

These tubes are similar to the multi-electrode types in that they have seven electrodes, all of which affect the electron stream; and they are similar to the multi-unit tubes in that they perform simultaneously the double function of oscillator and mixer in superheterodyne receivers.

Complete classification of tubes by services and cathode voltages is given on the chart at the beginning of the DATA SECTION.

Radio Tube Characteristics

The term "CHARACTERISTICS" is used to identify the distinguishing electrical features and values of a radio tube. These values may be shown in curve form or they may be tabulated. When given in curve form, they are called characteristic curves and may be used for the determination of tube performance and the calculation of additional tube factors.

Tube characteristics are obtained from electrical measurements of a tube in various circuits under certain definite conditions of voltages. Characteristics may be further described by denoting the conditions of measurements. For example, Static Characteristics are the values obtained with different d-c potentials applied to the tube electrodes, while Dynamic Characteristics are the values obtained with an a-c voltage on the control grid under various conditions of d-c potentials on the electrodes. The dynamic characteristics, therefore, are indicative of the performance capabilities of a tube under actual working conditions.

Static characteristics may be shown by plate characteristics curves and transfer (mutual) characteristics curves. These curves present the same information, but in two different forms to increase its usefulness. The plate characteristic curve is obtained by varying plate voltage and measuring plate current for different control-grid bias voltages, while the transfer-characteristic curve is obtained by varying control-grid bias voltage and measuring plate current for different plate voltages. A plate-characteristic family of curves is illustrated by Fig. 10. Fig. 11 gives the transfer characteristic family of curves for the same tube.

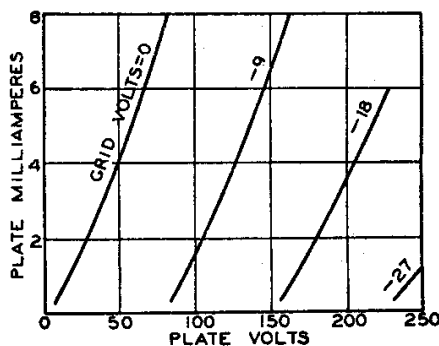


Fig. 10

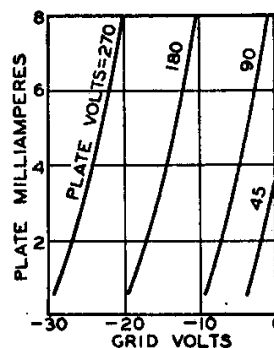


Fig. 11

Dynamic characteristics include amplification factor, plate resistance, control-grid—plate transconductance and certain detector characteristics, and may be shown in curve form for variations in tube operating conditions.

The **amplification factor**, or μ , is the ratio of the change in plate voltage to a change in control-electrode voltage in the opposite direction, under the condition that the plate current remains unchanged, and that all other electrode voltages are maintained constant. For example, if, when the plate voltage is made 1 volt more positive, the grid voltage must be made 0.1 volt more negative to hold plate current unchanged, the amplification factor is 1 divided by 0.1, or 10. In other words, a small voltage variation in the grid circuit of a tube has the same effect on the plate current as a large plate voltage change—the latter equal to the product of the grid voltage change and amplification factor. The μ of a tube is useful for calculating stage gain, as discussed on page 13.

Plate resistance (r_p) of a radio tube is the resistance of the path between cathode and plate to the flow of alternating current. It is the quotient of a small change in plate voltage by the corresponding change in plate current and is expressed in ohms, the unit of resistance. Thus, if a change of 0.1 milliamper (0.0001 ampere) is produced by a plate voltage variation of 1 volt, the plate resistance is 1 divided by 0.0001, or 10000 ohms.

Control-grid—plate transconductance, or simply **transconductance (g_m)**, is a factor which combines in one term the amplification factor and the plate resistance, and is the quotient of the first by the second. This term is also known as mutual conductance. Transconductance may be more strictly defined as the ratio of a small change in plate current (amperes) to the small change in the control-grid voltage producing it, under the condition that all other voltages remain unchanged. Thus, if a grid-voltage change of 0.5 volt causes a plate-current change of 1 milliamper (0.001 ampere), with all other voltages constant, the transconductance is 0.001 divided by 0.5, or 0.002 mho. A "mho" is the unit of conductance and was named by spelling ohm backwards. For convenience, a millionth of a mho, or a micromho, is used to express transconductance. So, in the example, 0.002 mho is 2000 micromhos.

Conversion transconductance (g_c) is a characteristic associated with the mixer (first detector) function of tubes and may be defined as the quotient of the intermediate-frequency (i-f) current in the primary of the i-f transformer by the applied radio-frequency (r-f) voltage producing it; or more precisely, it is the limiting value of this quotient as the r-f voltage and i-f current approach zero. When the performance of a frequency converter is determined, conversion transconductance is used in the same way as control-grid—plate transconductance is used in single-frequency amplifier computations.

Maximum peak inverse voltage characteristic of a rectifier tube is the highest peak voltage that a rectifier tube can safely stand in the direction opposite to that in which it is designed to pass current. In other words, it is the safe arc-back limit with the tube operating within the specified temperature range. Referring to Fig. 12, when plate A of a full-wave rectifier tube is positive, current flows from A to C, but not from B to C, because B is negative. At the instant plate A is positive, the filament is positive (at high voltage) with respect to plate B. The voltage between the positive filament and the negative plate B is in inverse relation to that causing current flow. The peak value of this voltage is limited by the resistance and nature of the path between plate B and filament. The maximum value of this voltage at which there is no danger of breakdown of the tube is known as maximum peak-inverse voltage. The relations between peak inverse voltage, rms value of a-c input voltage, and d-c output voltage depend largely on the individual characteristics of the rectifier circuit and the power supply. The presence of line surges or any other transient, or wave-form distortion may raise the actual peak voltage to a value higher than that calculated for sine-wave voltages. Therefore, the **actual** inverse voltage, and not the calculated value, should be such as not to exceed the rated maximum peak inverse voltage for the rectifier tube. A cathode-ray oscillograph or a spark gap connected across the tube is useful in determining the actual peak inverse voltage. In single-phase, full-wave circuits with sine-wave input and with no condenser across the output, the peak inverse voltage on a rectifier tube is approximately 1.4 times the rms value of the plate voltage applied to the tube. In single-phase, half-wave circuits with sine-wave input and with condenser input to the filter, the peak inverse voltage may be as high as 2.8 times the rms value of the applied plate voltage. In polyphase circuits, mathematical determination of peak inverse voltage requires the use of vectors.

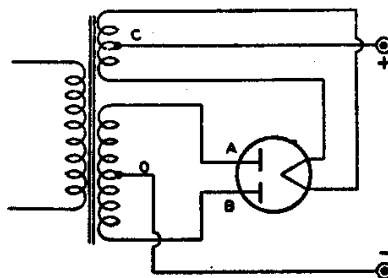


Fig. 12

Maximum peak plate current is the highest steady-state peak current that a rectifier tube can safely stand in the direction in which it is designed to pass current. The safe value of this peak current in hot-cathode types of rectifiers is a

function of the available emission and the duration of the pulsating current flow from the rectifier tube during each half cycle. In a given circuit, the actual value of peak plate current is largely determined by filter constants. If a large choke is used in the filter circuit next to the rectifier tubes, the peak plate current is not much greater than the load current, but if a large condenser is used in the filter next to the rectifier tubes, the peak current is often many times the load current. In order to determine accurately the peak current in any circuit, the best procedure usually is to measure it with a peak-indicating meter or to use an oscillograph.

Plate dissipation is the power dissipated in the form of heat by the plate as a result of electron bombardment. It is the difference between the power supplied to the plate of the tube and the power delivered by the tube to the load.

Screen dissipation is the power dissipated in the form of heat by the screen as a result of electron bombardment. With tetrodes and pentodes, the power dissipated in the screen circuit is added to the power in the plate circuit to obtain the total B-supply input power.

The **plate efficiency** of a power amplifier tube is the ratio of the a-c power output to the product of the average d-c plate voltage and d-c plate current at full signal, or

$$\text{Plate efficiency (\%)} = \frac{\text{power output watts}}{\text{average d-c plate volts} \times \text{average d-c plate amperes}} \times 100$$

The **power sensitivity** of a tube is the ratio of the power output to the square of the input signal voltage (RMS) and is expressed in mhos as follows:

$$\text{Power sensitivity (mhos)} = \frac{\text{power output watts}}{(\text{input signal volts, RMS})^2}$$

Radio Tube Applications

The diversified applications of a radio tube may, within the scope of this chapter, be grouped broadly into five kinds of operation. These are: Amplification, rectification, detection, oscillation, and frequency conversion. Although these operations may take place at either radio or audio frequencies and may involve the use of different circuits and different supplemental parts, the general considerations of each kind of operation are basic.

AMPLIFICATION

The amplifying action of a radio tube was mentioned under TRIODES, page 7. This action can be utilized in radio circuits in a number of ways, depending upon the results to be achieved. Four classes of amplifier service recognized by engineers are covered by definitions standardized by the Institute of Radio Engineers. This classification depends primarily on the fraction of input cycle during which plate current is expected to flow under rated full-load conditions. The classes are class A, class AB, class B, and class C. The term, cut-off bias, used in these definitions is the value of grid bias at which plate current is some very small value.

Class A Amplifier. A class A amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

Class AB Amplifier. A class AB amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

Class B Amplifier. A class B amplifier is an amplifier in which the grid bias is approximately equal to the cut-off value so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific tube flows for approximately one-half of each cycle when an alternating grid voltage is applied.

Class C Amplifier. A class C amplifier is an amplifier in which the grid bias is appreciably greater than the cut-off value so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current flows

in a specific tube for appreciably less than one-half of each cycle when an alternating grid voltage is applied.

NOTE:—To denote that grid current does not flow during any part of the input cycle, the suffix 1 may be added to the letter or letters of the class identification. The suffix 2 may be used to denote that grid current flows during some part of the cycle.

For radio-frequency amplifiers which operate into a selective tuned circuit, as in radio transmitter applications, or under requirements where distortion is not an important factor, any of the above classes of amplifiers may be used, either with a single tube or a push-pull stage. For audio-frequency amplifiers in which distortion is an important factor, only class A amplifiers permit single-tube operation. In this case, operating conditions are usually chosen so that distortion is kept below the conventional 5% for triodes and the conventional 7 to 10% for tetrodes or pentodes. Distortion can be reduced below these figures by means of special circuit arrangements such as that discussed under **inverse feedback**. With class A amplifiers, reduced distortion with improved power performance can be obtained by using a push-pull stage for audio service. With class AB and class B amplifiers, a balanced amplifier stage using two tubes is required for audio service.

As a **class A voltage amplifier**, a radio tube is used to reproduce grid voltage variations across an impedance or a resistance in the plate circuit. These variations are essentially of the same form as the input signal voltage impressed on the grid, but of increased amplitude. This is accomplished by operating the tube at a suitable grid bias so that the applied grid-input voltage produces plate-current variations proportional to the signal swings. Since the voltage variation obtained in the plate circuit is much larger than that required to swing the grid, amplification of the signal is obtained. Fig 13 gives a graphical illustration of this method of amplification and shows, by means of the grid-voltage vs. plate-current characteristics curve, the effect of an input signal (S) applied to the grid of a tube. O is the resulting amplified plate-current variation.

The plate current flowing through the load resistance (R) of Fig. 14 causes a voltage drop which varies directly with the plate current. The ratio of this voltage variation produced in the load resistance to the input signal voltage is the voltage

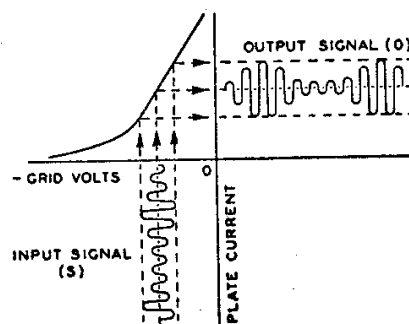


Fig. 13

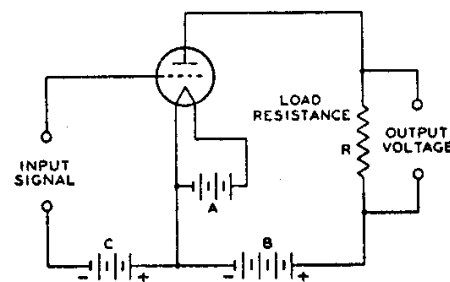


Fig. 14

amplification, or **gain**, provided by the tube. The voltage amplification due to the tube is expressed by the following convenient formulas:

$$\text{Voltage amplification} = \frac{\text{amplification factor} \times \text{load resistance}}{\text{load resistance} + \text{plate resistance}}, \text{ or}$$

$$\frac{\text{transconductance in micromhos} \times \text{plate resistance} \times \text{load resistance}}{1000000 \times (\text{plate resistance} + \text{load resistance})}$$

From the first formula, it can be seen that the gain actually obtainable from the tube is less than the tube's amplification factor but that the gain approaches the amplification factor when the load resistance is large compared to the tube's plate resistance. Fig. 15 shows graphically how the gain approaches the μ of the tube as load resistance is increased. From the curve it can be seen that to obtain high gain in a voltage amplifier, a high value of load resistance should be used.

In a resistance-coupled amplifier, the load resistance of the tube is approximately equal to the resistance of the plate resistor in parallel with the grid resistor of the following stage. Hence, to obtain a large value of load resistance, it is necessary

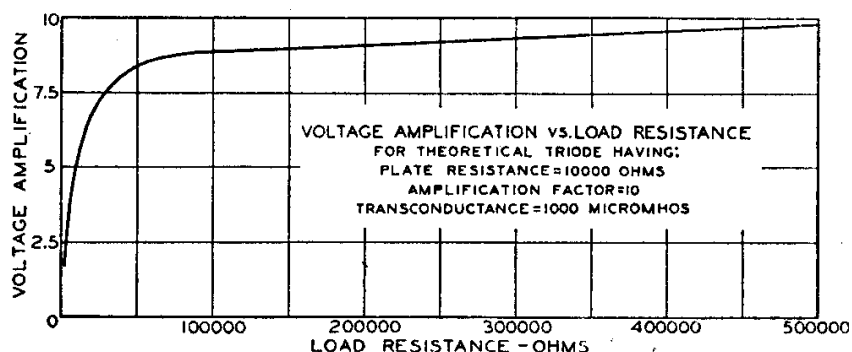


Fig. 15

to use a plate resistor and a grid resistor of large resistance. However, the plate resistor should not be too large because the flow of plate current through the plate resistor produces a voltage drop which reduces the plate voltage applied to the tube. If the plate resistor is too large, this drop will be too large, the plate voltage on the tube will be too small and the voltage output of the tube will be too small. Also, the grid resistor of the following stage should not be too large, the actual maximum value being dependent on the particular tube type. A higher value of grid resistance is permissible when cathode bias is used than when fixed bias is used. When cathode bias is used, a loss in bias due to grid-emission effects is nearly completely offset by an increase in bias due to the voltage drop across the cathode resistor. The recommended values of plate resistor and grid resistor for the tube types used in resistance-coupled circuits, and the values of gain obtainable, are shown in the RESISTANCE-COUPLED AMPLIFIER SECTION.

The input impedance of a radio tube, that is, the impedance between grid and cathode, consists of (1) the capacitance between grid and cathode, (2) a resistance component resulting from the time of transit of electrons between cathode and grid, and (3) a resistance component developed by the part of the cathode lead inductance which is common to both the input and output circuits. Components (2) and (3) are dependent on the frequency of the incoming signal. The input impedance is very high at audio frequencies when a tube is operated with its grid biased negative. Hence, in a class A_1 or class AB_1 transformer-coupled audio amplifier, the loading imposed by the grid on the input transformer is negligible. The secondary impedance of a class A_1 or class AB_1 input transformer can, therefore, be made very high since the choice is not limited by the input impedance of the tube; however, transformer design considerations may limit the choice. At the higher radio frequencies, the input impedance may become very low even when the grid is negative, due to the finite time of passage of electrons between cathode and plate and to the appreciable lead reactance. This impedance drops very rapidly as the frequency is raised and increases input-circuit loading. In fact, the input impedance may become low enough at very high radio frequencies to affect appreciably the gain and selectivity of a preceding stage. Tubes such as the Acorn* types have been developed to have low input capacitances, low electron transit time and low lead inductance so that their input impedance is high even at the ultra-high radio frequencies.

A super-control amplifier tube is a modified construction of a pentode or a tetrode type and is designed to reduce modulation-distortion and cross-modulation in radio-frequency stages. Cross-modulation is the effect produced in a radio receiver by an interfering station "riding through" on the carrier of the station to which the receiver is tuned. Modulation-distortion is a distortion of the modulated carrier and appears as audio-frequency distortion in the output. This effect is produced by a radio-frequency amplifier stage operating on an excessively curved

* Registered Trademark.

characteristic when the grid bias has been increased to reduce volume. The offending stage for cross-modulation is usually the first radio-frequency amplifier, while for modulation-distortion, the cause is usually the last intermediate-frequency stage.

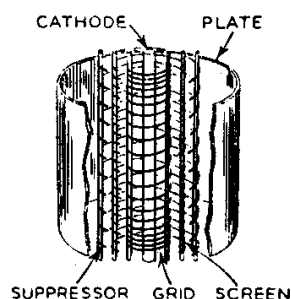


Fig. 16

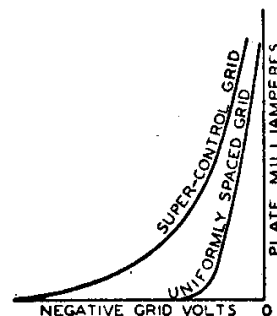


Fig. 17

The characteristics of super-control types are such as to enable the tube to handle both large and small input signals with minimum distortion over a wide range. A cross-section of the structure of a 6K7, a typical super-control pentode, is shown in Fig. 16. The super-control action is due to the structure of the grid which provides a variation in amplification factor with change in grid bias. The grid is wound with coarse spacing at the middle and with close spacing at the ends. When weak signals and low grid bias are applied to the tube, the effect of the non-uniform turn spacing of the grid on cathode emission and tube characteristics is essentially the same as for uniform spacing. As the grid bias is made more negative to handle larger input signals, the electron flow from the sections of the cathode enclosed by the ends of the grid is cut off. The plate current and other tube characteristics are then dependent on the electron flow through the coarse section of the grid. This action changes the gain of the tube so that large signals may be handled with minimum distortion due to cross-modulation and modulation distortion. Fig. 17 shows a typical plate-current vs. grid-voltage curve for a super-control type compared with the curve for a type having a uniformly spaced grid. It will be noted that while the curves are similar at small grid-bias voltages, the plate current of the super-control tube drops quite slowly with large values of bias voltage. This slow change makes it possible for the tube to handle large signals satisfactorily. Since super-control types can accommodate large and small signals, they are particularly suitable for use in sets having automatic volume control. Super-control tubes also are known as remote cut-off types.

As a **class A power amplifier**, a radio tube is used in the output stage of radio receivers to supply relatively large amounts of power to the loudspeaker. For this application, large power output is of much greater importance than high-voltage amplification, so that gain possibilities are sacrificed in the design of power tubes to obtain power-handling capability. Power tubes of the triode type in class A service are characterized by low power sensitivity, low plate-power efficiency, and low distortion. Power tubes of the pentode type are characterized by high power sensitivity, high plate-power efficiency, and relatively high distortion. Beam power tubes such as the 6L6 have a still higher power sensitivity and efficiency and have a higher power output capability than triode or conventional pentode types.

A class A power amplifier is also used as a driver to supply power to a class AB or a class B output stage. It is usually advisable to use a triode type, rather than a pentode, in a driver stage because of the lower distortion of the triode.

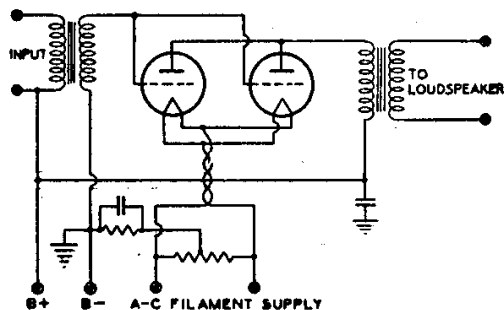


Fig. 18

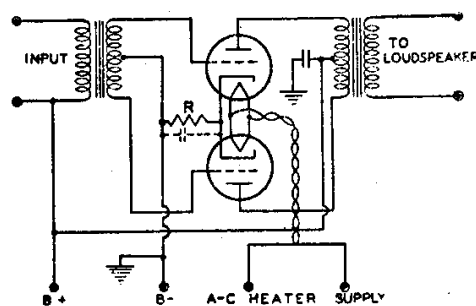


Fig. 19

Either push-pull or parallel operation of power tubes may be employed with class A amplifiers to obtain increased output. The parallel connection (Fig. 18) provides twice the output of a single tube with the same value of grid-signal voltage. The push-pull connection (Fig. 19) requires twice the input-signal voltage, but has, in addition to an increase in power, a number of important advantages over single-tube operation. Distortion due to even-order harmonics and hum due to plate-supply-voltage fluctuations are either eliminated or decidedly reduced through cancellation. Since distortion is less than for single-tube operation, appreciably more than twice single-tube output can be obtained by decreasing the load resistance. Should oscillations occur in the push-pull or parallel stages, they can often be eliminated by connecting a non-inductive resistor of approximately 500 ohms in series with each grid lead at the tube socket.

Operation of power tubes so that the grids run positive is inadvisable except under conditions such as are discussed later in this section for class AB and class B amplifiers.

Power output for triodes as single-tube class A amplifiers can be calculated without serious error from the plate family of curves by assuming a resistance load. The proper plate current, grid bias, and optimum load resistance, as well as the per cent second-harmonic distortion, can also be determined. The calculations are made graphically and are illustrated by Fig. 20 for given conditions. The procedure is as follows: Draw a straight line XY through the points P and X on the plate family of curves. P is known as the zero-signal bias point and may readily be located by determining the zero-signal bias, E_{c0} , from the following formula:

$$\text{Zero-signal bias (P)} = \frac{0.68 \times E_b}{\mu}$$

where E_b is the chosen value of d-c plate voltage at which the tube is to be operated and μ is the amplification factor of the tube. X is a point on the d-c bias curve at zero volts and is determined by the value of the maximum-signal plate current, $I_{\text{max.}}$, which is equal to twice the zero-signal plate current, or $2I_0$. In the case of filament types of tubes, the calculations are given on the basis of a d-c operated filament. When, however the filament is a-c operated, the calculated value of d-c bias should be increased by approximately one half the filament-voltage rating of the tube.

Line XY is known as the load resistance line. Its slope corresponds to the value of the load resistance. The load resistance in ohms is equal to $(E_{\text{max.}} - E_{\text{min.}})$ divided by $(I_{\text{max.}} - I_{\text{min.}})$, where E is in volts and I in amperes.

For power output calculations, it is assumed that the peak alternating grid voltage is sufficient (1) to swing the grid from the zero-signal bias value to zero bias on the positive swing and (2) to a value twice the zero-signal bias value on the negative swing. During the positive swing, the plate voltage and plate current reach values of $E_{\text{min.}}$ and $I_{\text{max.}}$; during the negative swing, they reach values of $E_{\text{max.}}$ and $I_{\text{min.}}$. Since power is the product of voltage and current, the average power output, as indicated by a wattmeter, is given by

$$\text{Power output} = \frac{(I_{\text{max.}} - I_{\text{min.}})(E_{\text{max.}} - E_{\text{min.}})}{8}$$

where E is in volts, I in amperes, and power output in watts.

In the output of a power amplifier triode, some distortion is present. This distortion is predominately second-harmonic in single-tube amplifiers. The percentage of second-harmonic distortion may be calculated by the following formula:

$$\% \text{ 2nd harmonic distortion} = \frac{\frac{I_{\text{max.}} + I_{\text{min.}}}{2} - I_0}{I_{\text{max.}} - I_{\text{min.}}} \times 100$$

where I_0 is the zero-signal plate current in amperes.

Example: Determine the load resistance and undistorted power output of a triode operated at 250 volts on the plate, given its amplification factor of 3.5 and its plate characteristics curves as shown in Fig. 20.

Procedure: Draw the load line XY through the operating point (P) and the zero d-c grid bias point (X)

$$P = \frac{0.68 \times 250}{3.5}, \text{ or } -48.5 \text{ volts}$$

$$X = 2 \times 0.0335, \text{ or } 0.067 \text{ ampere}$$

By substituting the curve values in the power output formula, we find

$$\text{Power output} = \frac{(0.067 - 0.006)(357 - 118)}{8} = 1.8 \text{ watts}$$

The resistance of the load line XY is

$$\frac{357 - 118}{0.067 - 0.006}, \text{ or } 3920 \text{ ohms}$$

If now, the values from the curves are substituted in the distortion formula, we have

$$\text{2nd harmonic distortion} = \frac{\frac{0.067 + 0.006}{2} - 0.0335}{0.067 - 0.006} \times 100 = 4.9\%$$

It is customary to make the selection of load resistance such that the distortion as calculated from the above equation does not exceed 5 per cent. When the method shown above is used to determine the slope of the load resistance line, 2nd harmonic distortion in the output of a triode power amplifier is generally less than 5 per cent. Ordinarily, the plate load resistance for a single-tube amplifier is approximately equal to twice the plate resistance.

Power output for triodes in push-pull power amplifiers may be determined by means of the plate family, given E_o as the desired operating plate voltage. The method is to erect a vertical line at $E = 0.6 E_o$ (see Fig. 21), intersecting the $E_c = 0$ curve at the point I_{max} . This establishes I_{max} . Then,

$$\text{Power output} = \frac{I_{max} \times E_o}{5}$$

If I_{max} is expressed in amperes and E_o in volts, power output is in watts.

Fig. 21 illustrates the application of this method to the case of two type 45's operated at $E_o = 250$ volts.

$$\text{Power output} = \frac{0.096 \times 250}{5} = 4.8 \text{ watts}$$

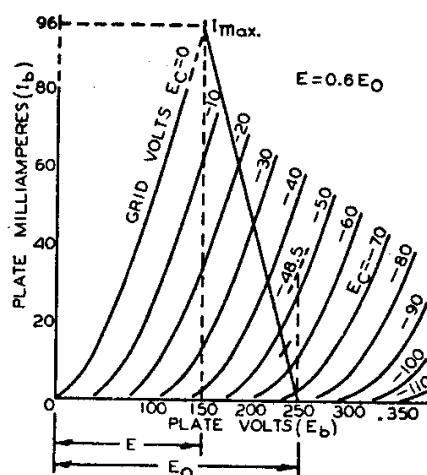


Fig. 21

The method for determining the proper load resistance for triodes in push-pull is as follows: Draw a load line through I_{max} and through the E_o point on the zero-current axis. Four times the resistance represented by this load line is the

plate-to-plate load for two triodes in a class A push-pull amplifier. From the curves in Fig. 21, we have

$$\text{Plate-to-plate load} = \frac{E_o - 0.6 E_o}{I_{\text{max.}}} \times 4 = \frac{100}{0.096} \times 4 = 4160 \text{ ohms}$$

This simple formula is applicable to all power output triodes in push-pull. The operating grid-bias voltage can be anywhere between that specified for single-tube operation and that equal to one-half the grid-bias voltage required to produce plate-current cut-off at a plate voltage of $1.4 E_o$. Thus, for single-tube operation of the type 45, the grid-bias voltage is recommended as -50 volts for 250 volts on the plate. Plate-current cut-off at $1.4 E_o$, or 350 volts, occurs at -110 volts on the grid. One-half of this value is -55 volts, which is the most negative value permissible without departing from class A conditions. Operation beyond this point will be accompanied by rectification and will no longer be representative of a class A amplifier.

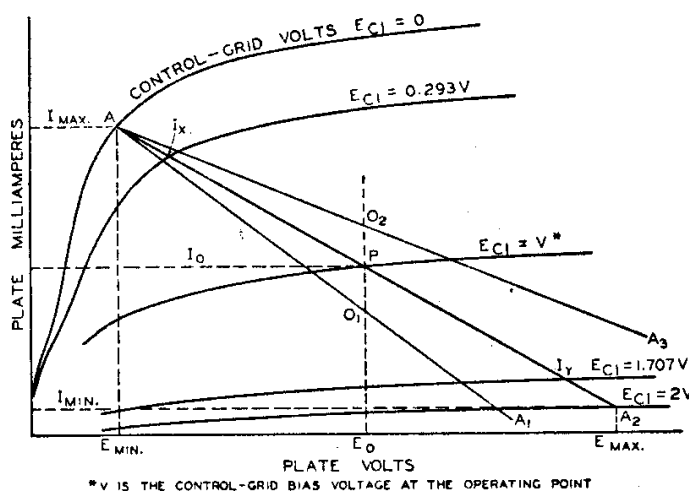


Fig. 22

measure the distance AO_1 . On the same line, lay off any equal distance O_1A_1 . For optimum operation, the change in bias from A to O_1 should nearly equal the change in bias from O_1 to A_1 . If this condition cannot be met with one line, then another line should be selected. When the most satisfactory line has been chosen, its resistance may then be determined by the following formula.

$$\text{Load resistance (Rp)} = \frac{E_{\text{max.}} - E_{\text{min.}}}{I_{\text{max.}} - I_{\text{min.}}}$$

The value of R_p may then be substituted in the following formula for calculating power output.

$$\text{Power output} = \frac{[I_{\text{max.}} - I_{\text{min.}} + 1.41 (I_x - I_y)]^2 R_p}{32}$$

For both of these formulas, if I is in amperes and E in volts, R_p is in ohms and power output is in watts.

Calculations for distortion may be made by means of the following formulas. The terms used have already been defined

$$\% \text{ 2nd harmonic distortion} = \frac{I_{\text{max.}} + I_{\text{min.}} - 2 I_o}{I_{\text{max.}} - I_{\text{min.}} + 1.41 (I_x - I_y)} \times 100$$

$$\% \text{ 3rd harmonic distortion} = \frac{I_{\text{max.}} - I_{\text{min.}} - 1.41 (I_x - I_y)}{I_{\text{max.}} - I_{\text{min.}} + 1.41 (I_x - I_y)} \times 100$$

$$\% \text{ total (2nd and 3rd) harmonic distortion} = \sqrt{(\% \text{ 2nd har. dist.})^2 + (\% \text{ 3rd har. dist.})^2}$$

The conversion curves given in Fig. 23 apply to radio tubes in general but are particularly useful for power tubes. These curves can be used for calculating approximate operating conditions for a plate voltage which is not included in the published data on operating conditions. For instance, suppose it is desired to operate two 6L6's in class A₁ push-pull, fixed bias, with a plate voltage of 200 volts. The nearest published operating conditions for this class of service are for a plate voltage of 250 volts. The operating conditions for the new plate voltage can be determined as follows: First compute the ratio of the new plate voltage to the plate voltage of the published data. In the example, this ratio is $200/250 = 0.8$. This figure is the Voltage Conversion Factor, F_v . Multiply by this factor to obtain the new values of grid bias and screen voltage. This gives a grid bias of $-16 \times 0.8 = -12.8$ volts, and a screen voltage of $250 \times 0.8 = 200$ volts for the new conditions.

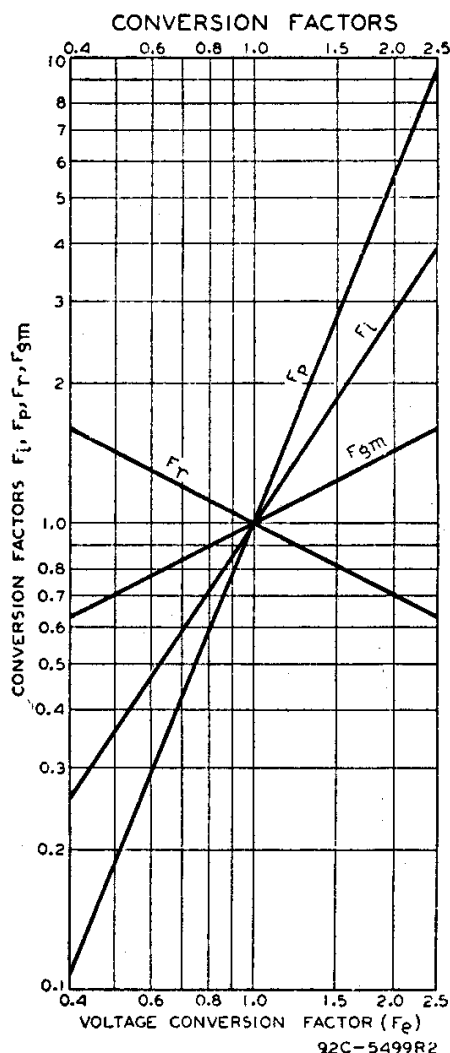


Fig. 23

To obtain the rest of the new conditions, multiply the published values by factors shown on the chart as corresponding to a voltage conversion factor of 0.8. In this chart,

F_i applies to plate current and to screen current,

F_p applies to power output,

F_r applies to load resistance and plate resistance,

F_{gm} applies to transconductance.

Thus, to find the power output for the new conditions, determine the value of F_p for a voltage conversion factor of 0.8. The chart shows that this value of F_p is 0.6. Multiplying the published value of power output by 0.6, the power output for the new conditions is $14.5 \times 0.6 = 8.7$ watts.

A class AB power amplifier employs two tubes connected in push-pull with a higher negative grid bias than is used in a class A stage. With this higher negative bias, the plate and screen voltages can usually be made higher than for class A because the increased negative bias holds plate current within the limit of the tube's plate dissipation rating. As a result of these higher voltages, more power output can be obtained from class AB operation.

Class AB amplifiers are subdivided into class AB₁ and class AB₂. In class AB₁ there is no flow of grid current. That is, the peak signal voltage applied to each grid is not greater than the negative grid-bias voltage. The grids therefore are not driven to a positive potential and do not draw grid current. In class AB₂, the peak signal voltage is greater than the bias so that the grids are driven positive and draw grid current.

Because of the flow of grid current in a class AB₂ stage there is a loss of power in the grid circuit. The sum of this loss and the loss in the input transformer is the total driving power required by the grid circuit. The driver stage should be capable of a power output considerably larger than this required power in order that distortion introduced in the grid circuit be kept low. The input transformer used in a class AB₂ amplifier usually has a step-down turns ratio.

Because of the large fluctuations of plate current in a class AB₂ stage, it is important that the power supply should have good regulation. Otherwise the fluctuations in plate current cause fluctuations in the voltage output of the power supply, with the result that power output is decreased and distortion is increased. To obtain satisfactory regulation it is usually advisable to use a choke-input filter.

It is sometimes advisable to use a mercury-vapor rectifier tube rather than a vacuum type because of the better regulation of the mercury-vapor type. In all cases, the resistance of the filter chokes and power transformer should be as low as possible.

A **class B power amplifier** employs two tubes connected in push-pull, so biased that plate current is almost zero when no signal voltage is applied to the grids. Because of this low value of no-signal plate current, class B amplification has the same advantage as class AB, that large power output can be obtained without excessive plate dissipation. The difference between class B and class AB is that, in class B, plate current is cut off for a larger portion of the negative grid swing.

There are several tube types designed especially for class B amplification. The characteristic common to all these types is high amplification factor. With this high amplification factor, plate current is small when grid voltage is zero. These tubes, therefore, can be operated in class B at a bias of zero volts so that a bias supply is not required. A number of the class B amplifier tube types consist of two triode units mounted in one tube. The two triode units can be connected in push-pull so that only one tube is required for a class B stage. Examples of class B twin triode types are the 6N7, 6A6, and 1G6-G.

Because a class B amplifier is usually operated at zero bias, each grid is at a positive potential during the positive half-cycle of its signal swing and consequently draws considerable grid current. There is, therefore, a loss of power in the grid circuit. This imposes the same requirement on the driver stage as in a class AB₂ stage; that is, the driver should be capable of considerably more power output than the power required for the class B grid circuit in order that distortion be low. The interstage transformer between the driver and class B stage usually has a step-down turns ratio.

The fluctuations in plate current in a class B stage are large so that it is important that the power supply have good regulation. The discussion of the power supply for a class AB₂ stage, therefore, also applies to the power supply for a class B amplifier.

An **inverse-feedback** circuit, sometimes called a **degenerative** circuit, is one in which a portion of the output voltage of a tube is applied to the input of the same or a preceding tube in opposite phase to the signal applied to the tube. Two important advantages of feedback are: (1) reduced distortion from each stage included in the feedback circuit and (2) reduction in the variations in gain due to changes in line voltage, possible differences between tubes of the same type, or variations in the values of circuit constants included in the feedback circuit.

Inverse feedback is used in audio amplifiers to reduce distortion in the output stage where the load impedance on the tube is a loudspeaker. Because the impedance of a loudspeaker is not constant for all audio frequencies, the load impedance on the output tube varies with frequency. When the output tube is a pentode or beam power tube having high plate resistance, this variation in plate load impedance can, if not corrected, produce considerable frequency distortion. Such frequency distortion can be reduced by means of inverse feedback. Inverse feedback circuits are of the **constant voltage** type and the **constant-current** type.

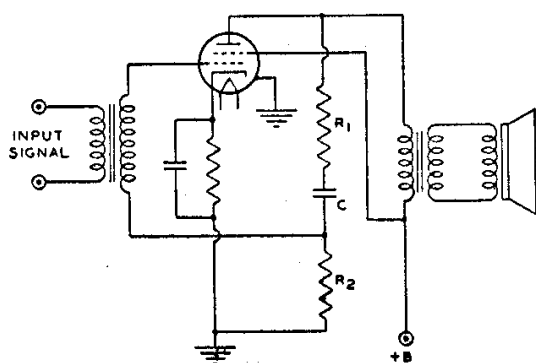


Fig. 24

The application of the **constant voltage** type of inverse feedback to a power output stage using a single beam power tube is illustrated by Fig. 24. In this circuit, R_1 , R_2 , and C are connected across the output of the 6L6 as a voltage divider. The secondary of the grid-input transformer is returned to a point on this voltage divider. Condenser C blocks the d-c plate voltage from the grid. However, a portion of the tube's a-f output voltage, approximately equal to the output voltage multiplied by the fraction $R_2/(R_1 + R_2)$, is applied

to the grid. There results a decrease in distortion which can be explained by the curves of Fig. 25.

Consider first the amplifier without the use of inverse feedback. Suppose that when a signal voltage e_s is applied to the grid the a-f plate current i_p has an irregularity in its positive half-cycle. This irregularity represents a departure from the waveform of the input signal and is, therefore, distortion. For this plate-current waveform, the a-f plate voltage has a waveform shown by e'_p . The plate-voltage waveform is inverted compared to the plate-current waveform because a plate-current increase produces an increase in the drop across the plate load. The voltage at the plate is the difference between the drop across the load and the supply voltage; thus, when plate current goes up, plate voltage goes down; when plate current goes down, plate voltage goes up.

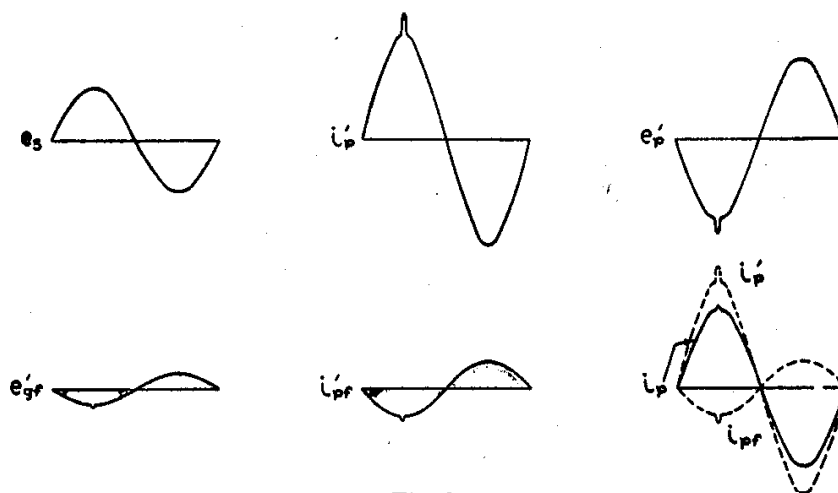


Fig. 25

Now suppose that inverse feedback is applied to the amplifier. The distortion irregularity in plate current is corrected in the following manner. With an inverse feedback arrangement, the voltage fed back to the grid has the same waveform and phase as the plate voltage, but is smaller in magnitude. Hence, with a plate voltage of waveform shown by e'_p , the feed-back voltage appearing on the grid is as shown by e'_gf . This voltage applied to the grid produces a component of plate current i'_pf . It is evident that the irregularity in the waveform of this component of plate current would act to cancel the original irregularity and thus reduce distortion.

After the correction of distortion has been applied by inverse feedback, the relations are as shown in the curve for i_p . The dotted curve shown by i_{pf} is the component of plate current due to the feedback voltage on the grid. The dotted curve shown by i'_p is the component of plate current due to the signal voltage on the grid. The algebraic sum of these two components gives the resultant plate current shown by the solid curve of i_p . Since i'_p is the plate current that would flow without inverse feedback, it can be seen that the application of inverse feedback has reduced the irregularity in the output current. In this manner inverse feedback acts to correct any component of plate current that does not correspond to the input signal voltage, and thus reduces distortion.

From the curve for i_p , it can be seen that, besides reducing distortion, inverse feedback also reduces the amplitude of the output current. Consequently, when inverse feedback is applied to an amplifier there is a decrease in power output as well as a decrease in distortion. However, by means of an increase in signal voltage, the power output can be brought back to its full value. Hence, the application of inverse feedback to an amplifier requires that more driving voltage be applied to obtain full power output but this output is obtained with less distortion.

Inverse feedback may also be applied to resistance-coupled stages as shown in Fig. 26. The circuit is conventional except that a feedback resistor, R_f , is connected between the plates of tubes T_1 and T_2 . The output signal voltage of T_1 and a portion of the output signal voltage of T_2 appears across R_f . Because the distortion generated in the plate circuit of T_2 is applied to its grid out of phase with the input signal, the distortion in the output of T_2 is comparatively low. With sufficient inverse feedback of the constant-voltage type in a power-output stage, it is not necessary to employ a network of resistance and capacitance in the

output circuit to reduce response at high audio frequencies. Inverse feedback circuits can also be applied to push-pull class A and class AB₁ amplifiers. When the circuit in Fig. 24 is used in push-pull, the input transformer must have a separate secondary for each grid. Inverse feedback is not recommended for use in amplifiers drawing grid power because of the resistance introduced in the grid circuit.

Constant-current inverse feedback is usually obtained by omitting the by-pass condenser across a cathode resistor. This method decreases the gain and the distortion but increases the plate resistance of the tube. When the plate resistance of an output tube is increased, the output voltage rises at the resonant frequency of the loudspeaker and accentuates hang-over effects.

Inverse feedback is not generally applied to a triode power amplifier such as the 2A3 because the variation in speaker impedance with frequency does not produce much distortion in a triode stage having low plate resistance. It is sometimes applied in a pentode stage but is not always convenient. As has been shown, when inverse feedback is used in an amplifier, the driving voltage must be increased in order to give full power output. When inverse feedback is used with a pentode, the total driving voltage required for full power output may be inconveniently large. Because a beam power tube gives full power output on a comparatively small driving voltage, inverse feedback is especially applicable to beam power tubes. By means of inverse feedback, the high efficiency and high power output of beam power tubes can be combined with freedom from the effects of varying speaker impedance.

A **corrective filter** can be used to improve the frequency characteristic of an output stage, using a beam power tube or a pentode, when inverse feedback is not applicable. The filter consists of a resistor and a condenser connected in series across the primary of the output transformer. Connected in this way, the filter is in parallel with the plate-load impedance reflected from the voice-coil by the output transformer. The magnitude of this reflected impedance increases with increasing frequency in the middle and upper audio range. The impedance of the filter, however, decreases with increasing frequency. It follows that by use of the proper values for the resistance and the capacitance in the filter, the effective load impedance on the output tubes can be made practically constant for all frequencies in the middle and upper audio range. The result is an improvement in the frequency characteristic of the output stage.

The resistance to be used in the filter for a push-pull stage is 1.3 times the recommended plate-to-plate load resistance; or, for a single-tube stage, is 1.3 times the recommended plate load resistance. The capacitance in the filter should have a value such that the voltage gain of the output stage at a frequency of 1000 cycles or higher is equal to the voltage gain at 400 cycles. A method of determining the proper value of capacitance for the filter is to make two measurements on the

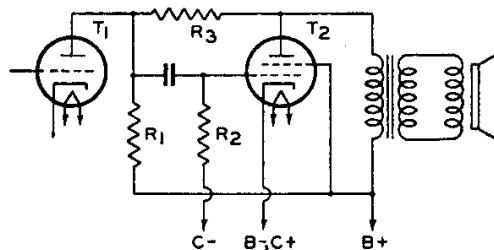


Fig. 26

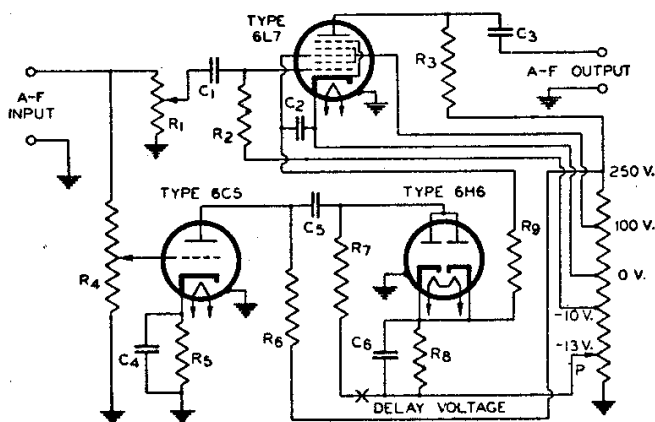


Fig. 27

output voltage across the primary of the output transformer: first, when a 400-cycle signal is applied to the input, and second, when a 1000-cycle signal of the same voltage as the 400-cycle signal is applied to the input. The correct value of capacitance is the one which gives equal output voltages for the two signal inputs. In practice, this value is usually found to be on the order of 0.05 μ f.

A volume expander can be used in a phonograph amplifier to make more natural the reproduction of music which has

a very large volume range. For instance, in the music of a symphony orchestra, the sound intensity of the loud passages is very much higher than that of the soft passages. When this music is recorded, it is not feasible to make the ratio of maximum amplitude to minimum amplitude as large on the record as it is in the original music. The recording process is therefore monitored so that the volume range of the original is compressed on the record. To compensate for this compression, a volume-expander amplifier has a variable gain which is greater for a high-amplitude signal than for a low-amplitude signal. The volume expander therefore amplifies loud passages more than soft passages and thus can restore to the music reproduced from the record the volume range of the original.

A volume expander circuit is shown in Fig. 27. The action of this circuit depends on the fact that the gain of the 6L7 as an audio amplifier can be varied by variation of the bias on the No. 3 grid. When the bias on the No. 3 grid is made less negative, the gain of the 6L7 increases. In the circuit, the signal to be amplified is applied to the No. 1 grid of the 6L7 and is amplified by the 6L7. The signal is also applied to the grid of the 6C5, is amplified by the 6C5, and is rectified by the 6H6. The rectified voltage developed across R8, the load resistor of the 6H6, is applied as a positive bias voltage to the No. 3 grid of the 6L7. Then, when the amplitude of the signal input increases, the voltage across R8 increases, and the bias on the No. 3 grid of the 6L7 is made less negative. Because this increases the gain of the 6L7, the gain of the amplifier increases with increase in signal amplitude and thus produces volume expansion of the signal.

The No. 1 grid of the 6L7 is a variable-mu grid and therefore will produce distortion if the input signal voltage is too large. For that reason, the signal input to the 6L7 should not exceed a peak value of 1 volt. This value is of the same order as the voltage obtainable from the usual magnetic phonograph pick-up. The no-signal bias voltage on the No. 3 grid is controlled by adjustment of contact P. This contact should be adjusted initially to give a no-signal plate current of 0.15 milliamperes in the 6L7. No further adjustment of contact P is required if the same 6L7 is always used. If it is desired to delay volume expansion until the signal input reaches a certain amplitude, the delay voltage can be inserted as a negative bias on the 6H6 plates at the point marked X in the diagram.

Another circuit using volume expansion is shown in CIRCUIT SECTION. This circuit can also be used to provide volume compression for microphone operation. Volume compression prevents overloading and blasting and compensates for differences in voice level produced by movements of the speaker at the microphone. In this circuit the 6H6 is connected as a voltage doubler. The d-c output is applied across potentiometer R₂₆. The arm and one side of R₂₆ is connected to the d.p.d.t. switch S₂ to permit reversing of the polarity of the voltage taken from R₂₆. The amount of d-c voltage across R₂₆ is dependent on the average signal level. When the level tends to increase, the voltage across R₂₆ increases; when the level decreases, the voltage decreases. The voltage taken from R₂₆ is applied in series with the control-bias of the master mixer tube. When the switch is set to "expand," the voltage becomes opposite in polarity to the bias of the tube. This lowers the bias and increases the amplification factor of the tube. When the switch is set to "compress," the two voltages are additive. The negative bias is, therefore, increased and the amplification factor is decreased.

A phase inverter is a circuit used to provide resistance coupling between the output of a single-tube stage and the input of a push-pull stage. The necessity for a phase inverter arises because the signal-voltage inputs to the grids of a push-pull stage must be 180 degrees out of phase and approximately equal in amplitude with respect to each other. Thus, when the signal voltage input to a push-pull stage swings the control grid of one tube in a positive direction, it should swing the other grid in a negative direction by a similar amount. With transformer coupling between stages, the out-of-phase input voltage to the push-pull stage is supplied by means of the center-tapped secondary. With resistance coupling, the out-of-phase input voltage is obtained by means of the inverter action of a tube.

Fig. 28 shows a push-pull power amplifier, resistance-coupled by means of a phase-inverter circuit to a single-stage triode T₁. Phase inversion in this circuit

is provided by triode T_2 . The output voltage of T_1 is applied to the grid of T_3 . A portion of the output voltage of T_1 is also applied through the resistors R_3 and R_4 to the grid of T_2 . The output voltage of T_2 is applied to the grid of T_4 . When the output voltage of T_1 swings in the positive direction, the plate current of T_2 increases. This action increases the voltage drop across the plate resistor R_2 and swings the plate of T_2 in the negative direction. Thus, when the output voltage of T_1 swings positive, the output voltage of T_2 swings negative and is, therefore, 180° out of phase with the output voltage of T_1 . In order to obtain equal voltages at E_a and E_b , the signal applied to the grid of T_2 should be less than the voltage at E_b in the ratio of the voltage gain of T_2 . Under the conditions where a twin-type tube or two tubes having the same characteristics are used at T_1 and T_2 , R_4 should be equal to the sum of R_3 and R_5 . The ratio of R_5 to R_3 plus R_5 should be the same as the voltage gain ratio of T_2 in order to apply the correct value of signal voltage to T_2 . The value of R_5 is, therefore, equal to R_3 divided by the voltage gain of T_2 ; R_3 is equal to R_4 minus R_5 .

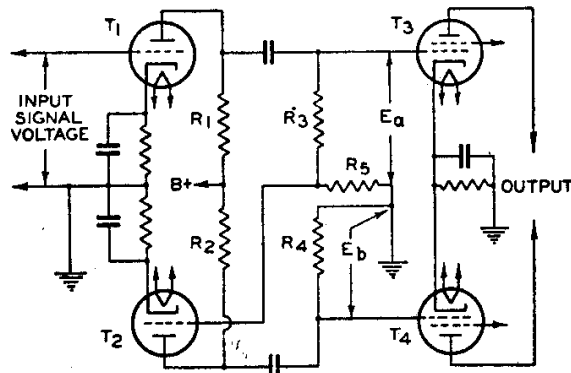
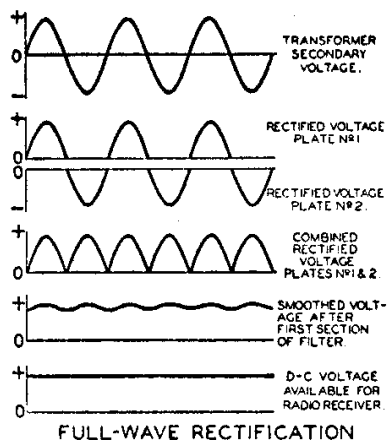


Fig. 28

Values of R_1 , R_2 , R_3 plus R_5 , and R_4 may be taken from the chart in the RESISTANCE-COUPLED AMPLIFIER SECTION. In the practical application of this circuit, it is convenient to use a twin-triode tube combining T_1 and T_2 . A phase-inverter circuit using a 6N7 is shown in the CIRCUIT SECTION.

RECTIFICATION

The rectifying action of a diode finds an important application in supplying a receiver with d-c power from an a-c line. A typical arrangement for this application includes a rectifier tube, a filter, and a voltage divider. The rectifying action of the tube is explained briefly under DIODES, page 5. The function of a filter is to smooth out the ripple of the tube output, as indicated in Fig. 29. The action of the filter is explained on page 40. The voltage divider is used to cut down the output voltage to the values required by the plates, screens, and grids of the tubes in the receiver.



FULL-WAVE RECTIFICATION

Fig. 29

A half-wave rectifier and a full-wave rectifier circuit are shown in Fig. 30. In the half-wave circuit, current flows through the rectifier tube to the filter on every other half-cycle of the a-c input voltage when the plate is positive with respect to the cathode. In the full-wave circuit, current flows to the filter on every half-cycle, through plate No. 1 on one half-cycle when plate No. 1 is positive with respect to the cathode, and through plate No. 2 on the next half-cycle when plate No. 2 is positive with respect to the cathode. Because the current flow to the filter is more uniform in the full-wave circuit than in the half-wave circuit, the output of the full-wave circuit requires less filtering. Rectifier operating information and circuits are given under each rectifier tube type and in the CIRCUIT SECTION.

Parallel operation of rectifier tubes permits of obtaining correspondingly increased output current over that obtainable with the use of one tube. For