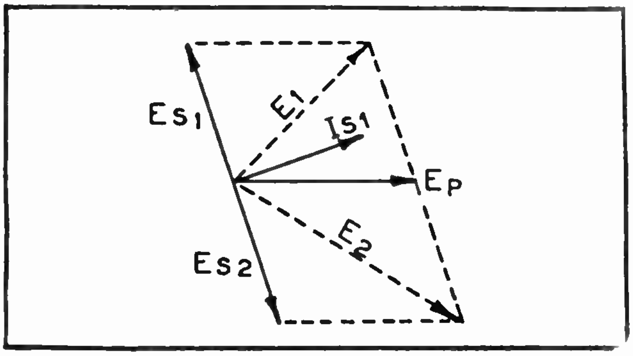

Figure 12C

circuit will be capacitive in character, causing the current I_{s1} to lead the primary voltage E_p. Figure 12C illustrates this condition. The resultant voltages E_1 and E_2 are no longer equal, E_2 is greater.

When the input signal is lower in frequency than the circuit is tuned to, the secondary circuit will be inductive, resulting in the relationship shown in figure 12D.

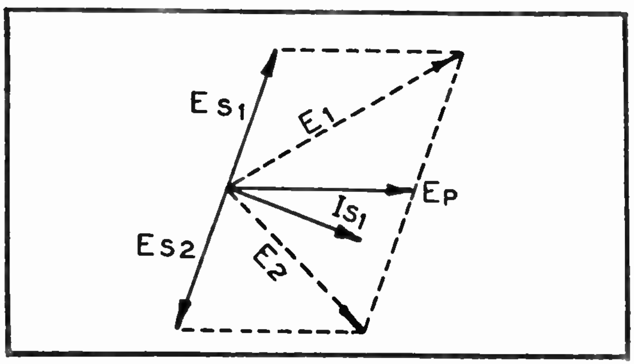

Figure 12D

The voltages E_1 and E_2 are again unequal, E_1 now being greater.

If the voltages E_1 and E_2 are plotted with respect to frequency, the resultant graph will be approximately as shown in figure 12E.

A plot of the voltage across R_1, figure 12, would resemble figure 12F, which is the characteristic of figure 12 with respect to frequency.

Noise reduction in this circuit, figure 12, is due to the large condenser connected across the diodes which are in series across the secondary circuit. The large condenser absorbs any short-time change of signal voltage across the secondary. Alignment of the r-f and i-f

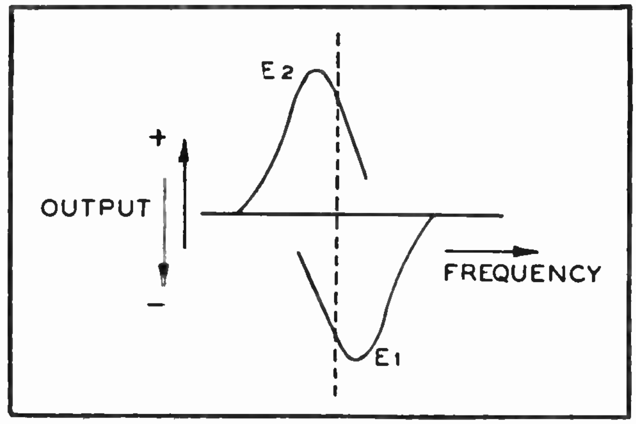

Figure 12E

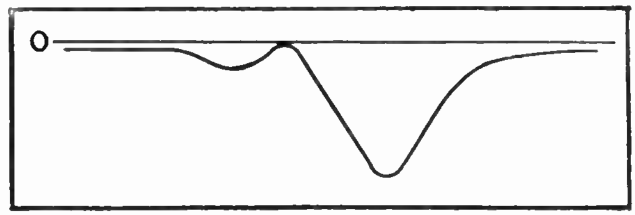

Figure 12F

amplifiers in radios using this detector may be accomplished with an unmodulated signal, by using the voltage across the condenser C as an output indication. By shunting overcoupled transformers, tuning of each circuit to maximum is possible.

In the FM detectors mentioned so far, it should be pointed out that the FM signal is first converted into an AM signal then rectified to obtain the audio signal. Until recently this was accepted as the only method for detecting an FM signal. A new circuit, developed by Philco, derives the audio signal from the FM signal without the intermediate step of converting it to an AM signal. By eliminating the need for detecting an AM signal, the system is insensitive to noise which produces amplitude variations. The new circuit is known as the Philco Advanced FM Detector because of its superior performance. An explanation of the Advanced FM Detector should be preceded by a review of several of the basic principles involved.

Agreement should be established on the phase relationships of voltages across the primary and secondary of

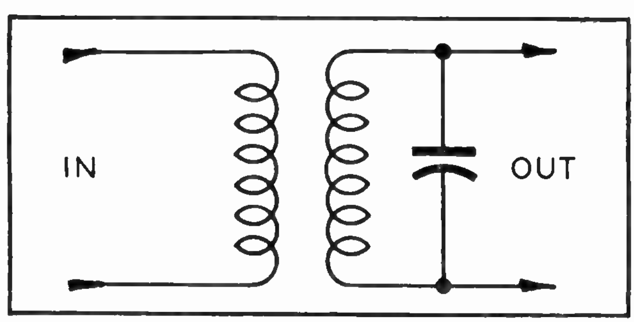

Figure 13

a tuned transformer at the resonant frequency. Figure 13 shows such a circuit.

These voltages can be shown to be 90° out of phase as follows:

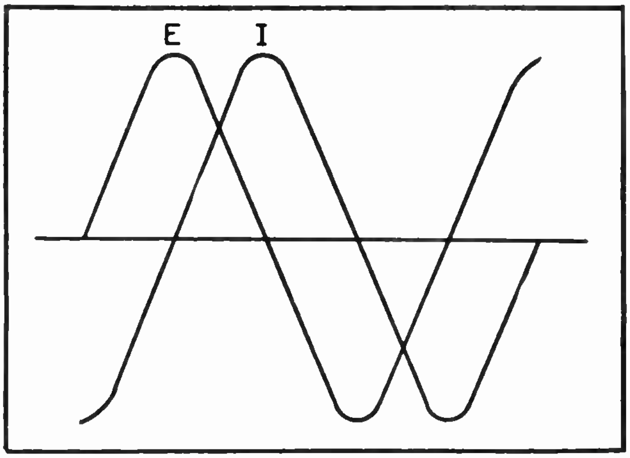

Figure 14

1. The current in the primary is 90° out of phase with the primary voltage. (Reason: Current always lags voltage by 90° in an inductor, neglecting resistance.)

2. Voltage induced in the secondary is 90° out of phase with the primary current. (Reason: Induced voltage is greatest when rate of change of current is greatest. See figure 14.)

3. Induced secondary voltage is in series with the resonant circuit, formed by L and C; therefore, circulating current in the secondary is in phase with the induced voltage.

4. The voltage drop across C will lag the current through it by 90°. (Reason: Voltage across a condenser always lags current through it, neglecting resistance.)

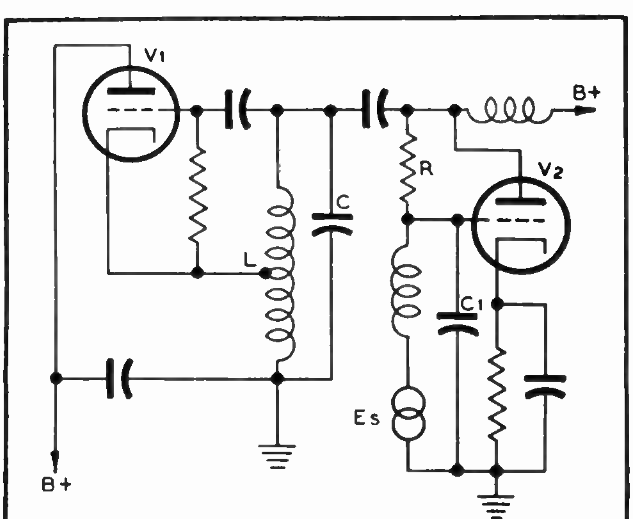

Figure 15

The operation of a reactance tube and oscillator combination should be explained. Figure 15 shows such a circuit. V_2 acts like an inductance across the oscillator tank because it draws a lagging current as an inductance does. V_2 draws a lagging current because the oscillator voltage is applied to its grid, shifted 90° in phase by the combination of R and C_1 and because the plate circuit is connected across the oscillator tank. The current of V_2

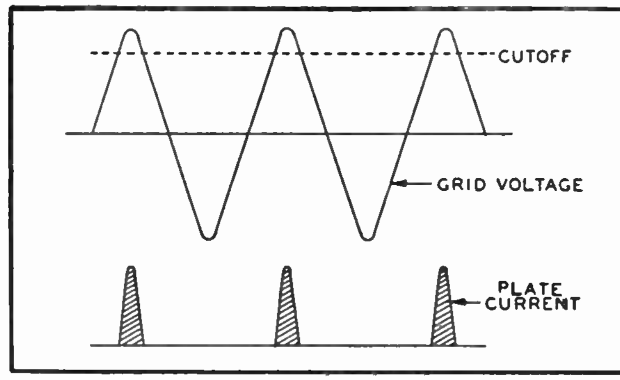

Figure 16

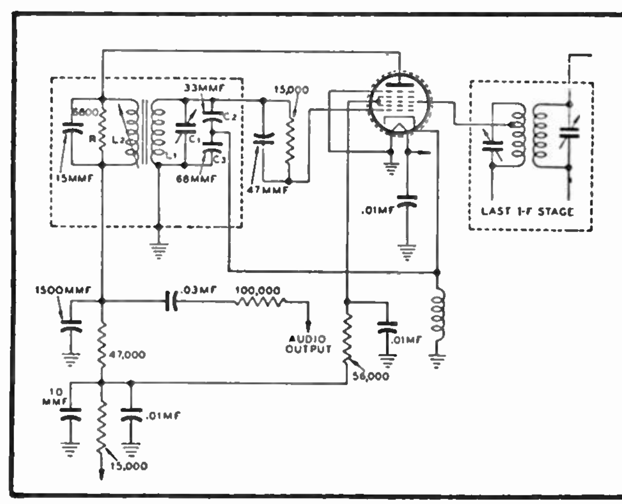

Figure 17

may be varied to change the reactance shunted across the oscillator, thus changing its operating frequency, by applying a second voltage E_s to its grid. This control voltage may be d.c. or a.c. Notice that this circuit changes the frequency of the oscillator by drawing a reactive (90° out-of-phase) current through the oscillator tank. Oscillator-frequency change is proportional to reactance change, and is proportional to V_2 current change over a limited range.

A brief mention of the relationship between oscillator grid voltage and plate current is desirable. It should be pointed out that plate current flows for less than 180° of the grid-voltage cycle, thus plate current is in the form of short pulses.

Figure 16 illustrates the relationship which exists between oscillator grid voltage and plate current but ignores, for simplicity in explanation, the distortion that actually occurs.

A schematic diagram of the Philco Advanced FM Detector is shown in figure 17.

Stated briefly, the circuit combines an oscillator, a reactance tube and a means for injecting an external signal, which "locks in" the oscillator in such a manner that the current change required in the reactance tube to make the oscillator frequency equal to the injected signal is proportional to the frequency change of the injected signal.

The oscillator circuit is formed by the cathode, grid and screen of an FM-1000, a tube especially designed for this circuit, and, L_1, C_1, C_2 and C_3. Because of the oscillator circuit, the electron flow past the oscillator grid will be in the form of pulses. Some of these electrons will be collected by the screen, others will continue on to the plate.

Assuming there is no injected signal, the pulses of plate current, controlled by the oscillator, flow through L_2, inducing a voltage back into L_1. The plate circuit is maintained resistive in character over the operating frequency range by the shunting resistor R. Referring to the relationship between voltages across the primary and secondary of a tuned transformer, remember they are 90° out of phase. This means that the voltage developed across the oscillator tank, as a result of current flow in L_2, is 90° out of phase with the original oscillator voltage. Thus the voltage developed across the tuned circuit L_1, C_1, C_2 and C_3 as a result of current flow in L_2, is reactive, changing the frequency of the oscillator as though the actual reactance of L_1 were changed. The value of the apparent reactance will change with plate current, which could be controlled by a voltage applied to the shielded grid G_3 in a manner similar to that described for the separate reactance tube. Actual operation of the reactance-tube section of the Advanced FM

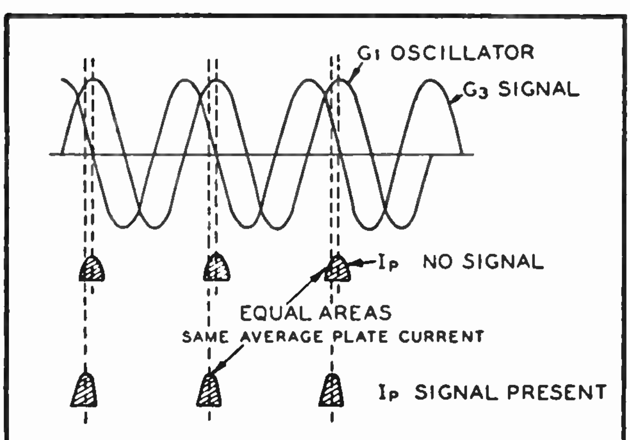

Figure 18

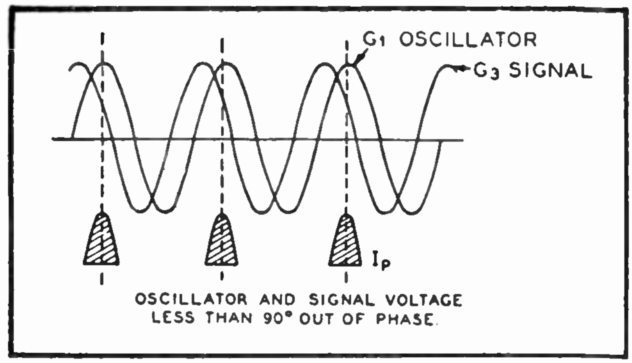

Figure 19

Detector, in controlling the oscillator frequency in response to the signal injected on G_3, is more complex. The control voltage in the Advanced FM Detector is an r-f voltage.

The explanation that follows will be easier to understand if it is accepted that an increase of plate current decreases frequency. This is because of the fact that the reactance coupled back into the oscillator is capacitive so it follows that a *larger capacitance* passes a larger current; a larger capacity decreases the frequency.

To explain the operation of the circuit when a signal is applied to G_3, let us start with the simplest case when the input signal is the same as the oscillator frequency and a stable condition has been reached. For this condition, the plate current through L_2 should remain the same as when no signal is present on G_3. Figure 18 shows the relationship between the oscillator grid voltage, the signal voltage and the plate current, illustrating why the average plate current remains unchanged.

Because the plate current flows in pulses, the oscillator voltage may be in such phase that the effect of the signal voltage on *average* value of the plate current pulse is *zero* even though the peak value of the current may change. The oscillator frequency remains unchanged as long as the average value of the current pulses through L_2 are not changed.

The action illustrated is substantially independent of signal amplitude. This is readily apparent by selecting various values for the signal voltage shown in figure 18;

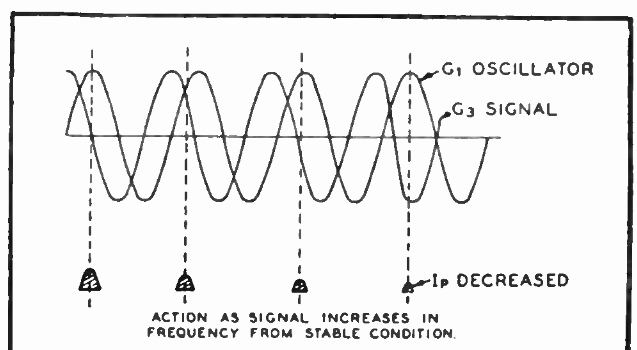

Figure 20

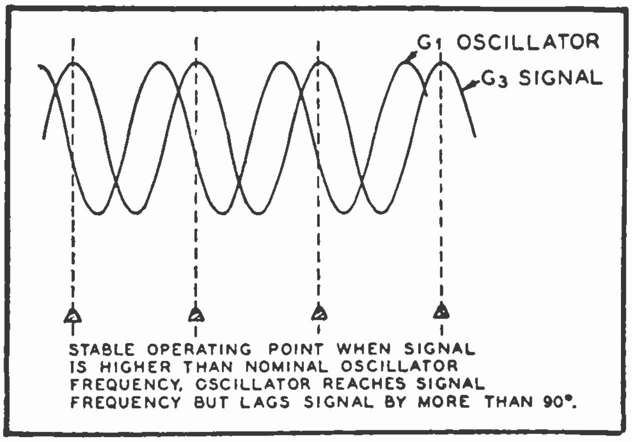

Figure 21

amplitude limiting is therefore unnecessary with this circuit.

Next consider an operating condition where the oscillator frequency equals the signal frequency, but the phase relationship is of that illustrated in figure 19.

Under this condition, the average value of the current pulse would increase, resulting in a larger reactive current flow in the oscillator, decreasing the frequency; or, since the effect occurs over a period of several cycles only, it constitutes a phase change. The phase of the oscillator voltage will shift until the stable condition shown in figure 18 is reached. It is possible to assume any phase relationship and, having understood that an increase in current through L_2 decreases the frequency, conclude, from the example above, that the oscillator phase will be shifted to that shown in figure 18.

The action of this circuit when the signal frequency is higher or lower than the oscillator frequency is similar to that given for a phase difference but with an important difference; the average value of the plate current changes to reach a new stable condition. Figure 20 illustrates a case when the signal moves higher in frequency. For purpose of illustration, the circuit has not acted to change the oscillator frequency. In the actual circuit the phase relationship between the signal and oscillator voltage would remain much closer to 90° and the action of the circuit is practically instantaneous.

Since a decrease in plate current will result, the frequency of the oscillator will increase until a new stable operating condition is reached. The new stable operating condition is shown in figure 21.

The condition is close to that shown in figure 18, but the phase relationship between the oscillator voltage and the signal voltage is altered so that the average plate-current decrease is sufficient to raise the oscillator frequency to equal the signal frequency. Thus the voltage across the resistor in series with the plate coil decreases with frequency. A similar analysis may be used to show that the plate current increases when the signal frequency is lower than the oscillator frequency.

The noise-ignoring characteristic of this new circuit is readily understood if it is realized that the current change required to move the oscillator frequency in step with a given change in signal frequency is the same regardless of the signal amplitude. The phase difference between the oscillator and signal voltages, for a given frequency deviation, varies with signal amplitude but the FM-1000 plate current does not, so amplitude variations in the signal do not appear in the output of the circuit.

By proper adjustment of the oscillator circuit and the tuned plate coil, the relationship between the input frequency and output voltage may be made linear over the required range of frequency deviation with an adequate safety margin for normal drift of circuit tuning. The circuit may be adjusted by using an FM signal generator and oscilloscope to obtain an actual plot of the output voltage with respect to frequency. In this case the oscilloscope pattern should appear as shown in figure 22.

The oscillator is adjusted to center the characteristic with respect to the mean frequency. Adjustment of the plate coil controls the linearity and affects the frequency slightly. It is usually necessary to repeat the adjustments of both windings several times for best setting.

A very fine adjustment of linearity may be made by connecting a circuit, having high attenuation for the modulation frequency, between the output of the circuit and an output indicator. Best linearity gives least output since distortion produces new frequencies other than the modulation frequency. The FM test signal must be adjusted to sweep only the stable lock-in range of the detector in this procedure. This circuit may be converted to an amplitude detector for adjustment of the amplifier circuits (i-f and r-f) by short-circuiting the oscillator.

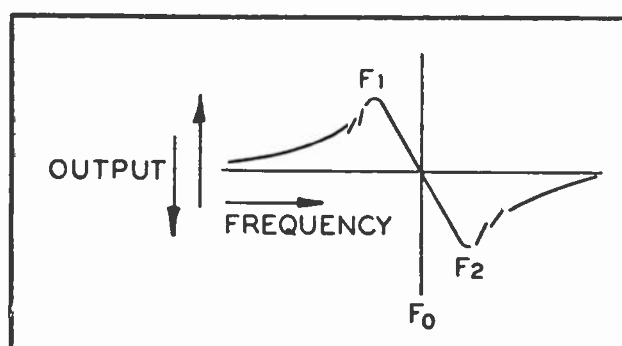

Figure 22

(This article will be continued in next month's SHOP PRACTICES AND SERVICE TECHNIQUES when we shall discuss the most modern advances in discriminator design contained in our present production receivers.)