F-M TRANSMITTERS

Lesson RRT-15

DE FOREST'S TRAINING, INC.

2533 N. Ashland Ave., Chicago 14, Illinois

RRT-15

Radio Reception
and Transmission

LESSON RRT-15

F-M TRANSMITTERS

CHRONOLOGICAL HISTORY OF RADIO AND TELEVISION DEVELOPMENTS

1926—First demonstration of true television given by Baird before the Royal Institute of Britain.

1927—Baird developed Noctovision, a device for seeing in the dark with the aid of infrared rays. Used in World War II.

1927—Two-way transatlantic radiotelephony was successfully established between New York and London, and by 1944 it was extended to include more than 70 other countries.

1927—The first Federal Radio Commission, consisting of five men, was created.

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

RADIO RECEPTION AND TRANSMISSION

LESSON RRT-15

FREQUENCY-MODULATED TRANSMITTERS

INDEX

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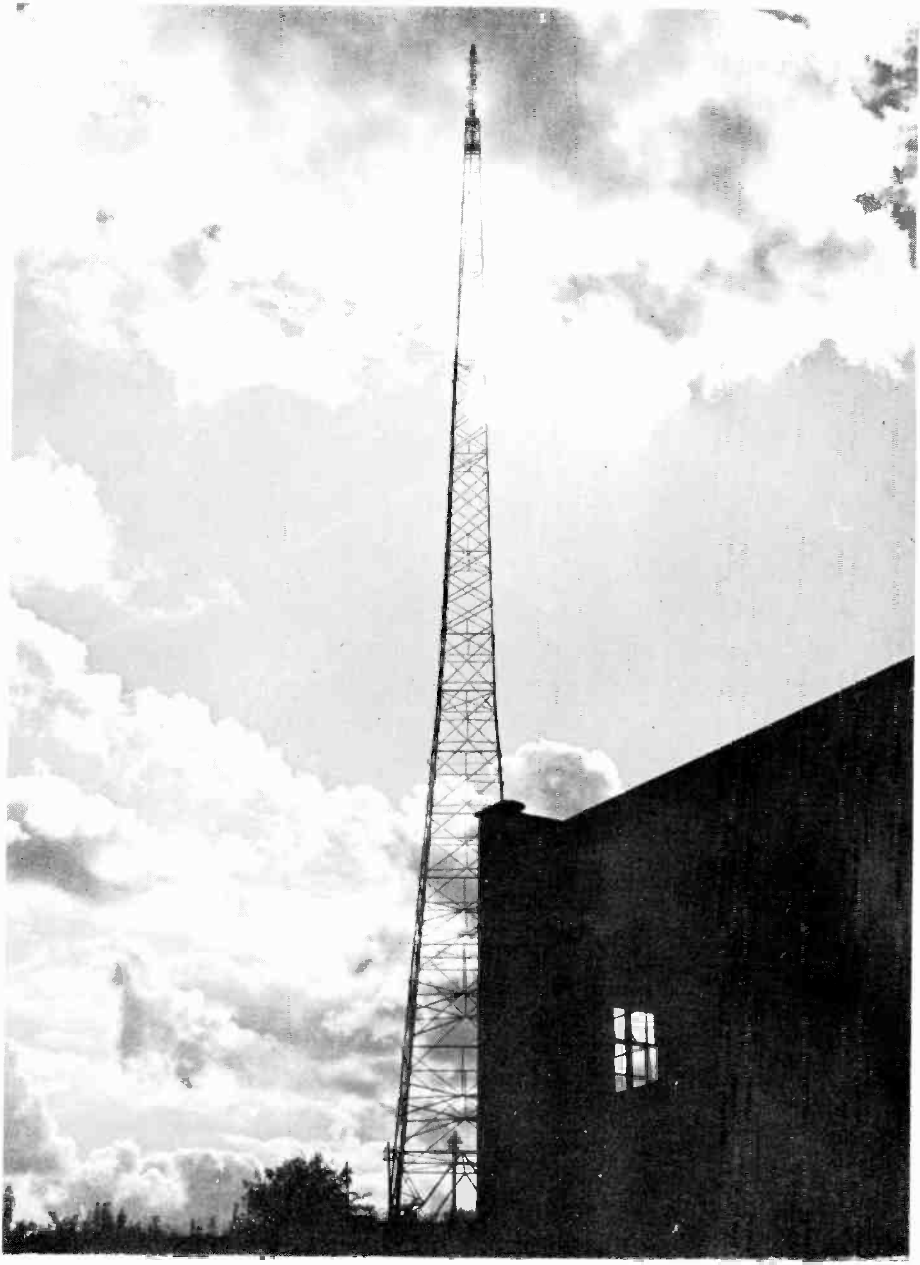
SMILES ALWAYS WIN

For years people have been going around saying, "Smile, and the world smiles with you." But the mere fact that the saying is trite and so much quoted that it is worn smooth, does not in any way invalidate its truth.

—Ediphone Voice Writing



F-M transmitter building and antenna tower which supports a type 54-A Western Electric Four-Bay Clover Leaf F-M radiator.

Courtesy Westinghouse Electric Corporation

FREQUENCY MODULATION

As previously defined, modulation is the process of molding or shaping a series of radio frequency waves in accordance with the signal voltage that is transmitted. There are three main forms of modulation, classed according to the manner in which the radio frequency waves are controlled.

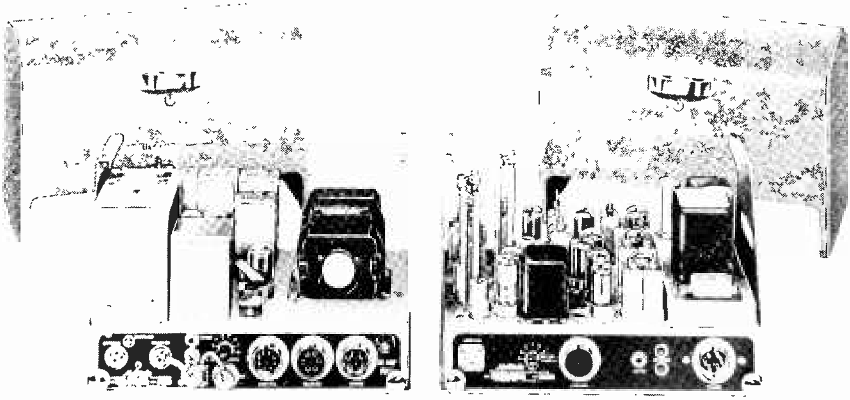
1. Keying, in which some form of switch interrupts a constant amplitude, fixed frequency carrier according to a prearranged code.
2. Amplitude modulation, in which the amplitude of a fixed frequency carrier is made to vary according to the frequency and amplitude of a modulating or signal voltage.
3. Frequency modulation, in which the frequency of a constant amplitude carrier is made to vary according to the frequency and amplitude of a modulating or signal voltage.

As with all general classifications, there are variations and combinations developed for special applications. For example, code may be transmitted by employing an audio frequency oscillator to modulate the carrier. The a-f oscillator is then keyed to provide what is sometimes called modulated continuous waves (mcw). As keying and amplitude modulation were described in an earlier lesson, at this time we will explain frequency modulation.

Expanding the general definition, in frequency modulation, the frequency of the carrier is varied alternately above and below its average, mean or resting value in accordance with the variations of the modulating or signal voltage. The amplitude or intensity of the signal voltage determines the amount of carrier frequency change, and the frequency of the signal voltage determines the rate, or the number of times per second, that the r-f carrier swings above and below its mean value.

To illustrate this action, the sine curve of Figure 1A represents a signal voltage, while an r-f carrier, with its frequency changing in step with the signal variations, is shown in Figure 1B. The lowest carrier frequency occurs during the negative peaks of the signal, and then gradually increases to maximum during the positive peaks. The average, or mean frequency of the carrier, occurs whenever the signal voltage has zero amplitude, one such point being indicated at the right in the drawing.

If the amplitude of the signal is increased, the variation or amount of change in frequency of the carrier is greater. As shown in Figure 1C, the signal has the same frequency, but greater amplitude than that of Figure 1A therefore, the frequency of the carrier of Figure 1D increases to a higher value during the positive peaks of signal voltage, and decreases to a lower value during the negative peaks, although in both cases, the mean or resting frequency is the same.



Frequency-modulated mobile transmitter and receiver designed for operation in the 152-162 megacycle band.

Courtesy Motorola, Inc.

The signal voltage of Figure 1E has the same amplitude but a higher frequency than that of Figure 1A therefore, the amount of carrier frequency change above and below the mean value is the same in both cases, but in Figure 1F, the number of frequency changes per second is greater to correspond to the higher signal frequency. Note carefully, that in every case, the amplitude of the f-m wave remains constant while its frequency changes, in contrast to amplitude modulation in which the carrier frequency remains constant and the amplitude varies.

SIDEBANDS

As explained previously, with amplitude modulation, for each modulating frequency, two sidebands are produced, spaced above and below the carrier by an amount equal to the frequency of the signal. This action is illustrated in Figure 2A, which shows the sidebands produced when a 1000 kilocycle carrier is 100% modulated by a 3000 cycle audio note. The amplitude of the sidebands depends upon the percentage of modulation and, for 100%

modulation, is equal to one half that of the carrier. Therefore, in Figure 2A, the 997 kc and 1003 kc sidebands are shown with one half the height of the 1000 kc carrier.

Sidebands are produced also when a carrier is frequency modulated by a single signal frequency and, following the plan of Figure 2A, Figure 2B illustrates the sidebands produced when a 100 mc carrier is modulated by a 5000 cycle signal. Here there are four sidebands, above and below the carrier, with a spacing of 5000 cycles. Theoretically, an infinite number of sidebands are formed, but those which are beyond the frequency swing of the carrier have relatively little strength. That is, only those near the carrier are of importance in the transmission of intelligence, and the rest can be ignored.

In 1922, J. R. Carson indicated mathematically that, due to the large number of sidebands produced in f-m, the system would require a greater percentage of bandwidth per station than a-m. However, a few years later, Armstrong showed experimentally that with f-m, the percentage of bandwidth containing the *significant* sidebands is, in fact, less than that required for a-m. The large increase in the number of f-m radio broadcasting stations is a direct result of Armstrong's observations.

In amplitude modulation, the addition of the sidebands causes the envelope of the total or resultant radiated waves to vary above and below the average carrier amplitude but, as indicated by the modulation envelopes of Figures 1B, 1D and 1F, the f-m carrier amplitude remains constant. However, the power of the carrier decreases with modulation as indicated by the height of ordinate J_0 in Figure 2B.

The term percentage of modulation, as used in a-m, has little meaning in f-m. However, the amplitude of the modulating voltage, relative to that of the f-m carrier, does affect the number of significant sidebands and it is these sidebands that determine the total bandwidth and the noise suppression capabilities of the system.

The amount of frequency shift, each side of the resting or mean frequency, is known as the deviation. For example, if a 1500 kc carrier were made to vary up to 1510 kc, then down to 1490 kc, and back to 1500 kc during each cycle of a modulating signal, the deviation would be 10 kc, while the total swing or bandwidth would be 1510 − 1490 = 20 kc.

MODULATION INDEX

The deviation is proportional to the *amplitude* of the modulation, and the ratio of the peak deviation to the *audio frequency* is termed the modulation index of an f-m signal. Thus, if the 100 mc carrier of Figure 2B is varied between the limits of 100 mc + 10 kc and 100 mc − 10 kc, at the rate of 5000 cycles a second, the modulation index, M, is:

$$M = \frac{d}{f_A} = \frac{10{,}000}{5000} = 2$$

when

d = deviation in cps and

f_A = modulating frequency in cps

In actual practice, the deviation is the same for different modulation frequencies having equal amplitudes therefore, the modulation index varies inversely with the audio modulating frequency. Thus, if the 100 mc carrier is frequency modulated with a 2000 cycle note, for a 10 kc deviation, the modulation index is:

$$M = \frac{d}{f_A} = \frac{10{,}000}{2000} = 5$$

and the resulting sidebands with 2000 cycle separation will have the relative amplitudes shown in Figure 2C.

The relative strengths of the respective sidebands depend upon the modulation index, as shown by the difference in amplitudes of the sideband frequencies labeled J_2 in Figures 2B and 2C, respectively. Changing the amplitude of the modulating signal changes the deviation, and thus the modulation index which, in turn, results in the sidebands having widely different magnitudes from those shown, although they would be located at the same points as far as frequency is concerned. Furthermore, an increase in the deviation causes an increase in the number of significant sidebands and therefore increases the bandwidth occupied by the f-m signal.

In order to control the width of the channel occupied by any one f-m station, the FCC has specified that the maximum deviation of an f-m carrier must be limited to 75 kc. The ratio between this maximum deviation and the highest modulating frequency used, forms a special modulation index, called the deviation ratio, which is given by:

$$R_d = \frac{d_{max}}{f_{max}}$$

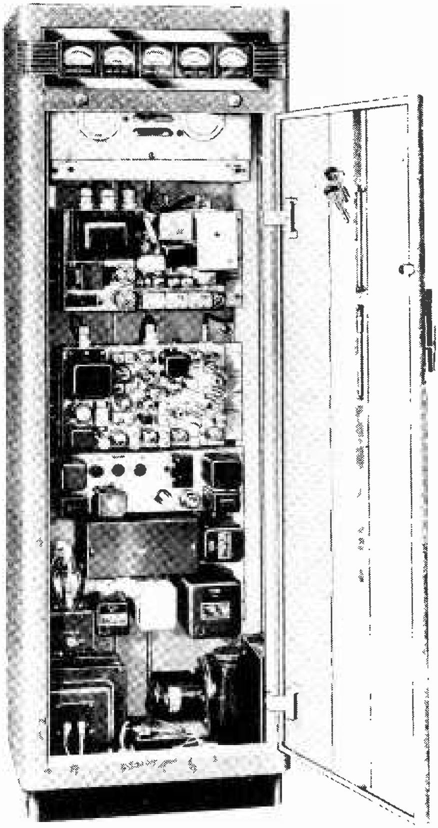
when

R_d = deviation ratio

d_{max} = maximum deviation in cps

f_{max} = highest modulating frequency in cps

Because the noise suppression capabilities of f-m are related directly to the deviation ratio, there is a maximum deviation ratio which can be used for each particular value of signal-to-noise ratio. However, beyond this critical deviation ratio, the signal becomes smothered in the noise, and in many cases, better communication can be maintained with low deviation ratios where high ratios or conventional a-m systems are incapable of giving service.



F-M central station transmitter designed for operation in the 25-44 megacycle band.
Courtesy Motorola, Inc.

Thus, for communication work where the maximum noise suppression capabilities of the f-m system must be obtained, deviation ratios of 1 to 3 are normally employed. For high-fidelity f-m broadcasting, a deviation ratio of 5 is ordinarily used therefore, the highest audio modulating frequency must be:

$$f_{max} = \frac{d_{max}}{R_d} = \frac{75,000}{5} = 15,000 \text{ cycles.}$$

The reason for designating this one case is that all other combinations of carrier deviation and signal frequency, having less than these maximum values, will produce a narrower bandwidth.

BESSEL'S FACTOR CHART

A convenient sideband table, shown as Chart 1 at the end of the lesson, has been developed with the aid of Bessel's Functions, for determining the amplitude of the carrier and of the various sidebands for different values of modulation index M.

Starting at the left of the chart, the first column lists the values of "M" from 0.0, or no modulation, to 10.0. The second column lists the corresponding values of the modulated carrier amplitude for the given values of M. For the symbols at the head of the column J_0 represents the listed values by which the no modulation amplitude of the carrier must be multipled for the different values of (M) while "F" designates the carrier mean frequency.

The third column lists the values by which the amplitude of unmodulated carrier must be multipled to determine the relative amplitude of the first pair of sidebands. Thus, for the symbols at the head of the column, J_1 represents the listed values for the first pair of sidebands with frequencies equal to the sum and difference of the carrier frequency "F" and the modulation frequency F_M.

The fourth column lists the relative values of the second pair of sidebands, J_2, with frequencies equal to the sum and difference of the carrier F and the second harmonic of the modulation frequency, $2F_M$. For the fifth column, J_3 represents relative sideband frequencies equal to the sum and difference of the carrier F and the third harmonic of the modulation frequency $3F_M$ and the same plan continues for the remaining columns. Values below 0.005 are not listed as the sidebands they represent can be disregarded.

To illustrate the use of the chart, we will use the values of a previous example with a modulating signal of 5000 cycles and a deviation of 10,000 cycles for a modulation index of 2. Going down the left column to the value of 2.0 and then reading horizontally, you will find five listed values. Column J_0 lists a value of .2239 which means the carrier component has an amplitude equal to 22.39% of its no modulation value. Column J_1 lists a value of .5767 which indicates that the first pair of sidebands, 5000 cycles above and below the carrier, have an amplitude equal to 57.67% of the unmodulated carrier.

Column J_2 lists a value of .3528 which indicates that the second pair of sidebands, 10,000 cycles above and below the carrier, have an amplitude equal to 35.28% of the unmodulated carrier. Column J_3 lists a value of .1289 and column J_4 a value of .0341 which indicate the relative amplitudes of the corresponding pairs of sidebands. Plotted in the form of a graph, these sidebands are shown in Figure 2B, spaced 5000 cycles horizontally and with heights or amplitudes proportional to the factors listed in the chart.

Following the same plan, the graph of Figure 2C represents the sidebands of a 2000 cycle modulation and a deviation of 10,000 cycles for a modulation index of 5. In this case there are eight pairs of significant sidemands with a 2000 cycle separation or spacing.

F-M BANDWIDTH

As the significant sidebands are those which are effective in conveying the intelligence, Figures 2B and 2C indicate that the f-m transmission bandwidth will vary with the frequency of the modulating signal. Since the *various sidebands are separated by an amount equal to the signal frequency,* to compute the bandwidth required for any particular signal frequency, it is necessary simply to multiply the modulating frequency by twice the number of significant sidebands produced.

Thus, for the conditions of Figure 2B, the required bandwidth is 5000 × (4 × 2) = 40,000 cycles (40 kc), and for Figure 2C, the bandwidth is 2000 × (8 × 2) = 32,000 cycles (32 kc). Of course, when speech or music is transmitted, the sidebands produced by several audio frequencies are present at the same time, and the bandwidth, which will continually vary, will depend not only upon the modulating frequencies, but also upon their amplitudes. It was mentioned previously that the maximum allowable f-m carrier deviation, corresponding to 100 per cent modulation for a-m, is ± 75 kc. However, if the amplitude of the highest audio note used, 15 kc, is sufficient to cause a ± 75 kc deviation, the modulation index will be 75,000/15,000 or 5, and according to the Bessel Factor Chart, 8 important pairs of sidebands will be formed. The required bandwidth then will be 15,000 × (8 × 2) = 240,000 cycles which greatly exceeds the total carrier swing, 2× 75 kc = 150 kc, allowed by the FCC.

However, the bandwidth required by the significant sidebands must not be confused with the FCC specification for the maximum carrier deviation. Actually, in commercial practice it seldom happens that a 15 kc note has sufficient amplitude to swing the carrier to the ± 75 kc limit.

Each f-m transmitting station is allocated a 200 kc channel with its carrier frequency located at the center. Thus, the total swing of 150 kc leaves guardbands of 25 kc at the sides of each cannel, so that whatever sidebands extend beyond the ± 75 kc limits will not cause interference in adjacent channels.

F-M vs. A-M

In general, f-m has certain advantages over a-m, and, to summarize the major differences between the two systems, mainly in regard to the transmitter, the following table has been prepared.

A-M	F-M
During modulation, the frequency of the carrier remains constant, but its amplitude is varied.	During modulation, the amplitude of the carrier remains constant, but its frequency is varied.
The rate at which the carrier **amplitude** varies is determined by the frequency of the modulating signal.	The rate at which the carrier **frequency** varies is determined by the frequency of the modulating signal.
The amount which the carrier **amplitude** varies is determined by the amplitude of the signal.	The range over which the carrier **frequency** varies is determined by the amplitude of the signal.
The maximum amount which the carrier amplitude can be varied, without producing distortion, **is limited** by the strength of the unmodulated carrier.	The maximum range over which the carrier frequency can be varied **is not limited** by the nature of the f-m system, but only by the design of a particular transmitter.
During modulation, the resultant wave becomes the sum of a component at the carrier frequency and **one pair** of sideband components located above and below the carrier by the amount of the modulation frequency.	During modulation, the resultant wave becomes the sum of a component at the carrier frequency and **numerous pairs** of sideband components located above and below the carrier at intervals equal to the modulation frequency.
The bandwidth required is equal to twice the highest modulation frequency employed, regardless of the degree of modulation.	The bandwidth required depends upon the level of modulation as well as upon the modulating frequency. The channel can never be less than twice the modulating frequency, and the greatest width occurs when the wave is subjected to its maximum modulation at the highest modulating frequency.

A-M	F-M
Since modulation can be effected only in or near the transmitter final r-f stage, a relatively large audio output from the modulator is required to provide the added power needed during modulation peaks.	It is not necessary to modulate in or near the final r-f stage because the f-m amplifier out-put does not have to be linear in regard to amplitude. Modulation can be introduced at an early stage, and therefore the power requirements of the modulator are extremely low.
The tubes in the final r-f stage must be operated at considerably less than their normal ratings, at carrier level conditions, in order that their rated plate dissipation values are not exceeded during modulation peaks. This arrangement lowers the over-all efficiency.	Since the r-f power output of the transmitter is constant, all the post-modulation r-f stages can be operated at their maximum class C ratings. This enables the overall efficiency of the system to be relatively high.

FREQUENCY MODULATION METHODS

As listed by Major Edwin H. Armstrong, two basic requirements of a frequency modulation transmitter are:

(1) "The frequency transmitted by an f-m system should vary alternately above and below a fixed value which is the assigned carrier. These variations should be symmetrical with respect to the said frequency, pass through it and return exactly to this carrier when modulation stops."

(2) "In the transmitter, the frequency deviation of the f-m wave at any instant must be directly proportional to the intensity of the modulating current resulting from the program. This deviation in frequency, however, must be independent of the frequency of this modulating current."

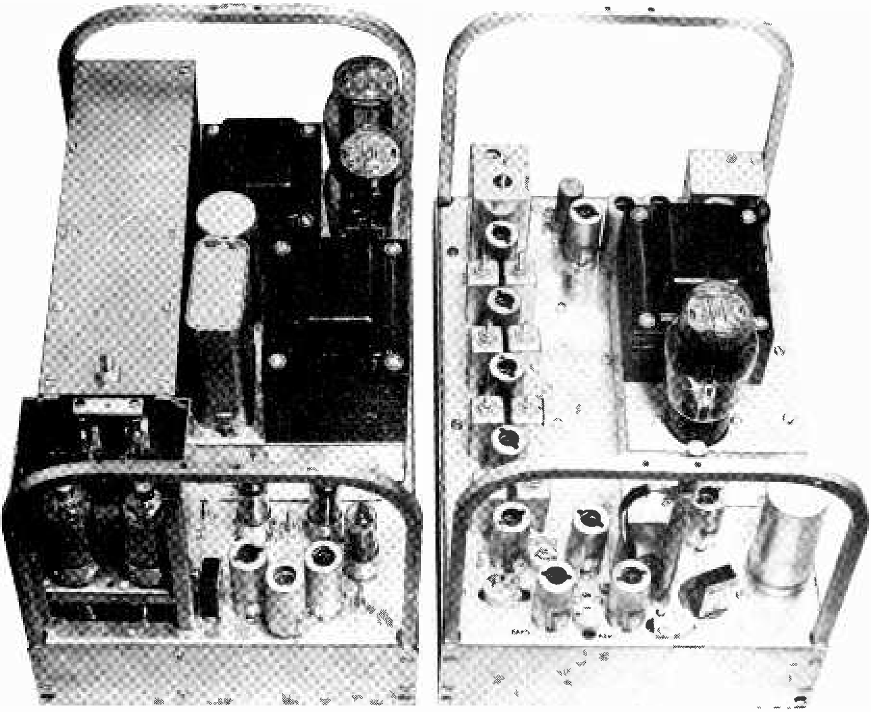
The simplest method of frequency modulating an r-f wave is that shown in Figure 3. The circuit of tube V is that of a Hartley oscillator with a condenser microphone connected in parallel with the LC tank. With no sound input to the microphone, the frequency of the oscillator is given by:

$$f_o = \frac{1}{2\pi\sqrt{LC_T}}$$

when

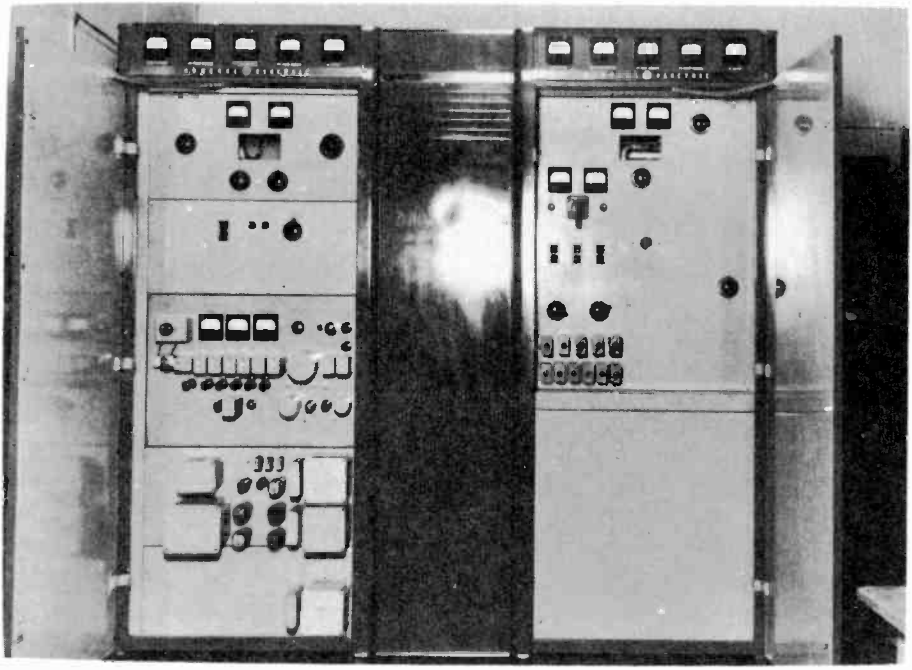
f_o = oscillator frequency, (cps)
L = the tank coil inductance (henrys)
C_T = the sum of the tank condenser capacitance C and the microphone capacitance C_M (farads)

When sound waves strike the microphone diaphragm, it is set into vibration, causing the effective capacitance of the microphone to vary accordingly. But this capacitor is connected across the main tank condenser, and as a result, the total tuning capacitance alternately is increased and decreased and the resonant frequency of the circuit varies. Consequently the oscillator frequency rises and falls above and below the resting frequency by an amount depending upon the strength or intensity of the sounds reaching the microphone, and at a rate determined by the frequency of the sound waves. In other words, a strictly frequency-modulated signal is developed.



Mobile frequency-modulation communications transmitter and receiver.
Courtesy Harvey Radio Laboratories, Inc.

While the simple arrangement of Figure 3 provides a convenient means of demonstrating frequency modulation of an r-f carrier, the amount of r-f energy which can be impressed safely across a condenser microphone is small. Also, the variation of



G-E 3-kw frequency modulation transmitter. Front view with doors open.
Courtesy General Electric Company

capacitance is too small to effect large degrees of carrier deviation, and consequently this circuit is of little practical use. The two modulation methods, commonly employed in f-m systems at present are: (1) the reactance-tube modulator, and (2) the Armstrong system of phase modulation.

REACTANCE-TUBE MODULATOR

The reactance-tube modulator consists of a combination of components so connected that the circuit functions as a variable reactance, when the modulating signal is applied to the input grid of the reactance tube. Although the name of this modulator circuit may give the impression that a special type of vacuum tube is employed, such is not the case. The tube is a conventional triode or pentode, and the variable reactance characteristic of the arrangement is due entirely to the manner in which the various circuit components are connected.

The principle of operation of this circuit can be explained by means of the greatly simplified diagram of Figure 4A. Here, Z_1 and Z_2 may be considered as two impedances connected from plate to cathode of the amplifier tube V, with the control grid connected to the junction between them. Arrow Z_o represents the output impedance of the circuit as measured between points X and Y.

It has been shown mathematically and experimentally that if Z_1 is much larger in value than Z_2, the output impedance, Z_o, is given approximately by:

$$Z_o = \frac{Z_1}{g_m Z_2}$$

when

g_m = the mutual conductance of tube V.

If Z_1 is a condenser with a reactance X_c, and Z_2 a resistor with a resistance R, then:

$$Z_o = \frac{X_c}{g_m R}$$

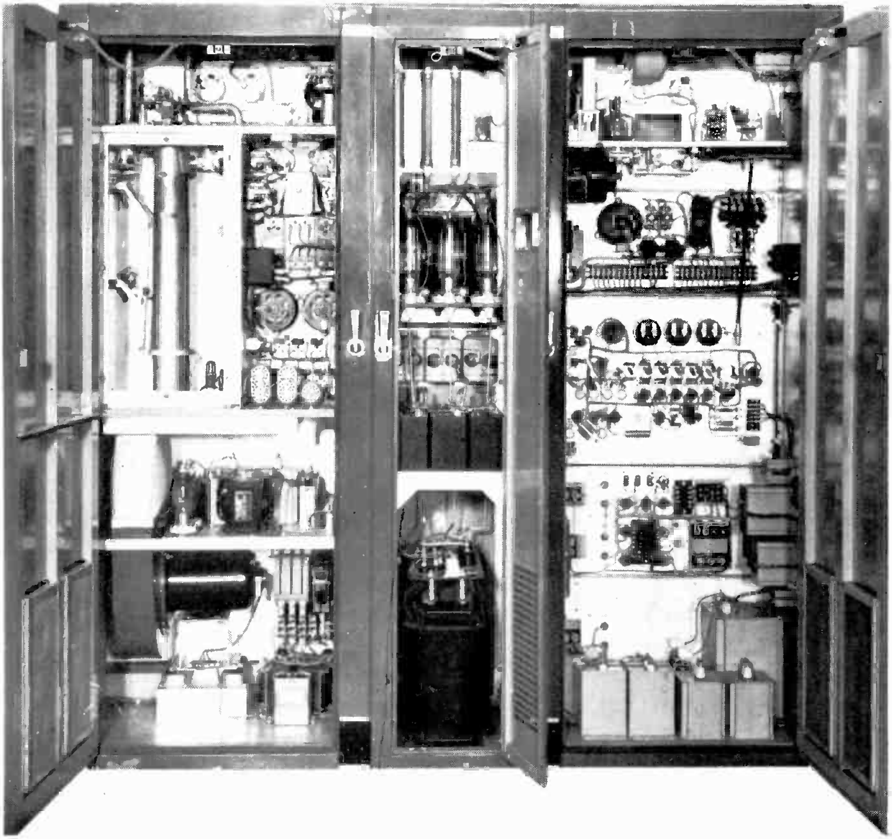
As specified above, the magnitude of X_c is much greater than that of R therefore the entire circuit is equivalent to a capacitor, the reactance of which is divided by a factor $g_m R$. In Figure 4A, the condenser represented by Z_1, and the resistor represented by Z_2, have fixed values and as long as g_m remains constant, the impedance of this equivalent capacitive circuit will not vary.

However, the mutual conductance of a vacuum tube will vary with the application of a voltage to its grid. Thus the output impedance, which is equivalent to a capacitive reactance, can be made to vary directly as the amplitude of, and at a rate depending on the frequency of a signal voltage applied to the grid of V.

All that remains, is to shunt this varying capacitive reactance (the reactance-tube circuit) across the tank circuit of the r-f oscillator of the transmitter. With this arrangement, the reactance variations, caused by the signal voltage, will result in corresponding frequency variations of the transmitter carrier wave.

A REACTANCE-TUBE MODULATED OSCILLATOR

A more complete, but simplified circuit of a reactance tube modulated oscillator is shown in Figure 4B where tube V_2 is the oscillator with its tuned tank LC in the grid circuit. The tank voltages are coupled to the grid through condenser C_2 and resistor R_1. Also connected across the tank is the series phase-shifting circuit C_1-R, with C_3 serving as a coupling condenser to permit the passage of the signals and as a blocking condenser to prevent the B supply from being shorted to ground through coil L.



Rear view with doors open of G-E 3-kw, f-m transmitter shown in the preceding illustration.
Courtesy General Electric Company

Since the C_1-R circuit is directly across or in parallel with the tank LC, whatever voltage exists across the tank will be operative also across C_1-R. But the capacitance of C_1 is small and highly reactive compared to the low resistance value of R, therefore the current through this circuit will be leading with respect to the voltage across LC. Thus, since the voltage drop across a resistor is in phase with the current, the voltage across R will be leading also.

Checking the diagram further, the C_1-R circuit is connected from the plate of the reactance tube V_1 to ground, with the grid tied directly to the junction between C_1 and R. Thus, the leading voltage drop across R is impressed on the grid circuit and in a tube circuit of this type, the changes of plate current are in phase with the grid voltage. Therefore, as the leading voltage across resistor R is impressed on the grid, the a-c component of the plate current will lead the LC tank voltage. This leading current is the same as that which would be present if an additional condenser were connected across tuning condenser C_1. Therefore, tube V_1 acts as a part or section of the tank tuning condenser.

Without transformer T, tube V_1 operates at the LC tank frequency and is self biased by the voltage drop across the bypassed cathode resistor R_2. In the avc systems of radio receivers, the gain of the controlled stages is obtained by a variation of grid bias voltage. Here, the overall action is much the same as the audio voltages, developed in the secondary of transformer T, are impressed across the grid circuit of V_1.

Due to the comparatively high frequency of the LC tank circuit, the signal voltages can be considered as causing a-f variations of grid bias with corresponding changes of plate current. With the tube acting as a part of the tank tuning condenser, these changes of plate current cause corresponding changes of oscillator frequency.

Since the extent or intensity of these changes depends upon the amplitude of the signal voltage, and the rate at which they occur depends upon the frequency of the signal voltage, this arrangement provides frequency modulation.

CARRIER-FREQUENCY STABILIZATION

Because of its connections to the reactance-tube modulator circuit, the carrier-frequency oscillator is somewhat difficult to stabilize. The oscillator is necessarily of the self-excited type, and even though it is stabilized by the usual methods, the presence of the modulator destroys the beneficial effects of such stabilization. Therefore, it is necessary to apply stabilization to the modulator as well as to the oscillator. Usually these methods include an electron-coupled r-f oscillator and voltage-regulated power supply but besides these, special stabilization circuits are incorporated in f-m transmitters which employ the reactance - tube modulator. One such arrangement operates by virtue of the ability of a circuit, called a discriminator, to compare or balance the frequency of the carrier - frequency oscillator with that of a crystal - controlled standard and apply the proper compensating voltages.

This stabilization arrangement is shown as part of the simplifined block diagram of a complete f-m transmitter in Figure 5. In regard to the entire layout, it indicates that after amplification, the audio signals from the pickup devices are applied to the reactance-tube circuit which modulates the carrier frequency oscillator as explained for Figure 4. The oscillator output frequency then is multiplied several times, an action which causes a corresponding increase in the carrier deviation. Finally, the f-m signal is applied to the power amplifier stage from which it is conveyed by a transmission line to the radiating antenna.

The output from one of the frequency multipliers is applied to the input of a mixer stage together with the frequency-multiplied output of the crystal oscillator. This stage is similar to that employed to mix the incoming carrier wave with the output of the local oscillator in the ordinary superheterodyne receiver. Due to the usual heterodyne action, the output of the mixer will contain a difference or beat frequency, which corresponds to the i-f employed in superhet receivers.

For example, in the block diagram of Figure 5 assume that when the carrier frequency oscillator generates its correct frequency, the number 1 mixer input has a value of 20 mc, and the frequency multiplied output of the crystal oscillator provides 20.4 mc to the number 2 mixer input. Under these conditions, the mixer output will contain a frequency of 20.4 − 20.0 = .4 mc which is equal to 400 kc. This 400 kc output is applied to the discriminator which is tuned to resonance at this frequency.

The theory of the discriminator operation will be explained in detail later under the subject of f-m receivers in which this circuit is employed as a second detector. At this time it can be stated that the discriminator output consists of a d-c voltage, the polarity and magnitude of which depend upon the frequency of the a-c signal applied to its input.

When the input frequency equals that to which the discriminator is tuned, the d-c output voltage is zero. When the input frequency differs from the resonant frequency, the discriminator output voltage is positive or negative, depending upon whether the input frequency is higher or lower than the resonant value. The magnitude of the discriminator d-c output voltage varies with the difference between the input and resonant frequencies.

The output voltage of the discriminator, applied to the control grid of the reactance tube modulator, acts to restore the frequency of the carrier-frequency oscillator to a value which causes zero discriminator output. That is, using the frequency values of the example above, when the oscillator is operating at its correct frequency, the output of the mixer will be 400 kc, the output of the discriminator will be zero, and no stabilization voltage will be applied to the modulator grid.

However, suppose that for some reason the frequency of the oscillator increases so that the number 1 mixer input becomes 20.005 mc. Since the crystal oscillator maintains the number 2 mixer input at 20.4 mc, the i-f output of the mixer will then be 20.4 − 20.005 = 0.395 mc, or 395 kc. Since this is 5 kc lower than the resonant frequency of the discriminator tuned input circuit, the discriminator will produce a d-c voltage of the necessary magnitude and polarity to cause the reactance-tube circuit to decrease the frequency of the carrier-frequency oscillator.

On the other hand, should the carrier frequency oscillator output fall below its correct value so that number 1 mixer input becomes 19.995 mc, then the mixer output frequency will be 20.4 − 19.995 = 0.405 mc, or 405 kc. This is 5 kc above the correct value, and therefore the polarity of the discriminator output will cause the oscillator frequency to increase.

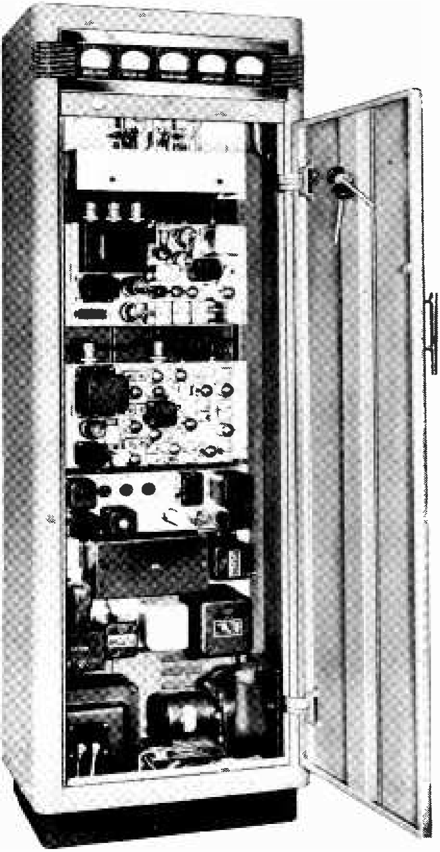
Another stabilization method consists of a modulator circuit employing two tubes with the grids operated in push-pull and the plates connected in parallel. With this arrangement, any variation in the plate supply voltage of the reactance tubes causes equal and opposite effects in their reactance, and the net reactance variation is zero.

In a third frequency-stabilization system, a reversible motor is attached to one of the oscillator tuning condensers and rotates the condenser in the proper direction to counteract any carrier frequency drift. The controlling voltage which determines the direction of motor rotation, is derived by comparing or balancing the carrier frequency against that of a crystal oscillator on the general plan explained for Figure 5.

PHASE MODULATION

In the f-m system invented by Major Armstrong, the desired result is obtained by causing the phase of the radiated wave to vary in accordance with the modulating signals. As will be explained, certain circuit arrangements are employed so that this action becomes the equivalent of the f-m produced by the reactance-tube method. Thus, for the purpose of these explanations, it may be assumed that phase modulation is indirectly one form of frequency modulation.

In the early a-c lessons it was stated that when two alternating quantities, A and B, pass through their corresponding zero values in the same direction and at the same instant, they are said to be in phase. If A passes through its zero value either before or after B, the two quantities are said to be out of phase. The overall principle of the phase modulation system is the generation of a fixed-frequency carrier which is combined with an out of phase modulating signal to produce a resultant f-m wave.



Frequency-modulation central station transmitter for operation in the 152-162 megacycle communication band.
Courtesy Motorola, Inc.

By using phase modulation, it is possible to dispense with the self-excited type of carrier frequency oscillators and obtain direct control of the transmitter frequency by means of crystal oscillators. This provides a high degree of accuracy and eliminates the need for a special frequency-stabilizing network, such as is required in transmitters producing f-m by the reactance-tube method.

SIDEBAND PHASE RELATIONSHIPS

The general nature of the sidebands produced in a-m and f-m systems has already been described, but to explain the methods by which phase modulation, (p-m), is converted to f-m, it is necessary to consider certain additional characteristics of these sidebands. Both a-m and f-m waves consist of components at the carrier and sideband frequencies, the amplitudes of which depend upon the amplitude of the unmodulated wave and upon the degree of modulation. Also, regardless of the degree of modulation, the a-m wave contains only one pair of sidebands for each modulating frequency, while depending upon the modulation index, the f-m wave can have many pairs of sidebands for each modulating frequency. However, when this index is 0.2 or less, the f-m wave has only one pair of significant sidebands, as listed in Chart 1.

As far as the amplitude and frequency are concerned, the center frequency and sideband components of a slightly modulated f-m wave, ($M = 0.2$ or less), can be the same as those of a partially modulated a-m wave. To illustrate this fact, Figure 6A represents the variation of a 20.1% amplitude modulated wave that can be resolved into the three components of carrier frequency, Figure 6B, upper sideband, Figure 6D and lower sideband, Figure 6E. With a circuit arrangement to be described a little later in this lesson, it is possible to remove the carrier frequency component of a modulated wave and when this is done, the remainder is the sum of the two sideband components, known as the "double sideband" and indicated by the curve of Figure 6C.

Corresponding curves for the components of an f-m wave are shown in Figure 7. The amplitude of the f-m wave of Figure 7A is indicated as 2.0 but, when modulated, this value decreases slightly, in this case from 2.0 to 1.98 as indicated in Figure 7B. With this one exception, the amplitudes of the corresponding waves of Figures 6 and 7 are the same.

Although the amplitude and frequency of these double sidebands are the same, they are differently phased with respect to the carrier. In the case of the a-m wave of Figure 6, the zero points of the double sideband occur at the same instants as those of the carrier component. On the other hand, in the case of the f-m wave of Figure 7, the respective zero points of the double sideband and the carrier are 90° out of phase. Re-read this paragraph carefully, for it explains the fundamental factor upon which the Armstrong system is based.

Since the double sidebands differ in their phase relationship with the carrier, the respective upper and lower sideband components, of which the double sidebands are composed, must also differ in their respective phase relationships. Assuming the two carrier components to be in phase, the upper and lower sidebands of the f-m wave lead the corresponding components of the a-m wave by 90°. When the carrier and sideband components of Figure 6 are added, and a-m wave is obtained, but the addition of these same components, with the sidebands shifted 90° along the time axis as in Figure 7, results in an f-m wave.

ARMSTRONG SYSTEM

The principle of operation of the Armstrong f-m system can be followed by reference to the transmitter block diagram of Figure 8. Here, the audio modulating signal is mixed with the r-f output of the crystal oscillator No. 1 in a "balanced modulator" which suppresses the carrier frequency component, so that instead of an a-m wave like that of Figure 6A, its output consists only of the double sideband of Figure 6C.

The double sideband output is then applied to a phase-shift circuit which displaces it along the time or horizontal axis by 90° so that its phase relationship with respect to the carrier component is like that shown in Figures 7B and 7C. Next, the output of oscillator No. 1 is combined with the double sideband in an r-f amplifier (frequency multiplier No. 1) to produce an f-m wave like that of Figure 7A.

The f-m wave is then multiplied in frequency, after which it is applied to the r-f power amplifier and thence to the radiating antenna. This path may lead from the frequency multiplier No. 1 directly to the power amplifier stage as indicated by the dotted arrow, or for reasons to be explained later, the output of frequency multiplier No. 1 may be applied to the mixer where it is combined with the output of crystal oscillator No. 2. The mixer output is then multiplied in frequency and applied to the power amplifier stage as shown by the solid line arrows.

A check of Figure 8 shows that the only two types of circuits which have not been explained previously are the balanced modulator and the 90° phase shifter. Therefore, before proceeding with the details of the Armstrong system, the action of these circuits will be described.

BALANCED MODULATOR

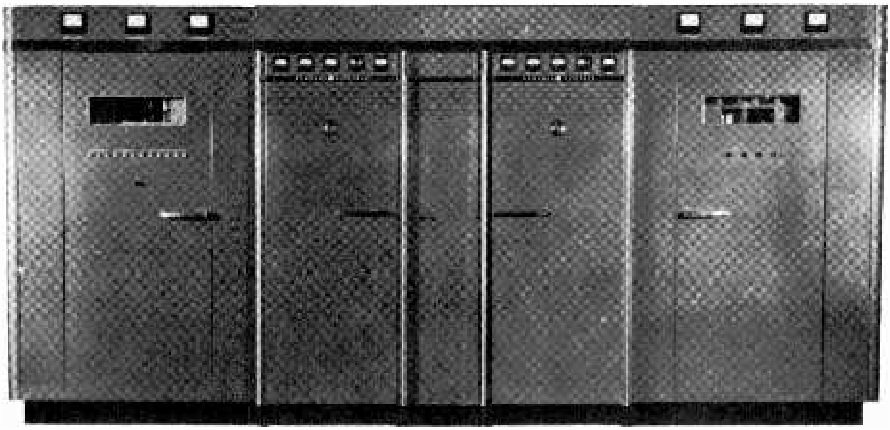
A simplified circuit of a balanced modulator is shown in Figure 9 where, by means of the center-tapped transformer T_1, the audio modulating voltage is impressed in push-pull on the grids of the two modulator tubes, V_1 and V_2. In addition, the r-f input is applied to the two grids in parallel by means of transformer T_2, the secondary of which is connected in series with the C bias supply.

If the instantaneous polarities of the voltages in the two halves of the input transformer secondary are considered, then the net a-c voltages applied to the grids of the two tubes at any instant are:

$$\text{For one tube, } E_1 = E_{RF} + \frac{E_{AF}}{2}$$

$$\text{For other tube, } E_2 = E_{RF} - \frac{E_{AF}}{2}$$

An analysis of the resulting mathematical expression for the plate current will reveal that only three frequencies are present in the output namely: ($E_{RF} + E_{AF}$), ($E_{RF} - E_{AF}$), and E_{AF}, that is the two sidebands and the modulating frequency while the carrier frequency, E_{RF}, has disappeared entirely.



G-E 10-kw. f-m transmitter. Front view with doors closed.
Courtesy General Electric Company

The action is similar to that which occurs in a push-pull a-f amplifier to eliminate d-c magnetization in the core of the output transformer. Here, with the carrier voltage impressed on the two grids in parallel, if one grid becomes positive, the other also becomes positive by an equal amount, and as a result, the plate currents of both tubes increase equally. In the primary of the output transformer, the induction effects of the two plate currents are opposite in polarity, and as both increase equally, the net result is zero. Thus, no carrier-frequency voltages developed across the secondary of transformer T_2 appear across the secondary of the output transformer T_3.

Also, by the proper choice of circuit constants, the output amplitude of the a-f input can be made relatively small; or by tuning the output transformer primary to the comparatively high r-f input, the low a-f input voltages will not appear in the output. Thus, with both the r-f and a-f voltages eliminated, the output contains only the sideband frequencies, the sum of which is the double sideband.

PHASE SHIFTER

The 90° phase-shifting operation is a separate step in the complete action of the p-m transmitter, and for this reason it is indicated in a separate block in the diagram of Figure 8 although the action occurs in the output circuit of the balanced modulator stage. Referring to Figure 9, condensers C_1 and C_2, in series with the primary of T_3, function to neutralize the inductive reactances of L_1 and L_2, the two halves of the primary winding. As a result, at some frequency a purely resistive plate load is presented to the tubes V_1 and V_2, and the plate currents will be in phase with the grid voltages. Since the variations of the magnetic field produced around a coil are in phase with the current in it, the field around the primary of T_3 will be in phase with the grid voltages of V_1 and V_2.

Reviewing transformer action, explained in the earlier lessons, the voltage available across the secondary lags the primary current and flux by 90°. Thus, in the circuit of Figure 9, the double sideband output voltage, available across secondary L_3, is 90° out of phase with the input voltage on the grids of V_1 and V_2. Due to the blocking action of condensers C_1 and C_2, the transformer primary carries the sideband frequencies only while resistors R_1 and R_2 complete the d-c plate circuits.

As indicated in the block diagram of Figure 8, the phase shifted output of the balanced modulator is mixed with the output of the crystal oscillator. If these outputs are of the relative proportions shown in Figures 7C and 7B, their combined output will have the slight frequency modulation indicated by the curve of Figure 7A. Here, a comparison of the solid and broken line curves shows that the addition of the 90° phase shifted sidebands creates a wave that is alternately leading and lagging in phase with respect to the unmodulated carrier.

VECTORS

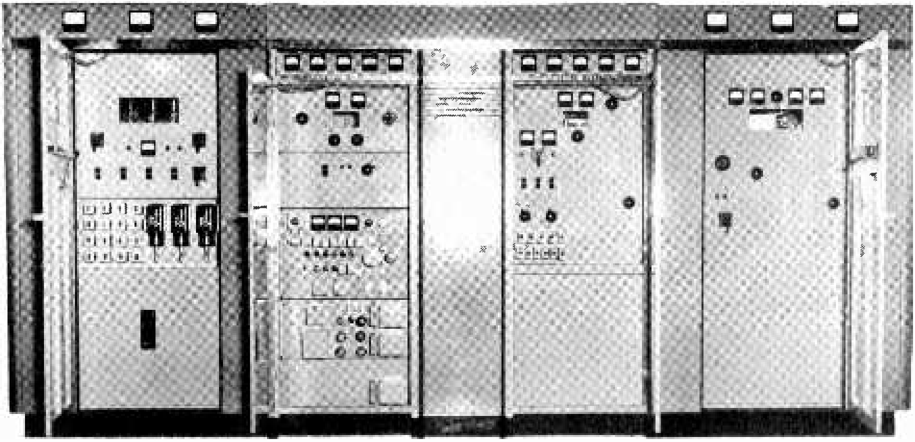
In the former lesson on Resonant Circuits, the explanations were simplified by the use of vectors and the same plan will be followed here. Reviewing briefly, all the various physical quantities can be divided into two general types, "Scalars" and "Vectors". Scalar quantities are those in which only the magnitude is of interest, such as length, temperature, weight, and resistance. Vector quantities are those having both magnitude and direction such as velocity, force, acceleration and voltage.

As no question of direction is involved, the addition of scalar quantities is relatively simple. For example, 6 pounds plus 4 pounds equals 10 pounds, no matter what the position of the objects, provided they are both at the same distance from the center of the earth. Even more simply, if the temperature of an object is raised 20° C, and its initial temperature was 50° C, its final temperature is 70° C, regardless of its location or position.

To indicate both magnitude and direction, a vector quantity is represented by a symbol consisting of a straight line with an arrowhead at one end, as at A in Figure 10. The length of the line is proportional to the magnitude, and its direction is indicated by the arrowhead and direction of the line. Thus, vector A in Figure 10 has a certain magnitude and a direction from left to right on the page, while vector B has a greater magnitude than A, and a direction diagonally upward to the left.

Vectors can be added graphically on the general plan illustrated in Figure 11 where vectors OA and OB represent two forces acting at right angles to each other. Each vector has been marked off into equal divisions which represent some unit of measure such as one or more pounds, volts or amperes. These divisions can be of any length or value as long as all are exactly the same in any one problem.

To perform the addition a parallelogram is completed, as shown by the broken line AR, which is equal in length and



Rear view, with doors open, of G-E 10-kw f-m transmitter shown in the previous illustration.

Courtesy General Electric Company

parallel to OB, and broken line BR which is equal in length and parallel to OA. Then the diagonal line, drawn from O to R, is the vector which indicates the magnitude and direction of the resultant or combined forces of OA and OB. Counting the divisions in the diagram, OA and OB each have 5 while OR has 7. Mathematically this can be expressed as,

$$OR = \sqrt{(OA)^2 + (OB)^2}$$

Thus, OR with a magnitude of 7 is in a direction 45° clockwise from OA and 45° counter-clockwise from OB. This graphical method of vector addition is applicable whether the forces A and B are equal or not, whether they are at right angles or not, and also to problems involving two or more vector quantities.

In our explanations of the various radio circuits, many a-c voltages and currents have been represented as sine waves, like those of Figures 1, 6 and 7. However, as electrical voltages and currents have both amplitude (magnitude) and polarity, they are vector quantities, and as such can be represented by vector diagrams like that of Figure 11.

In the diagram of Figure 11, the magnitudes of the forces are constant, and their directions 90° apart, but the magnitudes of a-c voltages and currents are constantly changing, while their directions reverse at the end of each half-cycle or alternation. Thus, the variations of an a-c quantity can be represented by a rotating vector like that of Figure 12.

Here, if the length of vector OA represents the maximum value of an a-c voltage, as it rotates counter-clockwise about the center point O, each complete revolution will represent one cycle. At any instant during the cycle, the instantaneous magnitude of this voltage is proportional to a line drawn, from the particular point on the circumference, perpendicular to the base line DOA.

For example, at the time instant C, the instantaneous value of the a-c voltage "e" is represented by the dotted line MC. At time instant B, the value of e is proportional to the length of OB, which here is equal to the maximum value OA. However, at the beginning of the cycle, point A, and also at point D, e is equal to zero.

Thus, for each complete cycle, e increases during the portion from point A to point B, then decreases and becomes zero at point D. Here the direction (polarity) reverses, and e increases to a maximum value at point E, finally decreasing to zero again at point A to complete the cycle.

The important point to bear in mind at this time is the relationship between the vector and the curve. If we are concerned only with the conditions at some particular instant or phase of a cycle, a vector drawn of proper length and at the correct angle, will provide as much information as the curve. This is important, because when more than one a-c value is under consideration, complete curves become rather complicated while vectors, drawn properly as to length and direction, can be made to serve the same purpose.

For example, the diagram in Figure 11 can represent two a-c voltages of equal amplitude and frequency, but which differ in phase by 90°. If these two voltages are combined in a mixing circuit, the resultant voltage will have the relative magnitude and phase as represented by vector OR. For diagrams of this type, it has been decided arbitrarily that angles measured in a counterclockwise direction from a reference line, indicate a leading phase angle, while those measured in a clockwise direction indicate a lagging phase. Therefore, in Figure 11, with vector OB as the reference line, voltage OA leads by 90°, and the resultant voltage OR leads by 45°. Also, with vector OA as the reference line, OR lags by 45°, and OB lags by 90°.

P-M TO F-M

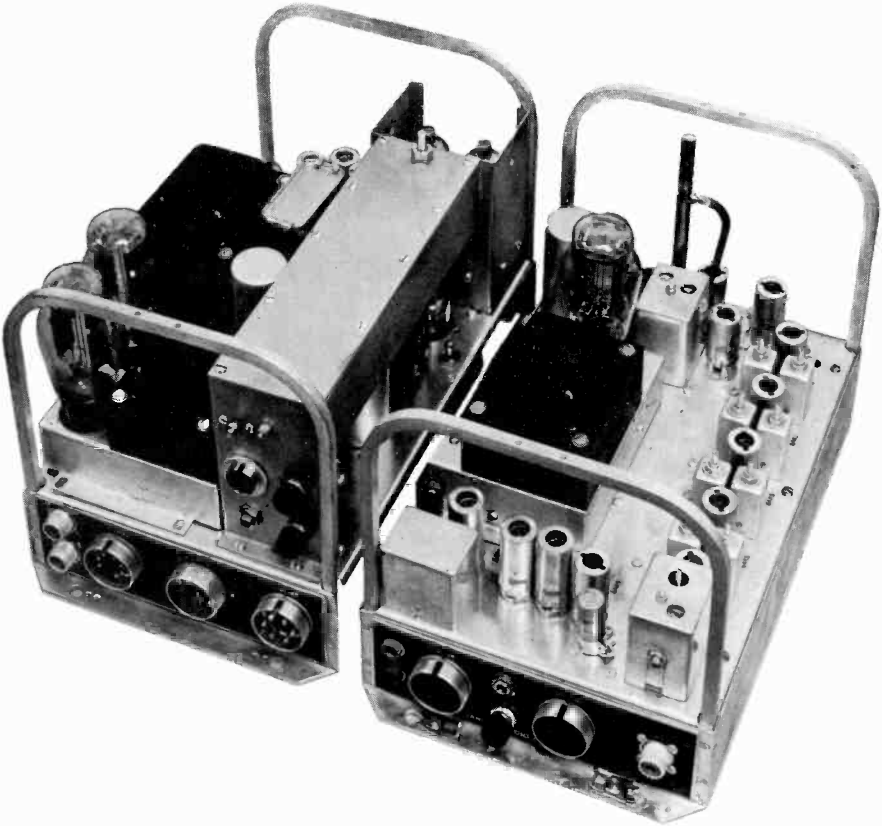
To illustrate the phase modulation process by means of vectors, in Figure 13A, vector E_c represents the carrier component which corresponds to the wave of Figure 7B. Vector E_S+ represents the positive maximum value and vector E_S- the negative maximum value of the double sideband component during each modulation cycle. The sine wave representation of the modulating voltage is shown by the curve of Figure 13B and, as indicated by the curves of Figure 7, during its positive alternation, the double sideband voltage leads the carrier by 90°. During the negative alternation, the double sideband lags the carrier by 90° therefore, in Figure 13A, both E_s vectors are drawn at right angles to vector E_c.

The amplitude of the carrier component remains constant but the amplitude of the double sideband is proportional to that of the modulating voltage. Therefore, in the lower row of diagrams in Figure 13, the lengths of the e_s vectors have been made equal to the corresponding numbered instantaneous voltages of curve 13B.

Starting at the beginning of a modulation cycle, ordinate "0" of Figure 13B, the instantaneous sideband amplitude, e_s, is zero and thus, as shown in Figure

13C, the resultant wave, e_m, is in phase with and equal to the carrier, ec. For all these diagrams, the "E" vectors represent maximum values while the "e" vectors represent instantaneous values. Moving over to ordinate 1, Figure 13B, the conditions are indicated by the upper half of the vector diagram of Figure 13D. Here, the sideband amplitude is represented by e_s+ and the resultant wave, represented by vector e_m, leads the carrier e_c by the angle θ.

Continuing on through the cycle, at ordinate 2, Figure 13B, the conditions are indicated by the upper half of the vector diagram of Figure 13E. Here, e_s+ has reached its maximum value and the resultant wave, e_m leads



Portable communications type f-m receiver and transmitter, designed for operation in the 152-162 megacycle band.

Courtesy Harvey Radio Laboratories, Inc.

the carrier e_c by the angle Δ. At ordinate 3, conditions duplicate those at ordinate 1 therefore the upper half of diagram 13F duplicates that of 13D and e_m leads e_c by the angle θ. At ordinate 4, the value of e_s has dropped to zero therefore e_m is in phase with e_c as indicated in Figure 13G.

The conditions at ordinate 5 are indicated by the lower half of vector diagram 13F where the negative polarity of e_s- causes the resultant wave, e'_m to lag the carrier e_c by the angle θ. In the same way, the lower half of diagram Figure 13E represents conditions at ordinate 6, diagram D represents conditions at ordinate 7 and diagram C represents conditions at ordinate 8 which corresponds to ordinate 1.

Summarizing the action just described, there are three main points to remember: (1) the resultant wave e_m is phase modulated by being caused alternately to lead and lag the carrier component e_c; (2) at any instant, the magnitude of the angle of lead or lag is proportional to the amplitude of the modulating signal; (3) the number of times per second that, with e_c as the reference line, the phase angle of e_m varies from zero to maximum lead, to zero, then to maximum lag and back to zero, is determined by the frequency of the modulating signal.

Referring again to Figure 12, the rate at which vector OA rotates is determined by the frequency of the a-c voltage or current which it represents. For instance, if OA completes one revolution in a time equal to T seconds, then the frequency F of the a-c quantity is given by:

$$F = \frac{1}{T} \text{ cycles per second}$$

If, during a particular cycle, OA is slowed down so that it rotates through an angle of only 330° in T seconds, then, during this cycle its frequency F_1 is less than F. Also, if OA is speeded up so that it rotates through an angle of 390° in T seconds, then during this interval its frequency F_2 is greater than F. This modulating or speeding up and slowing down of OA may be made to occur alternately at some desired number of times per second, in which case the instantaneous frequency will vary from F up to F_2, down to F_1 and finally return to F at the end of the cycle. In other words, although OA rotates at an average rate of F revolutions per second, during each modulation cycle its instantaneous rate of rotation varies alternately above and below average.

In Figure 13, e_c may be considered as rotating in a counterclockwise direction at a constant rate, such as 100 megacycles per second. Since e_m alternately leads and lags e_c, the maximum angle of lead, Δ, being equal to the maximum angle of lag, Δ', the average rate of rotation of e_m must be equal to the constant rate of e_C.

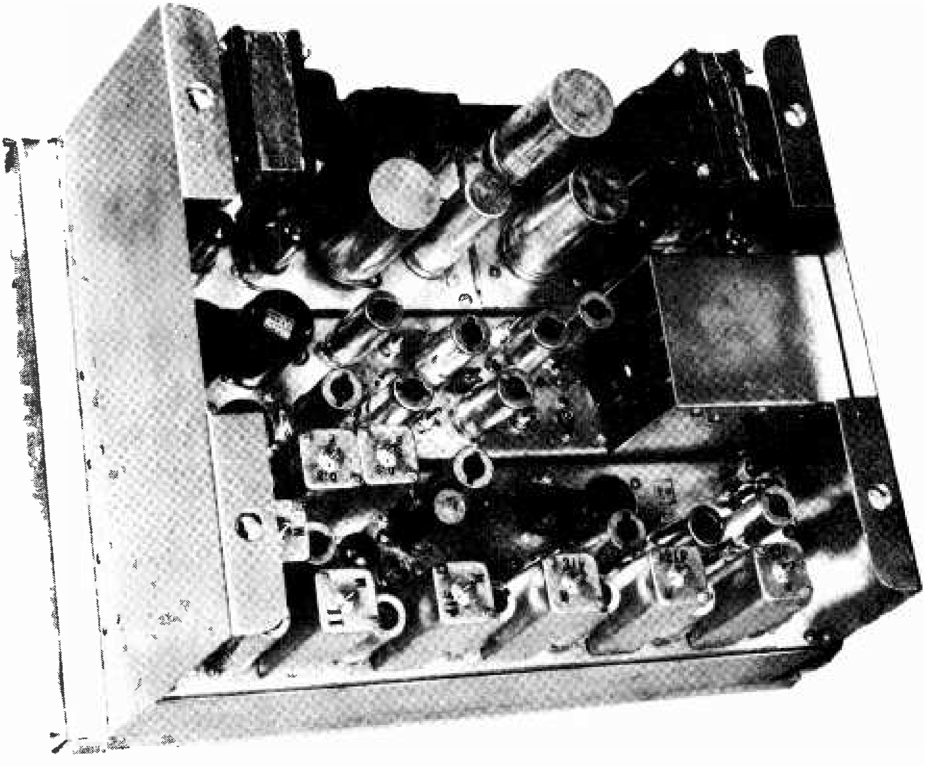
However, during the time that the angle of lead is increasing from zero to Δ, the rate of rotation or the frequency or e_m, is increasing. During the time that the phase angle decreases from Δ to zero, and then to Δ', the frequency of e_m is decreasing. Finally, the frequency of e_m increases while the phase angle decreases from Δ' to zero. Thus, the conclusion toward which this explanation has been leading is that, in the Armstrong f-m transmitting system, the frequency of the radiated f-m waves varies uniformly about its mean value in accordance with the phase modulation that is produced when the carrier component is re-combined with the sidebands which have been shifted 90° along the time axis.

DEVIATION COMPENSATION

For simplicity in the above explanation, a single fixed modulating frequency was assumed, but when speech or music is transmitted, the modulation signal consists of components having different frequency values. As explained earlier in this lesson, the arrangement of the reactance tube method meets the basic requirement of an f-m transmitter that the *frequency deviation* of the f-m wave be independent of the modulation frequency. However, in the Armstrong system, the *phase deviation* is independent of the modulation frequency. This resulting action represents the chief difference between f-m and p-m systems.

The diagrams of Figure 13 indicate two instants of peak phase deviation for each audio cycle, the actual values of the maximum lead and maximum lag angles depending upon the amplitude of the double sideband relative to that of the carrier component. When, without any change of amplitude, the frequency of the modulating signal is increased, more cycles of the audio voltage occur within any given interval, and the period of time between successive instants of maximum phase lead and lag is reduced. That is, the phase modulated resultant, e_m in Figure 13, must vary about its mean frequency at a greater rate, so that its deviation or change in frequency per unit of time, is greater than at the lower modulating frequency.

As a result, the Armstrong phase modulator circuit produces a wave whose frequency deviation is not only proportional to the amplitude of the signal voltage, but to its frequency as well. To correct this condition, it is necessary that the amplitude of the signal, applied to the input of the balanced modulator, be inversely proportional to its frequency as indicated by the curve of Figure 14A.



F-M 2-way radiotelephone communication unit-transmitter and receiver.
Courtesy Mobile Communications Company, Long Beach, Calif.

This action can be accomplished in the transmitter speech amplifier by inserting a correction filter, such as the series RC network, across the secondary of coupling transformer T in Figure 14B. Since the reactance of condenser C is inversely proportional to frequency, the voltage drop across C, applied to the grid of V_2, will decrease as the signal frequency increases. Therefore the deviation of the radiated wave will be independent of the modulation frequency, and will be determined by the modulation amplitude only, as is required for proper reproduction at the f-m receiver.

DEVIATION INCREASING METHODS

To prevent distortion of the final f-m wave, in the p-m systems the modulation index must be low so that only one pair of sidebands is produced. However, the low modulation index produces only a very slight degree of frequency modulation of the carrier, and this deviation must be increased greatly to reach the desired value of ± 75 kc.

As shown in the block diagram of Figure 8, this increase can be accomplished by passing the f-m wave through a series of frequency multipliers in which the deviation is multiplied by the same amount as the carrier. However, if the carrier is multiplied as many times as required to obtain the desired deviation, the final carrier frequency will be higher than the band that is allocated by the FCC for f-m broadcasting.

To overcome this difficulty, the frequency multiplier No. 1 output is applied to a mixer and heterodyned with the output of crystal oscillator No. 2. Operating on the same general plan as the mixer stage of a superheterodyne receiver, the frequency of the output of this mixer is lower than that of either input. This lower frequency becomes the carrier but it is modulated by the full deviation of the frequency multiplier No. 1 output. Thus, the mixer stage reduces the carrier frequency but does not change the deviation.

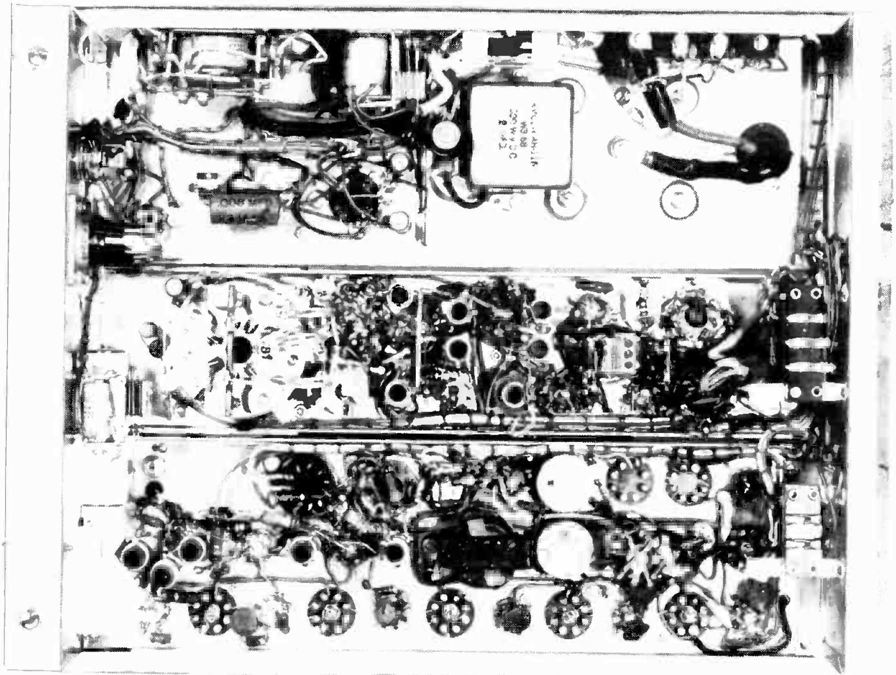
The output of the mixer is then passed through a second series of frequency multipliers which increase both the carrier frequency and deviation to the values desired for transmission. The output of frequency multiplier No. 2 is the input for the power amplifier which raises the power level of the signal to the desired value. The output of the power amplifier is carried by the transmission line to the radiating antenna.

PHASITRON

A second method of phase modulaton has been developed by Dr. Robert Adler and is in use commercially by the General Electric Co. In this system, the entire modulation process is performed by a single, specially designed tube, called the "phasitron", the construction of which is shown in the simplified cut-a-way drawing of Figure 15A. Actually, the various electrodes are cylindrical and completely surround the cathode. The position and shape of the focusing electrodes are such that the electrons, moving from the cathode to the anodes, are formed into a fairly thin disk with the general shape shown in Figure 15B. The waves or "ruffles" around the edge of this "electron disk" are caused by a voltage applied across the deflector electrode and the deflector grids.

This voltage, generated by the carrier frequency crystal oscillator, is applied to the separately terminated grids in such a way that the waveform at the edge of the electron disk rotates at a rate determined by the frequency of the crystal oscillator. The outer edge of this "rotating" disk is in contact with the first anode at the level of the alternately spaced rectangular openings.

Attracted by the second anode, electrons from the disk pass through these openings to make up the second anode or output current. Due to the shape and spacing of the first anode open-



Bottom-of-chassis view of 2-way F-M communication unit shown in previous illustration.
Courtesy Mobile Communications Company

ings, the waveform at the edge of the rotating disk provides a sine wave variation of 2nd anode current at the frequency of the crystal oscillator.

To phase modulate the second anode current, the modulating current is carried in a coil placed around the outside of the tube. The magnetic flux lines set up by current in this coil cut through the rotating disk at right angles to the direction of electron flow. Thus, in Figure 15B, the electrons move from the center to the outer edge and if the disk is in its normal horizontal position, the magnetic flux lines will be vertical.

Like the current in a conductor, a stream of electrons sets up a magnetic field at right angles to the direction of motion. Thus, at the surface of the disk, the flux lines set up by the moving electrons will be parallel to those set up by the external coil. Due to the reaction between these magnetic fields, the electrons will be shifted at right angles to their direction of motion by an amount and in a direction proportional to the instantaneous values of amplitude and direction of the modulating current in the external coil.

In effect therefore, the modulating current causes the speed of rotation of the sine waveform at the edge of the electron disk to vary above and below its mean value and these variations cause the second anode r-f current to be phase-modulated in accordance with the modulating signal. This phase modulation results in frequency modulation in the same way as explained for e_m in Figure 13.

F-M WAVE PROPAGATION

The present f-m station channel width is 200 kc, while the a-m broadcast station occupies a bandwidth of only 10 kc therefore, as but few 200 kc channels could be allocated in the standard broadcast band, the f-m stations are assigned frequencies in the region of 100 mc.

As both a-m and f-m wave propagation employ the same medium, it may be of benefit to review the lesson on Antennas in order to recall the behavior of electromagnetic waves in space. It is known that the ionized layers (E, F_1 and F_2) contain comparatively large numbers of free electrons, and thus have the property of refracting radio waves. Whether or not the wave will be bent back to the earth depends on its frequency, the height of the refracting layer, and the density of ionization. In general, the waves of a-m stations in the standard broadcast band are reflected, whereas the high-frequency f-m carrier waves penetrate the ionized layers and do not return to earth.

High-frequency waves have the property of traveling in straight lines, much like light, and, therefore, are often called "Quasi-Optical". In general, for satisfactory reception of f-m signals, a receiver should be within the "line of sight" coverage of a transmitter although tests have shown it is possible to provide good signal strength at distances greater than twice the line of sight when the radiation power of the f-m station is relatively great.

A condition which very often occurs, particularly at high frequencies, is the creation of a "shadow" area. This is the reduction of signal strength behind an object which is large enough to reflect the initial wave. Shadow areas become more noticeable as the frequency of the wave is increased. However, such conditions are partially corrected by erecting the f-m transmitter antenna relatively high, and designing it for the purpose of concentrating the radiated power toward the horizon.

IMPORTANT WORDS USED IN THIS LESSON

BALANCED MODULATOR—An a-m modulator with two tubes in a balanced or symmetrical circuit arrangement. The carrier is impressed in push-pull and the modulating signal in parallel on the grids of the two tubes. The output contains only the upper and lower sidebands and the original audio signal. The carrier is balanced out.

DEVIATION—In f-m, the amount of change in frequency either above or below the mean frequency of a carrier.

DISCRIMINATOR—A tuned circuit system that converts changes of frequency into corresponding changes of amplitude.

FREQUENCY MODULATION—A method of varying the frequency of an r-f carrier in accordance with the characteristics of the audio or other signal which is transmitted.

100% MODULATION—In f-m broadcast systems, 100% modulation is defined as existing when the peak deviation is 75 kc.

MODULATION INDEX—The ratio of the peak frequency deviation to the frequency of the modulating signal. Also known as the deviation ratio.

PERCENTAGE OF MODULATION—In frequency modulation, the percentage of modulation is the ratio (expressed in per cent) of the actual deviation to the designated maximum deviation.

PHASITRON—A special type of tube for generating wideband phase deviations.

PHASE MODULATION—The method of varying the phase of an r-f carrier, with respect to its unmodulated condition, in accordance with the audio or other signal which is transmitted.

PHASE-SHIFT CIRCUIT—A circuit arrangement consisting of a resistance and reactance connected in series, and employed to vary the phase relationship between two a-c quantities.

REACTANCE-TUBE MODULATOR—An f-m modulating system in which an electron tube functions as a reactance that varies in accordance with the modulating signal and causes corresponding changes in the frequency of an oscillator.

WIDE-BAND F-M—That system of frequency modulation as standardized by the FCC in which the peak frequency deviation is 75 kc for 100% modulation.

BESSEL FACTORS FOR FINDING AMPLITUDES OF CENTER AND SIDEBAND FREQUENCY COMPONENTS

CHART I

Modulation Index M	J_0 (M) F	J_1 (M) F ± F_M	J_2 (M) F ± $2F_M$	J_3 (M) F ± $3F_M$	J_4 (M) F ± $4F_M$	J_5 (M) F ± $5F_M$	J_6 (M) F ± $6F_M$	J_7 (M) F ± $7F_M$	J_8 (M) F ± $8F_M$	J_9 (M) F ± $9F_M$	J_{10} (M) F ± $10F_M$	J_{11} (M) F ± $11F_M$	J_{12} (M) F ± $12F_M$	J_{13} (M) F ± $13F_M$	J_{14} (M) F ± $14F_M$
0.0	1.000														
0.01	1.000	.005													
0.05	.9994	.025													
0.1	.9975	.0499													
0.2	.9900	.0995													
0.3	.9776	.1483	.0112												
0.4	.9604	.1960	.0197												
0.5	.9385	.2423	.0306												
0.6	.9120	.2867	.0437												
0.7	.8812	.3290	.0589	.0069											
0.8	.8463	.3688	.0758	.0102											
0.9	.8075	.4059	.0946	.0144											
1.0	.7652	.4401	.1149	.0196											
2.0	.2239	.5767	.3528	.1289	.0341										
3.0	−.2601	.3391	.4861	.3091	.1320	.0430	.0114								
4.0	−.3971	−.0661	.3641	.4302	.2811	.1321	.0491	.0152							
5.0	−.1776	−.3276	.0466	.3648	.3912	.2611	.1310	.0534	.0184						
6.0	.1506	−.2767	−.2429	.1148	.3576	.3621	.2458	.1296	.0565	.0212					
7.0	.3001	−.0047	−.3014	−.1676	.1578	.3479	.3392	.2336	.1280	.0589	.0235				
8.0	.1717	.2356	−.1130	−.2911	−.1054	.1858	.3376	.3206	.2235	.1263	.0608	.0256	.0100		
9.0	−.0903	.2453	.1448	−.1809	−.2655	−.0551	.2043	.3275	.3051	.2149	.1247	.0622	.0274	.0108	
10.0	−.2459	.0435	.2546	.0584	−.2196	−.2341	−.0145	.2167	.3179	.2919	.2075	.1231	.0634	.0290	.0120

F represents the Carrier or Mean Frequency
F_M represents the Audio Frequency

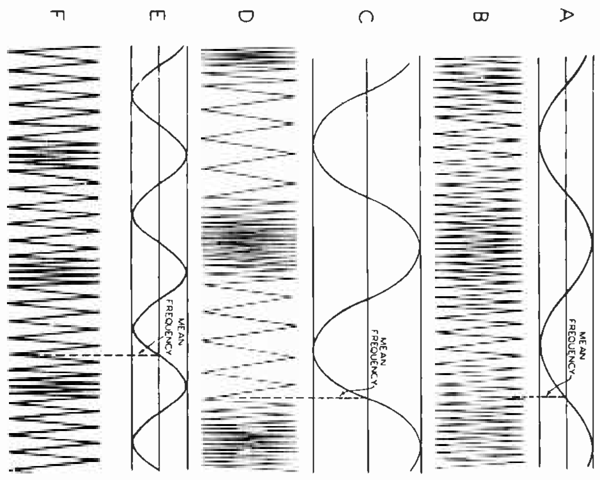


FIGURE 1

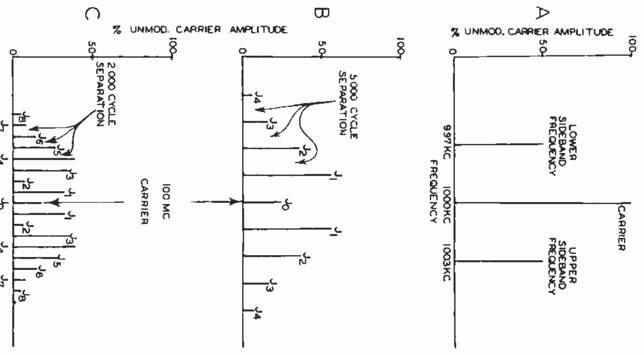


FIGURE 2

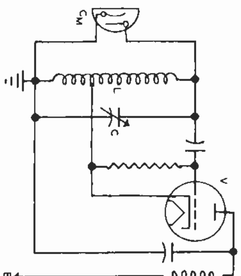


FIGURE 3

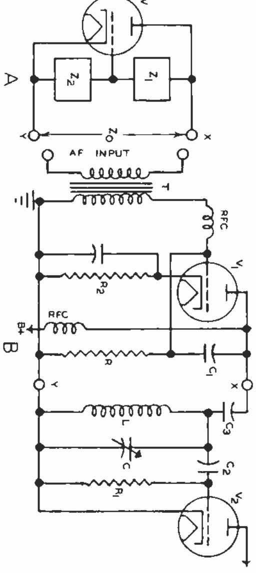


FIGURE 4

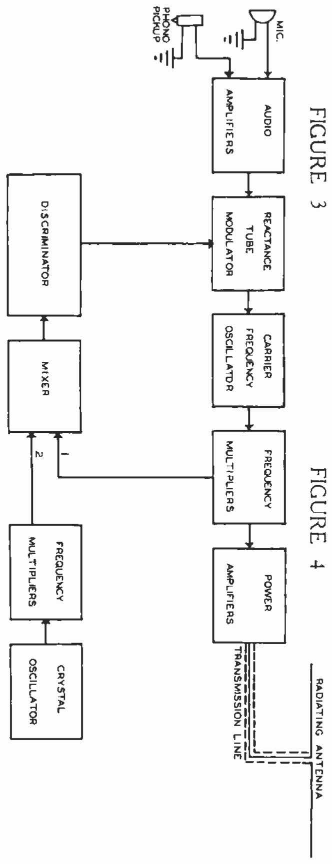


FIGURE 5

RRT-15

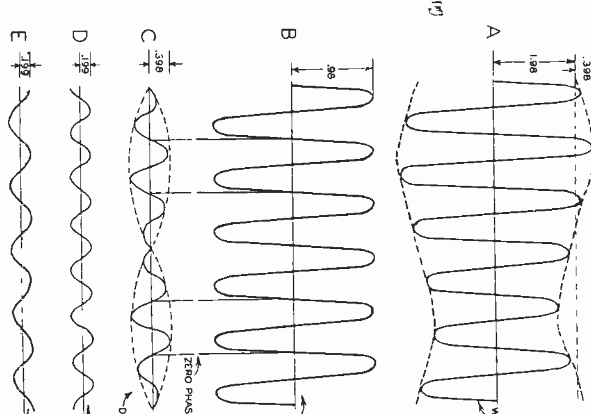


FIGURE 6

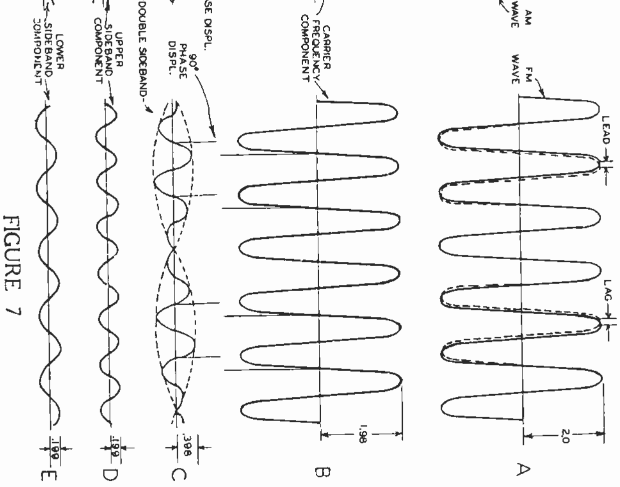


FIGURE 7

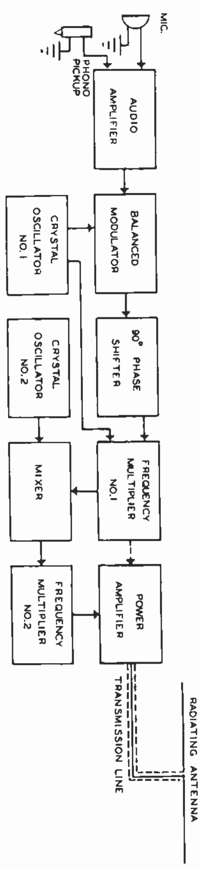


FIGURE 8

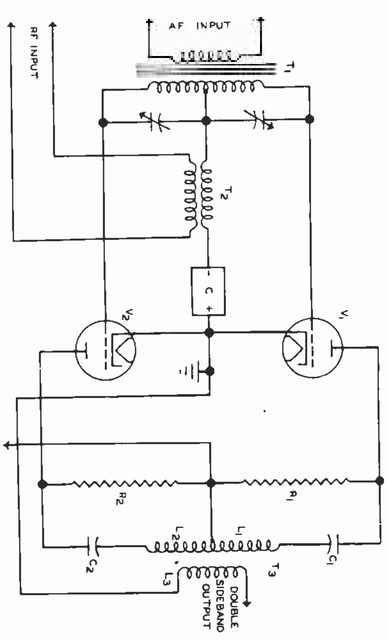


FIGURE 9

RRT-15

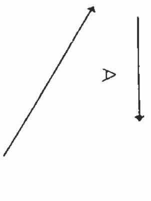


FIGURE 10

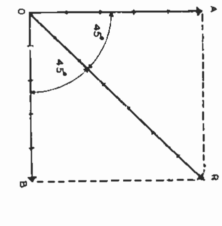


FIGURE 11

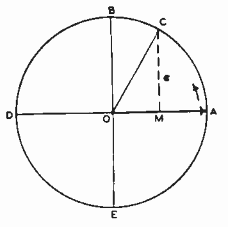


FIGURE 12

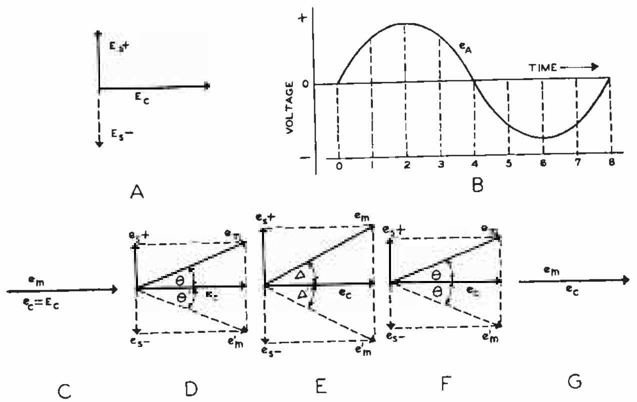


FIGURE 13

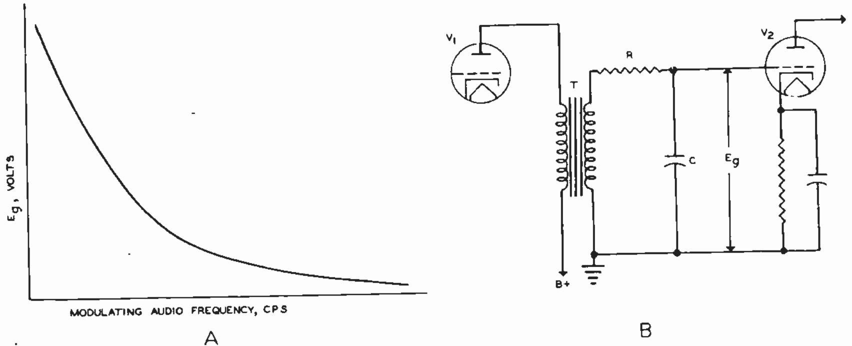


FIGURE 14

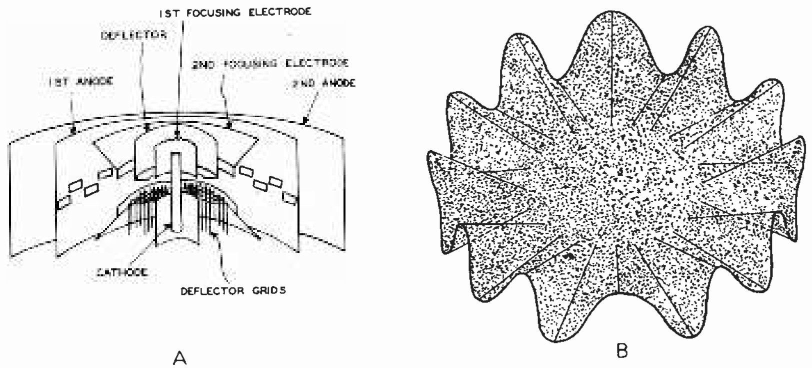


FIGURE 15

F-M BROADCAST BAND

Frequency mc	Channel No.	Frequency mc	Channel No.	Frequency mc	Channel No.
88.1	201	94.9	235	101.5	268
88.3	202	95.1	236	101.7	269
88.5	203	95.3	237	101.9	270
88.7	204	95.5	238	102.1	271
88.9	205	95.7	239	102.3	272
89.1	206	95.9	240	102.5	273
89.3	207	96.1	241	102.7	274
89.5	208	96.3	242	102.9	275
89.7	209	96.5	243	103.1	276
89.9	210	96.7	244	103.3	277
90.1	211	96.9	245	103.5	278
90.3	212	97.1	246	103.7	279
90.5	213	97.3	247	103.9	280
90.7	214	97.5	248	104.1	281
90.9	215	97.7	249	104.3	282
91.1	216	97.9	250	104.5	283
91.3	217	98.1	251	104.7	284
91.5	218	98.3	252	104.9	285
91.7	219	98.5	253	105.1	286
91.9	220	98.7	254	105.3	287
92.1	221	98.9	255	105.5	288
92.3	222	99.1	256	105.7	289
92.5	223	99.3	257	105.9	290
92.7	224	99.5	258	106.1	291
92.9	225	99.7	259	106.3	292
93.1	226	99.9	260	106.5	293
93.3	227	100.1	261	106.7	294
93.5	228	100.3	262	106.9	295
93.7	229	100.5	263	107.1	296
93.9	230	100.7	264	107.3	297
94.1	231	100.9	265	107.5	298
94.3	232	101.1	266	107.7	299
94.5	233	101.3	267	107.9	300
94.7	234				

FROM OUR *President's* NOTEBOOK

CAN YOU SING A SONG?

Can you sing a song to greet the sun,
Can you cheerily tackle the work to be done,
Can you vision it finished when only begun,
Can you sing a song?

Can you sing a song at the close of the day,
When weary and tired, the work's put away,
With the joy that it's won and the best of
the pay,
Can you sing a song?

Yours for success,

E. B. DeVry

PRESIDENT

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