CHAPTER 1

AMPLIFIER FUNDAMENTALS

1. Definition of Amplifier

A *vacuum-tube amplifier* is a device used to increase to usable strength the power or voltage of the signals developed in electronic circuits. For example: The output of a microphone must be amplified (fig. 1) before it can produce an audible sound from a loudspeaker; a radar echo signal must be amplified to make it strong enough to operate an indicator. The output signal, as in A, may have the same waveform as the input, or it may have a different waveform as in B; but in either case the amplitude of the output is greater than that of the input signal.

2. Principles of Operation of Amplifier

An amplifier consists of one or more vacuum tubes together with their associated circuits (fig. 2). It works in accordance with the fundamental principles of vacuum-tube operation explained in TM 11-662.

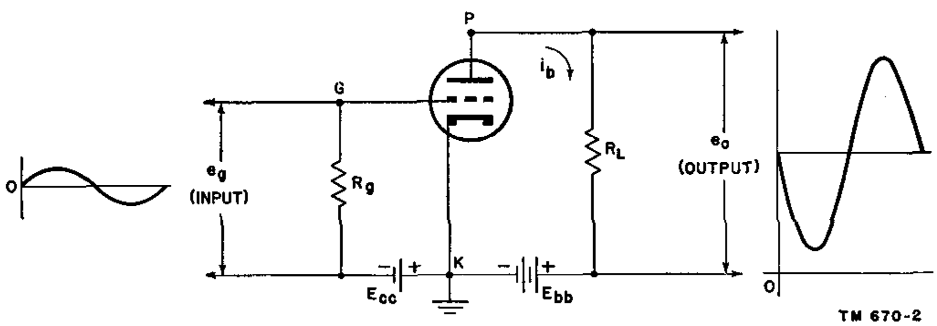

Figure 2. Simple amplifier stage.

a. Basic Amplifier Circuit.

(1) The heart of the amplifier stage is the *tube*. The tube shown in figure 2 is a triode. Power for the output circuit is supplied by battery E_{bb}, connected in series with load resistor R_L between cathode *K* and plate *P* of the tube. The battery places the plate at a positive voltage in respect to the cathode, and causes a direct current, i_b, through the tube and R_L. The arrow indicates the direction of electron flow.

(2) The bias battery, E_{cc}, connected as shown, places grid *G* at a negative voltage in respect to the cathode. Usually, no current exists in the grid circuit. The alternating signal voltage, e_g, is applied to the grid across grid resistor R_g. The grid signal causes variations in the plate current, which consists of a d-c (direct-current) component caused by E_{bb}, and an a-c (alternating-current) component caused by e_g. The a-c component of the plate current develops an alternating voltage drop across R_L (in addition to the d-c voltage drop). This alternating voltage drop is of greater amplitude than e_g, and is the output voltage. If load resistor R_L were omitted from the circuit, no useful output voltage could be obtained. The grid signal would cause the plate *current* to vary, but the plate *voltage* would

remain constant, since at every instant it would be identical with E_{bb}.

b. Additional Amplifier Stages. Often a single stage will not provide sufficient amplification of a very weak signal. It then becomes necessary to connect two or more stages in *cascade,* as shown in the block diagram of figure 3. The output voltage of one stage is used as the input signal for the following stage, thus providing a greater over-all amplification than either stage could provide by itself. Several methods of *coupling* between stages are available (par. 4*d*). The polarity of the signal is reversed by each stage, as explained in paragraph 6*b*.

waveform of the input signal (A of fig. 1). The extent to which this is accomplished depends partly on the frequency response of the amplifier. An amplifier that does not accomplish this result is said to *introduce distortion.* For many applications, the amplifier is designed purposely to introduce a large degree of distortion, as in B.

d. Efficiency. Any additional a-c power in the output not supplied by the input signal must come from the d-c supply. However, a part of the d-c power is wasted, in that it does not appear as a useful output. The extent to which this occurs is expressed as the *efficiency* of the amplifier. In large radio transmitters, efficiency may be an important consideration. In devices (2)

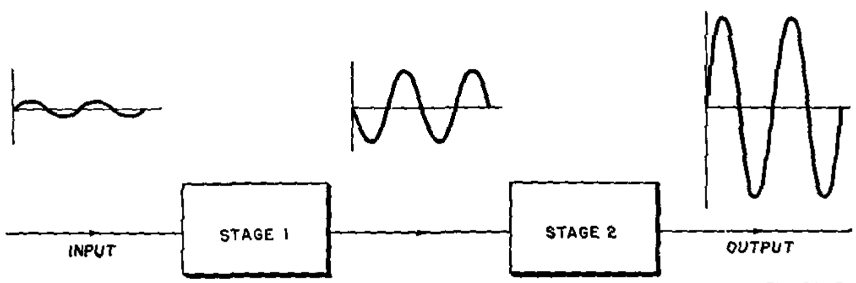

Figure 3. Two stages in cascade.

3. Amplifier Considerations

a. Gain. Amplification is expressed by comparing the amplitudes of the output and input voltages. The ratio of these two quantities is called the *voltage gain,* or simply the *gain,* of the amplifier. The output voltage may, or may not, deliver more power to the load than the stage receives at its input.

b. Frequency Response. Most amplifiers provide substantially the same gain for signals of slightly different frequencies. Over a band of frequencies for which the gain is constant, the *response* of an amplifier is said to be *flat.* For signals of frequencies above and below this band, the gain usually falls off more or less sharply. It is of interest in amplifier application to know over what range the response is flat, and how it may be expected to fall off beyond this range. This characteristic is called the *frequency response* of the amplifier.

c. Distortion. It often is desired that the amplifier reproduce in its output the exact

employing only small amounts of power, however, gain, frequency response, and distortion are of more importance.

4. Classification of Amplifiers

Amplifiers may be classified according to whether they are intended to provide increased voltage or increased power, whether plate current flows during the entire signal cycle or only a part of it as determined by the d-c bias, according to the frequency range over which flat response may be expected, or according to the coupling circuits used between stages or for coupling to the load. The first three of these bases of classification are discussed in this paragraph; the fourth is covered in later paragraphs.

a. Type of Service.

(1) *Voltage amplifier.* Voltage amplifiers are used to supply amplified voltages to the high-impedance grid circuits of power amplifiers, to cathode-ray tubes,

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and to high-impedance vacuum-tube voltmeters. A voltage amplifier is concerned primarily with delivering large, varying output voltages to its load circuit. Therefore, the load impedance for a voltage amplifier is usually large, to develop a large voltage across its terminals. The ratio of output voltage to input voltage is called the *voltage gain* of the amplifier.

(2) *Power amplifier.* A power amplifier is used to deliver power to its load circuit. *Power amplification* is the ratio of output power to driving power—that is, to the a-c power consumed in the grid circuit. *Power sensitivity* describes the power amplification when no grid power is consumed in the grid circuits. Power sensitivity is the ratio of power output to the square of the rms (root mean square) grid-signal voltage. The load impedance for power amplification is chosen to supply maximum power output at specified distortion and plate efficiency. *Plate efficiency* is the ratio of a-c power output to d-c plate power input. In amplifiers designed for low distortion, the plate efficiency is generally low, but high efficiency is possible where distortion is permissible.

(3) *Application of amplifier.* The sound system of figure 4 contains typical applications of both types of amplifier. The weak voltage developed in the microphone is amplified by the voltage amplifier. Since very little signal current flows in the output circuit of a voltage amplifier, the output of the voltage amplifier has insufficient power to cause an audible sound from the loudspeaker. Therefore, the voltage-amplifier output is applied to a power amplifier. The output voltage of the power amplifier may even be less than its input voltage, but it delivers a much larger current. Thus, since $P = I^2R$, sufficient power is obtained to produce sound of the required loudness.

b. D-C Bias. The grid bias determines operating conditions of an amplifier by controlling the portion of the cycle during which plate current flows. In figure 5, an a-c signal voltage is projected on the plate-current grid-voltage characteristic curve, to show the waveform of plate current resulting when different bias voltages and different amplitudes of grid signal are used.

(1) In *Class A operation,* grid bias and a-c grid voltages are adjusted so that plate current in a given tube flows at

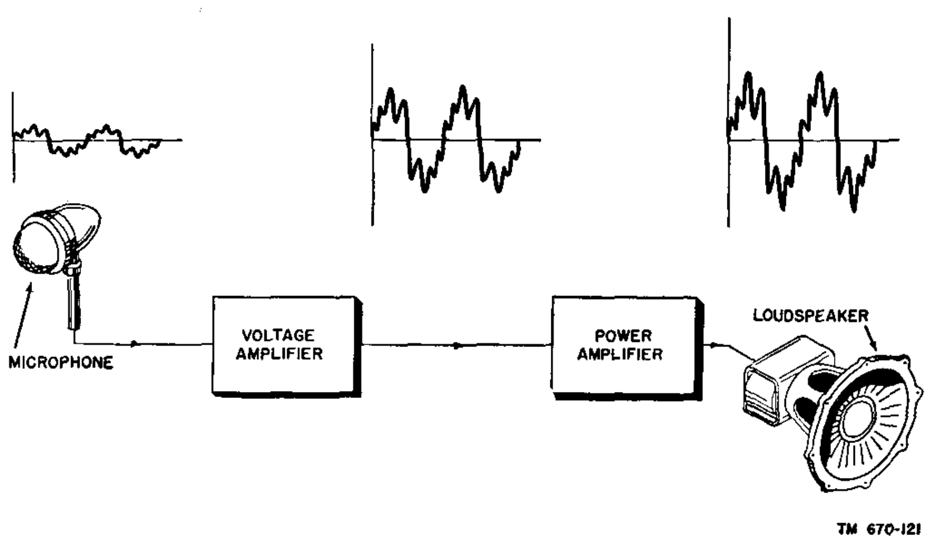

Figure 4. Sound-amplifier system.

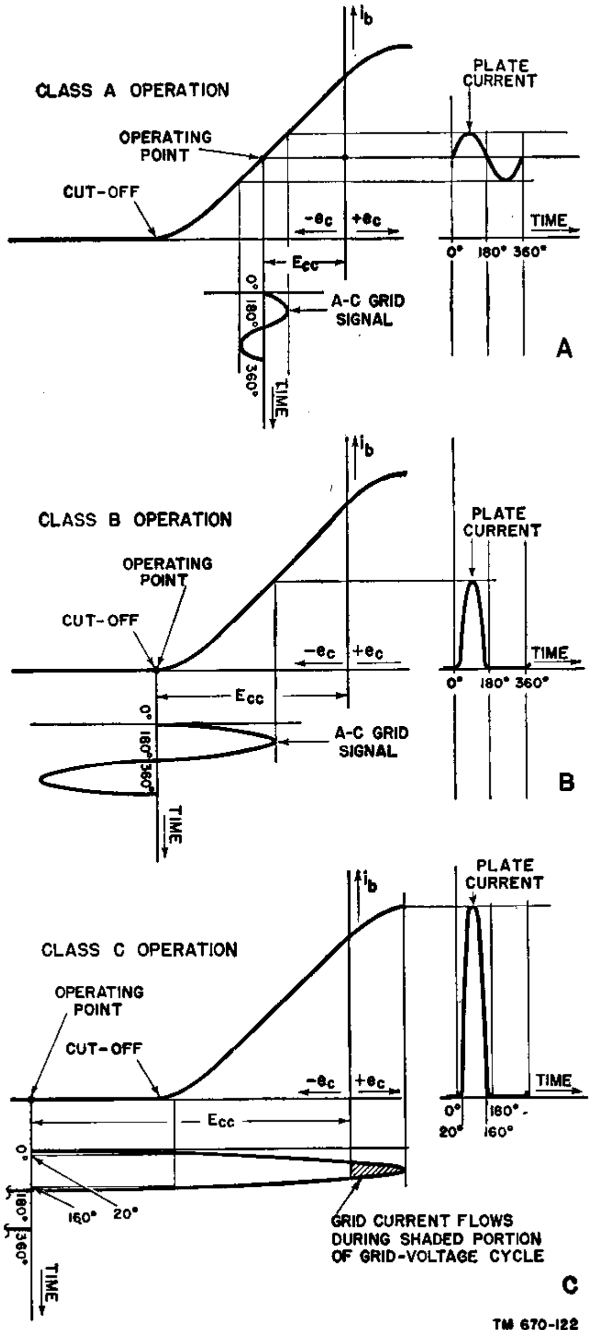

Figure 5. Classes of amplifier operation.

all times, as in A. To keep the distortion low, the grid signal swing is kept small, confining operation to the linear part of the characteristic curve. This also requires that d-c bias E_{cc} be such as to place the *operating point* near the middle of the straight part of the curve, as shown. Voltage amplifiers usually are operated under Class A conditions to obtain low distortion. Power output is small, and efficiency relatively low (10 to 20 percent).

(2) In *Class B operation,* the grid bias is made approximately equal to the cut-off value, which places the *operating point* at the cut-off point in B. Thus the plate current is close to 0 when no exciting grid voltage is applied. The plate current flows for approximately half of each cycle when an a-c grid voltage is applied. Class B power amplifiers give larger power output than Class A, better plate efficiency (50 to 60 percent), and a moderate ratio of power amplification. Class B operation introduces high distortion which is indicated by the difference between the output and input waveforms. Distortion may be minimized by operating two tubes in push-pull (paragraph 100). The grid circuit of a Class B power amplifier usually consumes power supplied by a *driver power amplifier.*

(3) In *Class AB operation,* the grid bias is less than cut-off, but greater than in Class A; the a-c grid voltage is such that plate current flows for appreciably more than half but less than the entire electrical cycle. For low signal levels these amplifiers have characteristics similiar to those of Class A, but produce somewhat more distortion; at high signal levels they operate like Class B power amplifiers with medium plate efficiency.

(4) In *Class C operation,* the grid bias is appreciably greater than the cut-off value, so that plate current flows for less than half of each cycle. In C, plate current flows from 20° to 160°. Class C amplifiers are characterized by high power output, high plate efficiency (60 to 70 percent), and very high distortion. Distortion usually is reduced to tolerable limits by using a parallel tuned circuit as a load instead of a

resistor. Class C amplifiers require moderate grid driving power. They are used to obtain large power output in the output stages of radio transmitters.

(5) Whenever the grid signal exceeds the bias, the grid is driven positive near the positive peaks of the signal, as shown by the shaded portion of the grid cycle in C. Grid current flows during this time, requiring additional driving power. Such operation is indicated by adding the number 2 to the class letter designation; thus, class C2 of class AB2 indicates that grid current flows during part of the cycle. Class AB1 or B1 indicates that no grid current flows.

c. Frequency Response. Amplifiers are classified also according to the frequency range over which they operate. These ranges are *a-f* (*audio-frequency*), *r-f* (*radio-frequency*), and *video-frequency*. The *response* of an amplifier is its gain at a particular frequency, or the manner in which the gain varies over a range of frequencies.

(1) A-f amplifiers are used to operate loudspeakers or motors. R-f amplifiers are used in radio transmitters to raise the power supplied to the antenna, and in radio receivers to increase the strength received by the antenna. Both often employ tuned circuits as loads, in order to suppress the output over all except the fairly narrow band of frequencies it is desired to amplify. Video-frequency amplifiers are designed with gain characteristics which are flat over a very wide frequency range. Video amplifiers are also called *broad-band* and *wide-band* amplifiers, and are used when the entire frequency range up to several megacycles is desired in the output. Because a signal consisting of repeated square pulses contains very high harmonics, video amplifiers are needed to give accurate reproduction of the input signal. For this reason they are known also as *pulse amplifiers*.

(2) Figure 6 compares the gain of a narrow-band amplifier with that of a broad-band amplifier. Note that the broad-band amplifier is *flat* (a term indicating constant gain) from 1 cycle to 1,000,000 cycles, whereas the narrow-band amplifier is flat only from 200 cycles to 5,000 cycles. The maximum gain of the narrow-band amplifier is 400, however, and the maximum gain of the wide-band amplifier is only 2. The considerable reduction in the gain of the wide-band amplifier is the penalty that is paid for the greater bandwidth. This is discussed later, in sections dealing with broad-band amplifiers.

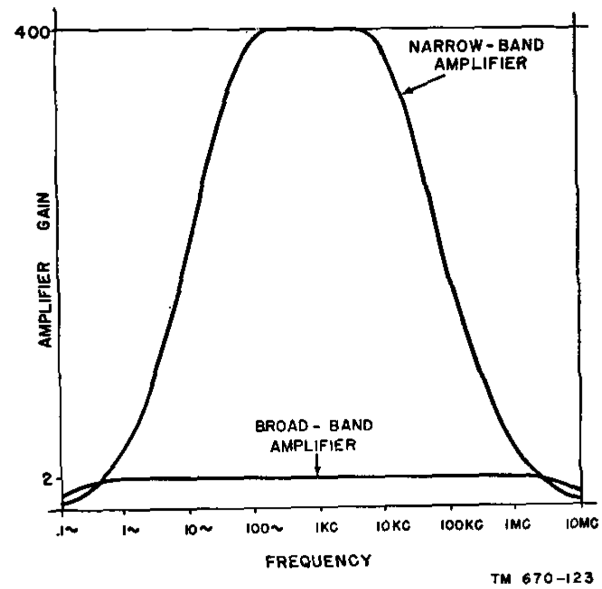

Figure 6. Gain of typical narrow-band and broad-band amplifier.

d. Coupling Methods. Four methods of coupling an amplifier to a load, or to a following stage, are available. They are (1) resistance coupling, (2) transformer coupling, (3) impedance coupling, and (4) direct coupling. The advantages of each method will be discussed later.

5. Distortion in Amplifiers

a. Distortion and Harmonic Frequencies. As already pointed out, whenever the output waveform of an amplifier differs from the input waveform, the amplifier is said to have *distorted* the signal. The waveform of any signal depends on its *harmonic content*—the relative amplitude and phase of the harmonic-frequency sine-wave components of the signal. Any device that changes the relative amplitude and phase of these harmonic components distorts the signal. Conversely, any device that adds new frequencies not present in the input signal changes the harmonic content and distorts the waveform. Amplifiers distort waveforms in both ways.

b. Types of Distortion. Four types of distortion may occur—(1) frequency distortion, (2) phase distortion, (3) amplitude distortion, and (4) intermodulation distortion. The first two types occur because the gain of an amplifier is not the same for all frequencies. This variation in gain is caused largely by the coupling circuits. Frequency and phase distortion cannot occur when the signal is a pure sine wave, because only one frequency is present. In amplitude distortion, the amplifier tube itself introduces new frequencies, so that even a sine wave input is distorted. Intermodulation distortion introduces new frequencies, but occurs only when more than a single frequency is present in the input.

(1) *Frequency distortion.* This type of distortion occurs when some components of a complex signal are amplified more than others. For example, figure 7 illustrates how frequency distortion may alter a signal consisting of a fundamental and its third harmonic. If the fundamental of the signal falls within the flat range of the amplifier response curve, and the third harmonic falls far down the slope at the high-frequency end of the curve, the fundamental is amplified, but the amplitude of the third harmonic may be negligible in the output. The result is an entirely different waveform in the output. Frequency distortion usually occurs where the amplifier gain falls off—at both low frequencies and very high frequencies. Within the flat range of an amplifier, however, there is no frequency distortion. Note that no *new* frequencies are produced by frequency distortion.

(2) *Phase distortion.* When signals pass through an amplifier they encounter a delay, known as *delay distortion* or *phase distortion,* which varies with frequency. It is caused chiefly by the reactive coupling circuits between amplifier stages. When a single pure sine wave is amplified, the delay, or phase shift, does not affect the amplified waveshape, and consequently there is no distortion. Similarly, when a complex wave is amplified, the output wave has the same shape as the input wave if the phase of each is shifted an amount proportional to each frequency on its own scale. In other words, the relative phase angles of the harmonics are not shifted in respect to the fundamental where distortion does not occur. However, when complex waveshapes are amplified, each component frequency of the waveshape may be shifted by an amount not proportional to the frequency, so that the output waveshape is not a faithful

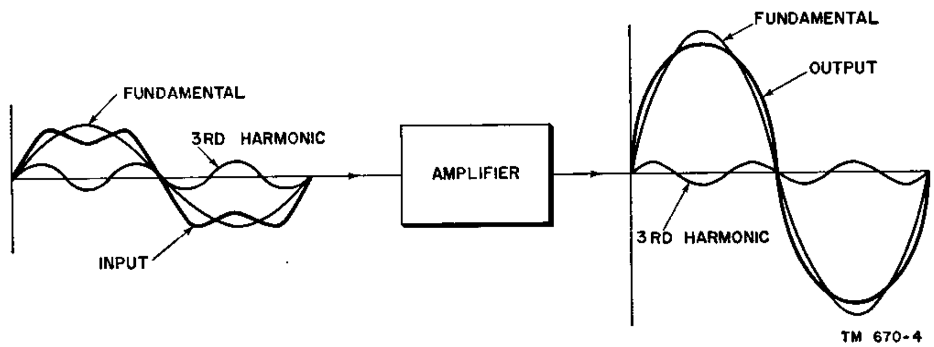

Figure 7. Frequency distortion.

representation of the input. In figure 8, a signal consisting of fundamental and third harmonic is passed through an amplifier producing phase distortion. Since both frequency components are amplified by identical ratios, their relative amplitudes are unchanged; the phase of the third harmonic, however, has been shifted by 90° in respect to the fundamental. So shown, the output waveform has been noticeably changed. In practice, frequency distortion and phase distortion almost invariably occur together. They have been separated in figures 7 and 8 to clarify the principles involved. Only one simple case is illustrated, out of the infinite variety of ways in which phase distortion can occur. In video amplifiers, special coupling circuits are used to minimize phase distortion.

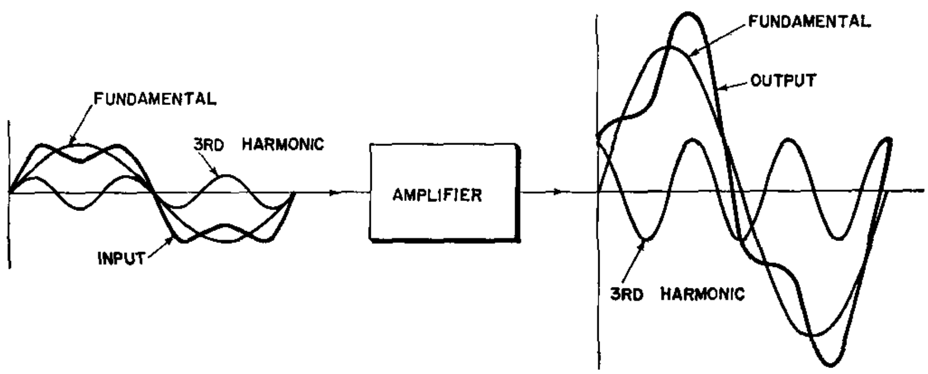

Figure 8. Phase distortion.

(3) *Amplitude distortion.* If a vacuum-tube amplifier is operated on any nonlinear part of its characteristic, a change in instantaneous grid voltage results in a change in instantaneous plate current which is not directly in proportion. The resulting distortion is *amplitude distortion,* or *nonlinear distortion.* Harmonic components are generated by the amplifier, and appear in the output in addition to those present in the input. As an extreme example, consider a Class B2 amplifier, whose grid-signal amplitude is even greater than is shown in B, figure 5. The output waveform resulting from a sine-wave grid signal is shown in A, figure 9. Below cut-off, the current through the tube remains zero, no matter how far the grid goes negative; above saturation, the plate current cannot increase, no matter how far positive the grid is driven. Such amplitude distortion often is required for producing special waveshapes used in radar and other applications. The new frequencies introduced by distortion are represented in B. Amplitude distortion can be produced in lesser degree, even though the tube is not driven beyond cut-off, if its characteristic is curved. Even in such cases, new frequencies are introduced, especially the second harmonic of each input frequency. Amplitude distortion can be reduced greatly by operating amplifier tubes within the linear region of their characteristics.

(4) *Intermodulation distortion.* A complex signal contains at least two frequency components. If such a signal is applied to an amplifier operating on any nonlinear part of its characteristic, *intermodulation distortion* results. Amplitude distortion causes harmonic components in the output waveshapes; intermodulation distortion causes, in addition, sum and difference frequencies of every pair of components of the

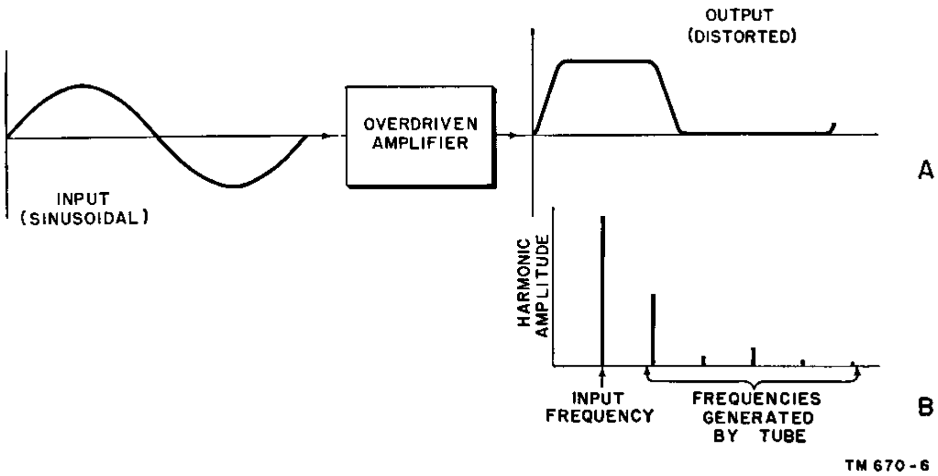

Figure 9. Amplitude distortion.

input waveshape. As an example, figure 10 shows the two new frequencies which appear when 60 cycles and 1,000 cycles are applied simultaneously to an amplifier which produces intermodulation distortion. Note that the two new frequencies have smaller amplitudes than either original signal, and that they appear at 60 cycles above and at 60 cycles below the 1,000-cycle signal. The two new frequencies, 940 cycles and 1,060 cycles, are not harmonics of either 60 cycles or 1,000 cycles. Harmonics of the two input frequencies would also be present as a result of amplitude distortion. In sound-system amplifiers, intermodulation distortion produces disagreeable, harsh sounds in the loudspeaker. Overloaded tubes and iron-core transformers are nonlinear and cause intermodulation distortion. Intermodulation distortion is minimized by operating apparatus on the most nearly linear portion of its characteristics.

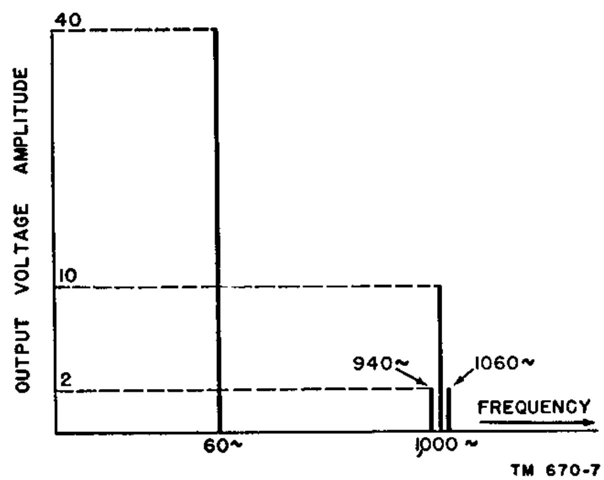

Figure 10. Intermodulation distortion.

6. Single-Stage Operation

a. Dynamic, Quiescent, and Static Conditions.

(1) In practical use, a single amplifier stage is operated in a manner similar to that illustrated in figure 2. A d-c voltage is applied to the plate through a load resistance or other impedance, and the varying signal to be amplified is applied to the grid. Grid bias is provided either by a battery, as shown, or by a method of self-bias, explained in TM 11-662. When so connected, the tube is said to be operating under *dynamic* conditions, because current and all voltages are changing from one instant to another: plate current, grid voltage, voltage from plate to cathode, and voltage drop across the load. Each of the quantities that changes continuously in dynamic operation does so by varying above and below some middle value. Thus (fig. 11), the in-

stantaneous voltage from cathode to grid e_c varies above and below the d-c grid-bias voltage, E_{cc}. This causes a corresponding variation in plate current i_b, as shown.

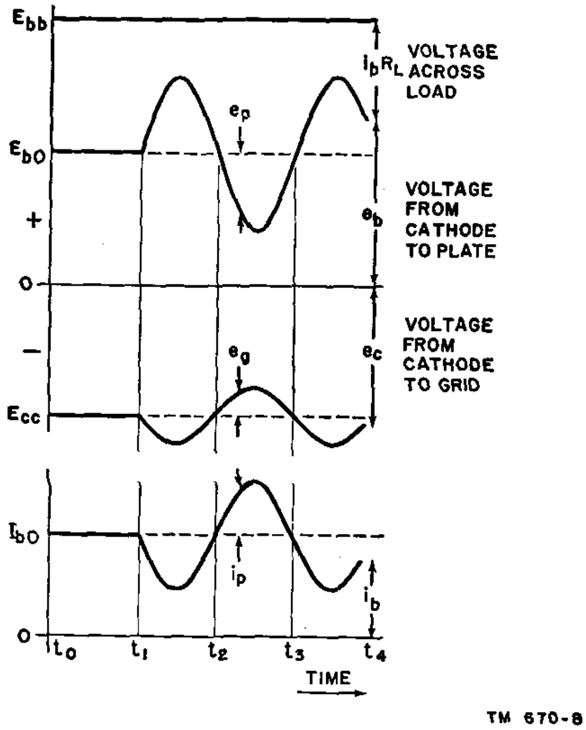

Figure 11. Voltage and current variations in Class A amplifier.

(2) In figure 2, the plate current flowing in load resistor R_L causes a varying voltage drop, i_bR_L. The instantaneous voltage across the tube, e_b, is equal to the difference between the plate-supply voltage, E_{bb} and i_bR_L. Since the latter varies, so does e_b (fig. 11).

(3) Consider what would happen if the signal voltage in figure 2 were short-circuited. The grid-bias voltage, E_{cc}, would appear as a steady voltage from cathode to grid, as is shown in figure 11 between the instants t_o and t_1. The plate current would not be cut off. A direct plate current, designated I_{bo}, would flow. It would produce a direct voltage drop, $I_{bo}R_L$, across the load, and place a direct voltage, E_{bo}, across the tube. These values—E_{cc}, I_{bo}, and E_{bo}—are known as the *quiescent values* of the grid voltage, plate current, and plate voltage, respectively. When the tube is operated with zero signal, but otherwise is the same as in figure 2, it is operating under *quiescent conditions*. The quiescent values are the values about which e_c, i_b, and e_b vary when an alternating voltage, e_g, is applied to the grid in series with E_{cc} (fig. 11). Each horizontal solid line represents a quiescent value. Each instantaneous value is seen to vary above and below the broken-line extension of the solid line. The excursions of the instantaneous plate current and plate voltage about I_{bo} and E_{bo} are the a-c components of these quantities. They are designated i_p and e_p, as shown. It is to be noted that the a-c component of the load voltage is identical with e_p, the a-c component of the plate voltage.

(4) Quiescent values and quiescent conditions should not be confused with *static conditions*. Static conditons prevail when the plate-supply voltage is connected directly to the plate, without any intervening load impedance. Under such conditions, varying the grid voltage would vary the plate current, but not the plate voltage. This is not a practical method of operating a tube, as no output voltage can be obtained. It is used by engineers to measure the effect of changing the grid and plate voltages separately, in steps. Such measurements may be used to determine the tube coefficients, μ (amplification factor), r_p (a-c plate resistance), and g_m (transconductance), and to plot *static plate-characteristic curves*, such as the curves ordinarily shown in tube manuals and explained in TM 11–662. These curves are useful in designing amplifiers, but are not needed for the present discussion.

b. Phase Relations. Operating under dynamic conditions, the output voltage of an R-C amplifier stage is 180° out of phase with its input (of opposite polarity), as in figure 11. When the grid voltage decreases (becomes more negative), the plate current also decreases. The drop across the load resistor, therefore, decreases. But, with this decrease, more supply voltage E_{bb} appears across the tube. Thus, a *decrease* in e_c causes an *increase* in e_b. Therefore, as e_c continuously decreases and increases with the a-c signal, the a-c variations of e_b are 180° out of phase with e_g (of opposite polarity). Note that the a-c component of the load voltage, measured as a voltage rise from cathode to plate, is identical with the a-c component of e_b. This alternating component of the voltage across R_L is the desired output voltage. Thus the output voltage is also 180° out of phase with the signal voltage (of opposite polarity).

c. Amplification.

(1) Consider a tube operated under static conditions. A small increase in plate voltage causes a corresponding increase in plate current. If the grid voltage is decreased (made more negative) by a small amount, the plate current is restored to its original value. The change in grid voltage required to accomplish this is, in general, much smaller than the change in plate voltage causing the increase. The ratio of these two changes—the plate-voltage change and the grid-voltage change—is defined as the *amplification factor*, or μ, of the tube. It expresses the relative effect of changes in plate and grid voltage to produce corresponding changes in plate current.

(2) Since an a-c voltage is a continuously varying voltage, the amplification factor also expresses how much greater an a-c plate voltage would have to be, as compared with the a-c grid signal, to produce the same a-c component of plate current. Such an a-c plate voltage is not actually applied, but the concept is important in understanding the following paragraph.

7. Voltage Equivalent Circuit

The gain of an amplifier is frequently a question of primary interest. It can be calculated more or less exactly, for any class of operation, from the static characteristic curves. The calculation of gain is greatly facilitated by the use of an *equivalent circuit,* however. Two types of equivalent circuit may be used. The purpose of this paragraph is to develop the *constant-voltage* equivalent circuit, and to explain the assumptions on which it is based. The constant-current equivalent circuit is discussed in paragraph 12.

a. It has been shown (fig. 11) that the plate current of an amplifier tube is composed of a d-c component, I_{bo}, and an a-c component, i_p. The plate circuit behaves as though it were energized by a battery, which causes I_{bo}, and an a-c generator, which causes i_p. Any circuit thus energized by two or more voltage sources can be analyzed by considering the effects of the two sources separately, then adding up the results. Figure 12 shows how the plate circuit of a simple amplifier stage may be represented by two equivalent circuits.

b. In the d-c circuit of figure 12, resistor R_b represents the d-c resistance of the tube through which the quiescent plate current, I_{bo}, flows because of battery E_{bb}. In the a-c circuit, r_p is the a-c plate resistance of the tube. The

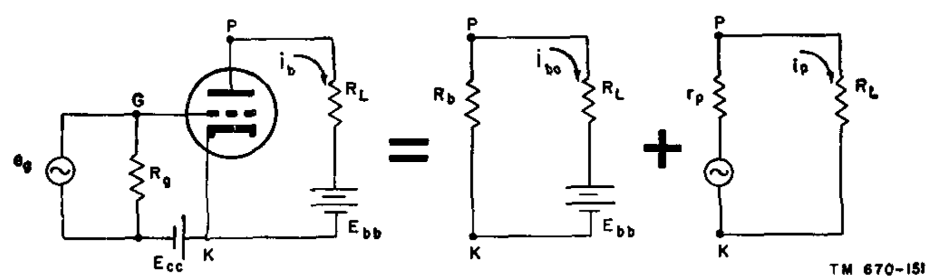

Figure 12. D-c and a-c equivalent circuits of simple amplifier.

a-c component of plate current i_p flows in both the tube and R_L. The generator that causes i_p is such that the sum of I_{bo} and i_p in the equivalent circuits will be the same as i_b, the varying plate current that flows in the actual tube circuit. (The d-c circuit is now of no further interest. It was introduced only to show that the a-c components of current and voltage in the plate circuit may be considered separately, for purposes of calculation.)

c. The generator of the alternating current in figure 12 has yet to be identified. If it were actually an alternating voltage applied to the plate of the tube, as represented in the equivalent circuit, it would cause the a-c plate current component, i_p. It follows from paragraph 6*c* (2) that this assumed generator voltage in the plate circuit must be μ times the grid signal, e_g, which actually produces i_p. The a-c equivalent circuit may, therefore, be drawn as in figure 13. It should be understood that this is *not* an actual circuit. It is a fictitious circuit having the same *alternating* current as the actual circuit. It is a useful tool for computing amplifier gain, as will be shown.

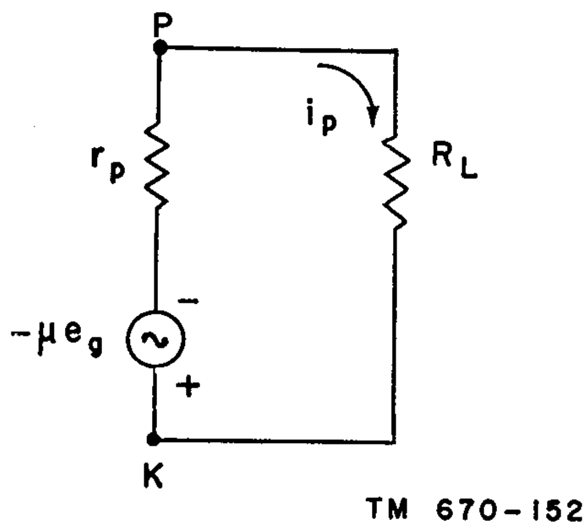

Figure 13. A-c equivalent circuit.

d. The equivalent plate generator has an instantaneous voltage of $-\mu e_g$ (fig. 13). The minus sign indicates the polarity reversal that takes place between the plate and grid voltages of the actual circuit. This is represented by assigning polarities to the generator terminals as shown, with the plate terminal negative with respect to the cathode terminal—just opposite from their actual polarities. This indicates that when the plate current is in its positive half-cycle, electrons are moving toward the positive generator terminal. This occurs when the grid voltage is in its positive half-cycle.

e. From the equivalent circuit of figure 13, the a-c plate current and the output voltage may be calculated by the methods applicable to simple series circuits:

$$i_p = \frac{-\mu e_g}{r_p + R_L}$$

$$\text{output voltage} = i_p R_L = -\mu e_g \left(\frac{R_L}{r_p + R_L}\right)$$

This expression shows that the output voltage is not simply μ times the applied signal, as in static operation, but less than this value.

f. The equivalent circuit gives the exact performance of the vacuum-tube amplifier only if certain assumptions hold true. These are (1) that the plate resistance and amplification factor of the tube (r_p and μ) remain constant under dynamic operating conditions, and (2) that distortion generated by the tube is negligible. In practice, both μ and r_p do vary somewhat. The variation usually is so small that published tube constants may be used for designing an amplifier, but performance should then be checked in the laboratory. Distortion is negligible only in a Class A amplifier, as its operation usually is confined to a fairly linear part of the characteristic.

8. Summary

a. Voltage amplifiers are used to increase the voltage of feeble signals. Power amplifiers are used to supply power to a load such as a loudspeaker or an antenna.

b. In Class A operation, plate current flows at all times; in Class B operation, plate current flows for approximately half of each cycle; in Class C operation, plate current flows for less than half of each cycle.

c. Audio-frequency amplifiers operate from about 50 cycles to 20,000 cycles; radio-frequency amplifiers operate from about 20,000 cycles up to many millions of cycles; and video-frequency amplifiers operate from about 20 cycles to 5,000,000 cycles.

d. The four types of distortion which occur in amplifiers are frequency, phase, amplitude, and intermodulation distortion. Frequency distortion occurs when the gain of an amplifier is different for signals of different frequency. Phase distortion occurs when the reactive coupling networks shift the phase of the signal components in respect to each other. Amplitude distortion results from operating on any non-linear part of the tube characteristic, thereby adding new frequency components to the signal. Intermodulation distortion causes sum and difference frequency components to appear in the output of an amplifier when it is amplifying two or more frequencies simultaneously.

e. A tube operates under static conditions when its load impedance is zero. An amplifier operates under quiescent conditions when no external signal is impressed on it. An amplifier operates under dynamic conditions when it has an external signal impressed on its grid, and its plate voltage changes because of the changing drop across the load resistor.

f. Amplifier operation is analyzed by means of the constant-voltage equivalent circuit or the constant-current equivalent circuit, which shows the a-c component of current and voltages for a single-stage amplifier. The constant-voltage equivalent circuit shows that the output voltage of an amplifier is—

$$e_o = -\mu e_g \left(\frac{Z_L}{r_p + Z_L}\right)$$

g. The networks with which amplifier stages are coupled are known as resistance-capacitance, impedance, transformer, and direct-coupling circuits.

9. Review Questions

a. What is the purpose of an amplifier?

b. What is the difference between a voltage amplifier and a power amplifier?

c. What is the meaning of power sensitivity? Plate efficiency?

d. How are amplifiers generally classified?

e. Name four types of distortion and describe each type.

f. Compare static, quiescent, and dynamic operating conditions.

g. What is the constant-voltage equivalent circuit? Why is it used?

h. What is a single-stage amplifier? A cascade amplifier?

i. What is the theoretical maximum voltage gain obtainable from a tube?

j. What is the phase relationship between applied grid-signal voltage and plate-load voltage in an amplifier having a pure resistance load?

k. Name three basic coupling methods.