Amplitude Modulation

(Continued)

ulation process, although the d.c. plate power input remains constant. Operating voltages and currents must be maintained at specific values in order to obtain good linearity of modulation. Especially important is the location along the grid characteristic at which the tube is operated. These values are such that the plate-circuit efficiency of a grid-modulated stage is reduced to approximately one-half that of a plate-modulated stage. 35% is usual with grid modulation. Both excitation and bias voltages are set considerably lower than corresponding characteristics in class-C operation.

The carrier efficiency in a grid-bias modulated system is highest at the modulation peak. The carrier must be maintained at a value which is equal to half of its peak voltage, the modulated values being then swung up and down about this particular value. The carrier efficiency is accordingly termed one-half the theoretical possible efficiency. Actually, however, the efficiency of grid-modulated r.f. amplifiers is approximately 35%. An advantage of the system is its low a.f. and r.f. power requirements. Very small audio levels will completely modulate the amplifier, while the actual r.f. excitation power reaching the grid need be sufficient only to overcome the grid losses.

A typical cathode-modulated amplifier is shown in Figure 5-D. In this circuit, the audio voltage is impressed across the cathode circuit. The cathode-modulated circuit may be considered to divide the modulation between plate and grid, the carrier efficiency being, as a result, intermediate between the two and usually 45%. Variations occur in both grid-bias and plate voltage during modulation.

Since the presence of a small amount of grid-bias modulation in this system tends to make the circuit behave somewhat as a grid-modulated stage, the output will not be so high as with plate modulation. The percentage of grid modulation is purposely kept small to increase the carrier efficiency. The percentage of grid modulation may be controlled by adjustment of the grid leak resistance and the position of the grid return along the tapped secondary of the cathode modulation transformer.

As the percentage of plate modulation is increased, the required audio power (from the modulator) and r.f. excitation likewise increase, although both of these requirements will be small as compared to those of plate modulation circuits.

Figure 5-E shows the circuit for suppressor modulation of r.f. pentodes. Here, the audio-frequency component is introduced through the coupling transformer in series with the negative d.c. suppressor bias. An extremely small amount of audio power is required to modulate an amplifier in this fashion, but the carrier efficiency, as in grid-bias modulation, is only about 35%, and distortion increases above 80% modulation.

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Amplitude Modulation

By the Engineering Department, Aerovox Corporation

THE three common methods of superimposing an audio-frequency component upon a radio-frequency carrier wave are termed *frequency modulation, phase modulation*, and *amplitude modulation*. Radiotelephony and some forms of tone telegraphy are made possible by modulation processes.

In amplitude modulation, the carrier frequency is maintained constant while the carrier amplitude is varied at the audio rate. Neither frequency nor phase is more than slightly disturbed in efficiently operated systems.

Amplitude modulation is widely used. Each of the standard broadcast stations and most of the radiotelephone communication stations now in operation employ this method. Moreover, amplitude-modulated signal generators are used to align and test several million of the receivers in current use.

The appearance of an amplitude-modulated carrier is shown in Figure 1. This illustration shows the carrier voltage or current wave before and after application of the modulating component. It is seen that both carrier and audio voltages are alternating components of widely different frequency. When the two are combined in the process of amplitude modulation, the amplitudes of successive positive and negative carrier peaks are altered in accordance, so that the "moulded" carrier traces out an envelope corresponding to the frequency and relative voltage of the audio component. The relationship of carrier and modulating voltages or currents and frequencies of these components is shown in Figure 2. A radio-frequency carrier before modulation is shown in 2-A, the modulating voltage wave in 2-B, and the completely modulated carrier in 2-C.

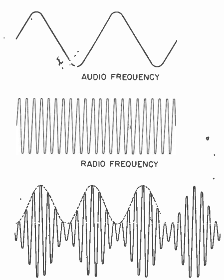

FIG.1

In order to combine the audio and carrier components in the modulation process, the alternating a.f. voltage is actually superimposed upon one of the d.c. operating voltages of the r.f. amplifier or oscillator, generally the plate or grid voltage. Accordingly, the a.c. and d.c. voltages add on one half-cycle of audio voltage and buck on the other half-cycle. This results in an increase in the normal d.c. voltage in the first instance and a reduction in the second case.

In consequence of this action, a variable d.c. voltage is applied to one of the r.f. tube electrodes, and the r.f. carrier voltage and current will be varied at the same rate. For complete modulation, as depicted by Figure 2, the carrier amplitude is increased, throughout the modulation envelope, to a maximum value equal to twice the unmodulated carrier amplitude and reduced to a minimum value of zero. In the conventional system operating ideally, both positive and negative carrier peaks are affected by the same amount, and the carrier frequency and phase remain unaltered.

In Figure 2-C, C is the unmodulated carrier amplitude and M the amplitude of the modulating voltage. The diagram shows the condition of complete modulation, i.e., M=C, and X=2C. From the relationships shown, it is evident that lower values of M than that shown would fail to raise the carrier amplitude to an instantaneous value of twice its unmodulated value on positive peaks of modulating voltage, or to reduce it entirely to zero on negative peaks of modulating voltage. Similarly, higher values of M would raise amplitude C to a level more than twice its unmodulated value while completely cutting off the carrier for brief intervals during the negative modulation swing. The carrier would disappear completely at the zero line, the negative modulation peaks being lost. Consequently, the dimension D is useful for indicating the extent of the process, or *modulation depth*.

The degree of modulation is useful information. The effective value of amplitude-modulated carrier current increases with modulation depth. In practice, the depth of modulation is determined conveniently from the ratio of modulated to unmodulated carrier amplitudes. This ratio is known as the *modulation factor*.

From the diagram of Figure 2, the modulation factor may be expressed as M/C. However, when measurements are made of successive modulated and unmodulated amplitudes, as with an oscilloscope, it is more convenient to measure each of these amplitudes with reference to the zero line rather than with respect to each other. This is because the original carrier amplitude disappears from the screen (or meter scale) during modulation. When measurements are made from zero, M is equal to the difference between the modulated and unmodulated carrier amplitudes, and the equation for modulation factor becomes:

$$\text{(1)} \quad \text{Modulation Factor} = \frac{X-C}{C}$$

These amplitude values are determined by means of a peak-reading vacuum-tube voltmeter connected across an appropriate tuned circuit, resonant to the carrier frequency, or they may be taken directly from an oscilloscope screen in any desirable linear units of measurement.

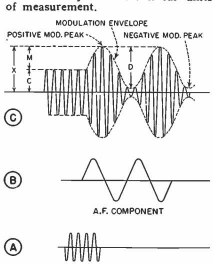

FIG. 2

In complete modulation, the modulation factor is 1.0. This follows from the requirement that the completely modulated carrier amplitude be exactly twice its unmodulated value, its ratio being unity. The *percentage of modulation*, common term for expressing modulation depth, may be obtained by multiplying the modulation factor by 100:

$$\text{(2)} \quad \%\ \text{Modulation} = \frac{X-C}{C}\,100$$

Several degrees of modulation depth are shown in Figure 3. 3-A corresponds to complete, or 100% modulation, 3-B to incomplete (approximately 50%) modulation, and 3-C to overmodulation (somewhat greater than 100%). Note from these voltage or current curves that the maximum and minimum modulated amplitudes are equal respectively to twice the unmodulated value and zero for 100% modulation, less than twice carrier and higher than zero for incomplete modulation, and greater than twice carrier for overmodulation. Observe also that by-products of overmodulation are the cut-off periods along the zero line.

In a completely-modulated transmitter, the instantaneous antenna current or voltage is raised to twice its normal value by positive modulation peaks and decreased to zero by negative modulation peaks. The antenna resistance remains constant as long as the carrier frequency is not shifted; so the power in the modulated wave is directly proportional to the square of the modulated carrier voltage or current: ($P = E^2/R = I^2R$). In any carrier that is modulated 100 percent by the amplitude method, the instantaneous peak power is therefore four times the unmodulated carrier power. The completely-modulated amplifier or oscillator must be capable of supplying this increased peak power output.

ADVANTAGES OF COMPLETE MODULATION

The audio-frequency voltage and power delivered by the detector in a radio receiver is proportional to the amplitude of the modulating voltage. This voltage is equivalent in magnitude and frequency to the modulation envelope. In order to obtain the largest undistorted detector output for a given carrier, the largest permissible a.f. voltage must be employed in the modulation process—which is another way of stating that the highest permissible values of modulation depth, modulation factor, or modulation percentage give the highest undistorted detector output levels.

100-percent modulation is the maximum permissible depth which may be applied to any carrier wave, since this percentage allows the carrier amplitude to be swung between zero and twice its normal value, the maximum safe limits. Higher percentages of

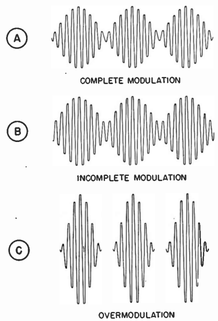

FIG. 3

modulation have already been shown to introduce cut-off periods (Figure 3-C), which because of the high damping they introduce, cause broad tuning. Frequency distortion, resulting from loss of the negative modulating voltage peaks and deviation of the carrier frequency during modulation, are also by-products of excessive modulation depth.

Complete modulation of a transmitter reduces heterodyne interference at distant points, improves the signal strength (and signal-to-noise ratio) in receivers in the service area, and affords a better increase in the station's service area than might be gained by reasonable increases in the transmitter carrier power. An audio increase of only 3 db, for example, is equivalent to *doubling* the carrier power. 100-percent modulation makes the most effective use of a carrier in the most economical manner.

SIDE-BAND GENERATION

One of the by-products of normal amplitude modulation is the heterodyne effect between the a.f. and r.f. components. As is the case when any two frequencies are combined, two beat notes are set up by the modulation process, due to interaction of carrier and modulating voltages. One of these beats is equal to the sum of the two frequencies, and the other to their difference. Consequently, two radio frequencies other than the transmitter or oscillator carrier are generated by the modulation process; one being equal to the carrier plus the modulating frequency—the other to the carrier minus the modulating frequency. These are the well-known *side frequen-*

cies, lying one above and one below the carrier, which set the limits of the *side bands*. The intelligence is conveyed by these side bands.

The initial phases of carrier, upper side frequency, and lower side frequency are 0, —90, and +90 degrees. These phase relationships are represented vectorially in Figure 4, where the components are either peak or effective carrier voltage and side-frequency voltages. S_U and S_L are the upper and lower side-frequency voltages, respectively, while C is the carrier voltage. With respect to the carrier vector, C, S_U rotates counterclockwise while S_L rotates clockwise. At maximum modulated amplitude, the side-frequency vectors are in phase with the carrier vector; at minimum modulated amplitude, 180° out of phase. With respect to the magnitudes of the side-frequency voltages or currents, the modulation percentage is:

$$\text{(3)} \quad \%\ \text{Modulation} = \frac{S_U + S_L}{C}\,100$$

The channel width of an amplitude-modulated emission is fixed by the separation of the upper and lower side frequencies and is the total width of the side bands so delineated. The channel width is thus twice the frequency of the modulating voltage. When the latter contains several frequencies, as in speech or music modulation, the highest modulating frequency in the complex group determines the maximum side-band width.

AMPLITUDE-MODULATION CIRCUITS

Figure 5 shows various circuits for amplitude modulation. 5-A and 5-B are arranged for plate modulation of the r.f. tube; 5-C for grid-bias modulation; 5-D, cathode modulation; and 5-E, suppressor modulation.

Plate modulation may be *constant current* or *constant voltage* in type. In the former case, the modulator delivers audio-frequency power to the r.f. tube. In the constant voltage system, the modulator may be considered equivalent to an audio-operated resistor in series with the d.c. plate voltage of the r.f. tube.

Figure 5-A is the Heising or constant current circuit. In this arrangement, d.c. power is supplied to both r.f. and modulator tubes through the iron-core reactor L by the common source Ep. The modulator plate current is maintained by the d.c. grid voltage of the modulator at the same value as the r.f. tube plate current.

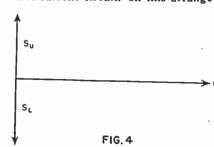

FIG. 4

Variations in the modulator grid voltage (produced by excitation from the audio amplifier) cause corresponding changes in the modulator plate current, an increase in the negative value causing a reduction in plate current, while a reduction in the negative value (or positive grid swing) causes the plate current to rise. These plate current variations give rise to induced voltages in the reactor L, which are in the proper direction with respect to Ep to maintain the supply current steady. When the modulator plate current increases, the amplifier plate current must decrease, and vice versa. The total current thus remains constant through the action of the reactor, while audio-frequency variations in the plate current of the r.f. tube produce corresponding variations in the carrier.

For 100-percent modulation, the r.f. amplitude is modulated between twice its resting value and zero. In order to accomplish this in the Heising circuit, several modulator tubes would need be connected in parallel to reduce the modulator plate resistance. (Actually, in order to secure complete modulation, the plate resistance would have to be reduced to zero). Or the modulator plate must be operated at a higher voltage than that of the r.f. tube. The latter method is most common and is accomplished by the series dropping resistor R which is shunted by the capacitor C, the function of the latter being to pass to audio voltage.

Figure 5-B shows plate modulation employing a coupling transformer. The modulator may be a class-A, class-B, or class —AB amplifier of sufficient power capability. Here the a.f. power is superimposed upon the d.c. plate power input to the r.f. tube by means of the transformer. The audio voltage is thus effectively in series with the d.c. plate voltage of the r.f. tube. The voltage required for complete modulation depends upon the a.f. voltage in the transformer primary, the turns ratio of the transformer, and the maximum d.c. power input to the plate of the r.f. tube. When the a.f. power output is sufficient, complete modulation with low distortion and good linearity is obtained when the impedances of modulator and r.f. tube plate circuits are matched through the coupling transformer.

In plate-modulated systems, the audio power which must be supplied by the modulator is equal to one-half the d.c. plate power input to the r.f. stage. It is clear from the foregoing explanations that since the instantaneous plate voltage of an r.f. tube under 100% modulation will be increased to twice its normal value, the tube must dissipate a detrimental amount of power unless its "resting" plate voltage is reduced to a safe value. For this reason tube tables indicate a lower value of plate voltage for telephony and modulated telegraphy than for unmodulated services.

Figure 5-C shows a grid-bias modulation circuit. Here, audio frequencies are introduced into the grid circuit of the r.f. tube through the coupling transformer T. This system utilizes variations in the grid-bias of the r.f. tube to secure amplitude modulation of the carrier. The peak grid voltage is varied by varying the d.c. bias at the audio-frequency rate, and the average power output is increased by the mod-

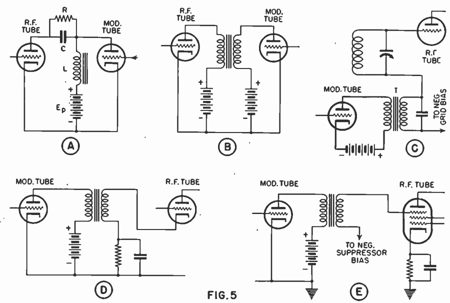

FIG. 5

(Continued on Page 4)