

Power Supply

§ 8-1 Power-Supply Requirements

Filament supply — Except for tubes designed for battery operation, the filaments or heaters of vacuum tubes used in both transmitters and receivers are universally operated on alternating current obtained from the power line through a step-down transformer (§ 2-9) delivering a secondary voltage equal to the rated voltage of the tubes used. The transformer should be designed to carry the current taken by the number of tubes which may be connected in parallel (§ 2-6) across it. The filament or heater transformer generally is center-tapped, to provide a balanced circuit for eliminating hum (§ 3-6).

For medium- and high-power r.f. stages of transmitters, and for high-power audio stages, it is desirable to use a separate filament transformer for each section of the transmitter, installed near the tube sockets. This avoids the necessity for abnormally large wires to carry the total filament current for all stages without appreciable voltage drop. Maintenance of rated filament voltage is highly important, especially with thoriated-filament tubes, since under- or over-voltage may reduce filament life.

Plate supply — Direct current must be used for the plates of tubes, since any variation in plate current arising from power-supply causes will be superimposed on the signal being received or transmitted, giving an undesirable type of modulation (§ 5-1) if the variations occur at an audio-frequency (§ 2-7) rate. Unvarying direct current is called *pure d.c.*, to distinguish it from current which may be unidirectional but of pulsating character. The use of pure d.c. on the plates of transmitting tubes is required by FCC regulations on all frequencies below 60 Mc.

Sources of plate power — D.c. plate power is usually obtained from rectified and filtered alternating current, but in low-power and portable installations may be secured from batteries. Dry batteries may be used for very low-power portable equipment, but in many cases a storage battery is used as the primary power source, in conjunction with an interrupter giving pulsating d.c. which is applied to the primary of a step-up transformer (§ 8-10).

Rectified-a.c. supplies — Since the power-line voltage ordinarily is 115 or 230 volts, a step-up transformer (§ 2-9) is used to obtain the desired voltage for the plates of the tubes in the equipment. The alternating secondary current is changed to unidirectional current by means of diode rectifier tubes (§ 3-1), and

then passed through an inductance-capacity filter (§ 2-11) to the load circuit. The *load resistance* in ohms is equal to the d.c. output voltage of the power supply divided by the current in amperes (Ohm's Law, § 2-6).

Voltage regulation — Since there is always some resistance in power-supply circuits, and since the filter normally depends to a considerable extent upon the energy storage of inductance and capacity (§ 2-3, 2-5), the output voltage will depend upon the current drain on the supply. The change in output voltage with change in load current is called the *voltage regulation*. It is expressed as a percentage:

$$\% \text{ Regulation} = \frac{100 (E_1 - E_2)}{E_2}$$

where E_1 is the no-load voltage (no current in the load circuit) and E_2 the full-load voltage (rated current in load circuit).

§ 8-2 Rectifiers

Purpose and ratings — A rectifier is a device which will conduct current only in one direction. The diode tube (§ 3-1) is used almost exclusively for rectification in d.c. power supplies used with radio equipment. The important characteristics of tubes used as power-supply rectifiers are the voltage drop between plate and cathode at rated current, the maximum permissible inverse peak voltage, and the permissible peak plate current.

Voltage drop — Tube voltage drop depends upon the type of tube. In vacuum-type rectifiers it increases with the current flowing because of space-charge effect (§ 3-1), but can be minimized by using very small spacing between plate and cathode as is done in some rectifiers for receiver power supplies. Mercury-vapor rectifiers (§ 3-5) have a constant drop of about 15 volts, regardless of current. This is much smaller than the voltage drops encountered in vacuum-type rectifiers.

Inverse peak voltage — This is the maximum voltage developed between the plate and cathode of the rectifier when the tube is not conducting; i.e., when the plate is negative with respect to the cathode.

Peak plate current — This is the maximum *instantaneous* current through the rectifier. It can never be smaller than the load current in ordinary circuits, and may be several times higher.

Operation of mercury-vapor rectifiers — Because of its constant voltage drop, the mercury-vapor rectifier is more susceptible to damage than the vacuum type. With the latter, the increase in voltage drop tends to

limit current flow on heavy overloads, but the mercury-vapor rectifier does not have this limiting action and the cathode may be damaged under similar conditions.

In mercury-vapor rectifiers a phenomenon known as "arc-back," or breakdown of the mercury vapor and conduction in the opposite direction to normal, occurs at high inverse peak voltages, hence such tubes always should be operated within their inverse-peak voltage ratings. Arc-back also may occur if the cathode temperature is below normal; therefore the heater or filament voltage should be checked to make sure that the rated voltage is applied. This check should be made at the tube socket, to avoid errors caused by voltage drop in the leads. For the same reason, the cathode should be allowed to come up to its final temperature before plate voltage is applied; the time required for this is of the order of 15 to 30 seconds. When a tube is first installed, or is put into service after a long period of idleness, the cathode should be heated for a period of 10 minutes or so before application of plate voltage.

§ 8-3 Rectifier Circuits

Half-wave rectifiers — The simple diode rectifier (§ 3-1) is called a *half-wave rectifier*, because it can pass only half of each cycle of alternating current. Its circuit is shown in Fig. 801-A. At the top of the figure is a representation of the applied a.c. voltage, with positive and negative alternations (§ 2-7) marked.

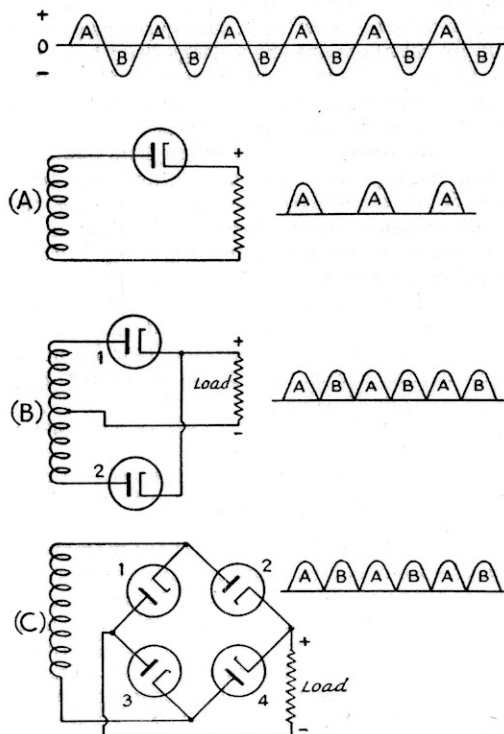


Fig. 801 — Fundamental vacuum-tube rectifier circuits.

When the plate is positive with respect to cathode, plate current flows through the load as indicated in the drawing at the right, but when the plate is negative with respect to cathode no current flows. This is indicated by the gaps in the output drawing. The output current is unidirectional but pulsating.

In this circuit the inverse peak voltage is equal to the maximum transformer voltage, which in the case of a sine wave is 1.41 times the r.m.s. voltage (§ 2-7).

Full-wave center-tap rectifier — Fig. 801-B shows the "full-wave center-tap" rectifier circuit, so called because both halves of the a.c. cycle are rectified and because the transformer secondary winding must consist of two equal parts with a connection brought out from the center. When the upper end of the winding is positive, current can flow through rectifier No. 1 to the load; this current cannot pass through rectifier No. 2 because its cathode is positive with respect to its plate. The circuit is completed through the transformer center-tap. When the polarity reverses the upper end of the winding is negative and no current can flow through No. 1, but the lower end is positive and therefore No. 2 passes current to the load, the return connection again being the center-tap. The resulting waveshape is shown at the right.

Since the two rectifiers are working alternately in this circuit, each half of the transformer secondary must be wound to deliver the full-load voltage; hence the total voltage across the transformer terminals is twice that required with the half-wave rectifier. Assuming negligible voltage drop in the particular rectifier which may be conducting at any instant, the inverse peak voltage on the other rectifier is equal to the maximum voltage between the outside terminals of the transformer. In the case of a sine wave, this is 1.41 times the total secondary r.m.s. voltage (§ 2-7).

Because energy is delivered to the load at twice the average rate as in the case of a half-wave rectifier, each tube carries only half the load current.

The bridge rectifier — The "bridge" type of full-wave rectifier is shown in Fig. 801-C. Its operation is as follows: When the upper end of the winding is positive, current can flow through No. 2 to the load but not through No. 1. On the return circuit, current flows through No. 3 by way of the lower end of the transformer winding. When the polarity reverses and the lower end of the winding becomes positive, current flows through No. 4 and the load and through No. 1 by way of the upper side of the transformer. The output waveshape is shown at the right.

The inverse peak voltage is equal to the maximum transformer voltage, or 1.41 times the r.m.s. secondary voltage in the case of a sine wave (§ 2-7). Energy is delivered to the load at the same average rate as in the case of the full-wave center-tap rectifier, each pair of tubes in series carrying half the load current.

§ 8-4 Filters

Purpose of filter — As shown in Fig. 801, the output of a rectifier is pulsating d.c., which would be unsuitable for most vacuum-tube applications (§ 8-1). A *filter* is used to smooth out the pulsations so that practically unvarying direct current flows through the load circuit. The filter utilizes the energy-storage properties of inductance and capacity (§ 2-3, 2-5), by virtue of which energy stored in electromagnetic and electrostatic fields when the voltage and current are rising is restored to the circuit when the voltage and current fall, thus filling in the “gaps” or “valleys” in the rectified output.

Ripple voltage and frequency — The pulsations in the output of the rectifier can be considered to be caused by an alternating current superimposed on a steady direct current (§ 2-13). Viewed from this standpoint, the filter may be considered to consist of bypass condensers which short-circuit the a.c. while not interfering with the flow of d.c., and chokes or inductances which permit d.c. to flow through them but which have high reactance for the a.c. (§ 2-13). The alternating component is called the *ripple*. The effectiveness of the filter may be measured by the *percent ripple*, which is the r.m.s. value of the a.c. ripple voltage expressed as a percentage of the d.c. output voltage. With an effective filter, the ripple percentage will be low. Five per cent ripple is considered satisfactory for c.w. transmitters, but lower values (of the order of 0.25 per cent) are necessary for hum-free speech transmission and receiver plate supplies.

The ripple frequency depends upon the line frequency and the type of rectifier. In general, it consists of a fundamental plus a series of harmonics (§ 2-7), the latter being relatively unimportant since the fundamental is hardest to smooth out. With a half-wave rectifier, the fundamental is equal to the line frequency; with a full-wave rectifier, the fundamental is equal to twice the line frequency, or 120 cycles in the case of a 60-cycle supply.

Types of filters — Inductance-capacity filters are of the low-pass type (§ 2-11), using series inductances and shunt capacitances. Practical filters are identified as *condenser-input* and *choke-input*, depending upon whether a capacity or inductance is used as the first element in the filter. Resistance-capacity filters (§ 2-11) are used in applications where the current is very low and the voltage drop in the resistor can be tolerated.

Bleeder resistance — Since the condensers in a filter will retain their charge for a considerable time after power is removed (provided the load circuit is open at the time), it is good practice to connect a resistor across the output of the filter to discharge the condensers when the power supply is not in use. The resistance usually is high enough so that only a relatively small percentage of the total output current is consumed in it during normal operation.

Components — Filter condensers are made in several different types. Electrolytic condensers, which are available for voltages up to about 800, combine high capacity with small size, since the dielectric is an extremely thin film of oxide on aluminum foil. Condensers for higher voltages usually are made with a dielectric of thin paper impregnated with oil. The *working voltage* of a condenser is the voltage which it will withstand continuously.

Filter chokes or inductances are wound on iron cores, with a small gap in the core to prevent magnetic saturation of the iron at high currents. When the iron becomes saturated its permeability (§ 2-5) decreases, consequently the inductance also decreases. Despite the air-gap, the inductance of a choke usually varies to some extent with the direct current flowing in the winding; hence it is necessary to specify the inductance at the current which the choke is intended to carry. Its inductance with little or no direct current flowing in the winding may be considerably higher than the load value.

§ 8-5 Condenser-Input Filters

Ripple voltage — The conventional condenser-input filter is shown in Fig. 802-A. No simple formulas are available for computing

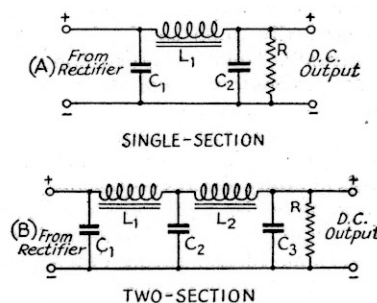


Fig. 802 — Condenser-input filter circuits.

the ripple voltage, but it will be smaller as both capacity and inductance are made larger. Adequate smoothing for transmitting purposes can be secured by using 4 to 8 $\mu\text{fd.}$ at C_1 and C_2 and 20 to 30 henrys at L_1 , for full-wave rectifiers with 120-cycle ripple (§ 8-4). A higher ratio of inductance to capacity may be used at higher load resistances (§ 8-1).

For receivers, as shown in Fig. 802-B, an additional choke, L_2 , and condenser, C_3 , of the same approximate values, are used to give additional smoothing. In such supplies the three condensers generally are 8 $\mu\text{fd.}$ each, although the input condenser, C_1 , sometimes is reduced to 4 $\mu\text{fd.}$ Inductances of 10 to 20 henrys each will give satisfactory filtering with these capacity values.

For ripple frequencies other than 120 cycles, the inductance and capacity values should be multiplied by the ratio $120/F$, where F is the actual ripple frequency.

The bleeder resistance, R , should be chosen to draw 10 per cent or less of the rated output

current of the supply. Its value is equal to $1000E/I$, where E is the output voltage and I the load current in milliamperes.

Rectifier peak current — The ratio of rectifier peak current to average load current is high with a condenser-input filter. Small rectifier tubes designed for low-voltage supplies (type 80, etc.) generally carry load-current ratings based on the use of condenser-input filters. With rectifiers for higher power, such as the 866/866-A, the load current should not exceed 25 per cent of the rated peak plate current for one tube when a full-wave rectifier is used, or one-eighth the half-wave rating.

Output voltage — The d.c. output voltage from a condenser-input supply will, with light loads or no load, approach the peak transformer voltage. This is 1.41 times the r.m.s. voltage (§ 2-7) of the transformer secondary, in the case of Figs. 801-A and C, or 1.41 times the voltage from the center-tap to one end of the secondary in Fig. 801-B. At heavy loads, it may decrease to the *average* value of secondary voltage or about 90 per cent of the r.m.s. voltage, or even less. Because of this wide range of output voltage with load current, the voltage regulation (§ 8-1) is inherently poor.

The output voltage obtainable from a given supply cannot readily be calculated, since it depends critically upon the load current and filter constants. Under average conditions it will be approximately equal to or somewhat less than the r.m.s. voltage between the center-tap and one end of the secondary in the full-wave center-tap rectifier circuit (§ 8-3).

Ratings of components — Because the output voltage may rise to the peak transformer voltage at light loads, the condensers should have a working-voltage rating (§ 8-4) at least as high and preferably somewhat higher, as a safety factor. Thus, in the case of a center-tap rectifier having a transformer delivering 550 volts each side of the center-tap, the minimum safe condenser voltage rating will be 550×1.41 or 775 volts. An 800-volt, or preferably a 1000-volt, condenser should be used. Filter chokes should have the inductance specified at full-load current, and must have insulation between the winding and the core adequate to withstand the maximum output voltage.

§ 8-6 Choke-Input Filters

Ripple voltage — The circuit of a single-section choke-input filter is shown in Fig. 803-A. For 120-cycle ripple, a close approximation of the ripple to be expected at the output of the filter is given by the formula:

$$\left. \begin{array}{l} \text{Single} \\ \text{Section} \\ \text{Filter} \end{array} \right\} \% \text{ Ripple} = \frac{100}{LC}$$

where L is in henrys and C in μfd . The product, LC , must be equal to or greater than 20 to reduce the ripple to 5 per cent or less. This figure represents, in most cases, the economical limit

for the single-section filter. Smaller percentages of ripple usually are more economically obtained with the two-section filter of Fig.

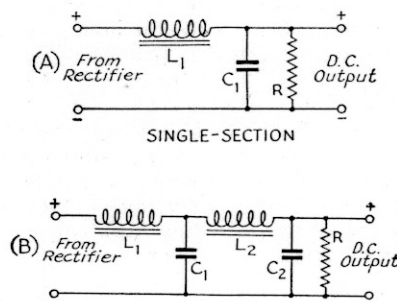


Fig. 803 — Choke-input filter circuits.

803-B. The ripple percentage (120-cycle ripple) with this arrangement is given by the formula:

$$\left. \begin{array}{l} \text{Two} \\ \text{Section} \\ \text{Filter} \end{array} \right\} \% \text{ Ripple} = \frac{650}{L_1 L_2 (C_1 + C_2)^2}$$

For a ripple of 0.25 per cent or less, the denominator should be 2600 or greater.

These formulas can be used for other ripple frequencies by multiplying each inductance and capacity value in the filter by the ratio $120/F$, where F is the actual ripple frequency.

The distribution of inductance and capacity in the filter will be determined by the value of input-choke inductance required (next paragraph), and the permissible a.c. output impedance. If the supply is intended for use with an audio-frequency amplifier, the reactance (§ 2-8) of the last filter condenser should be small (20 per cent or less) compared to the other a.f. resistance or impedance in the circuit, usually the tube plate resistance and load resistance (§ 3-2, 3-3). On the basis of a lower a.f. limit of 100 cycles for speech amplification (§ 5-9), this condition is usually satisfied when the output capacity (last filter capacity) of the filter is 4 to 8 μfd , the higher value being used for the lower tube and load resistances.

The input choke — The rectifier peak current and the power-supply voltage regulation depend almost entirely upon the inductance of the input choke in relation to the load resistance (§ 8-1). The function of the choke is to raise the ratio of average to peak current (by its energy storage), and to prevent the d.c. output voltage from rising above the average value (§ 2-7) of the a.c. voltage applied to the rectifier. For both purposes, its impedance (§ 2-8) to the flow of the a.c. component (§ 8-4) must be high.

The value of input-choke inductance which prevents the d.c. output voltage from rising above the average of the rectified a.c. wave is the *critical inductance*. For 120-cycle ripple, it is given by the approximate formula:

$$L_{\text{crit.}} = \frac{\text{Load resistance (ohms)}}{1000}$$

For other ripple frequencies, the inductance required will be the above value multiplied by the ratio of 120 to the actual ripple frequency.

With inductance values less than critical, the d.c. output voltage will rise because the filter tends to act as a condenser-input filter (§ 8-5). With critical inductance, the peak plate current of one tube in a center-tap rectifier will be approximately 10 per cent higher than the d.c. load current taken from the supply.

An inductance of twice the critical value is called the *optimum* value. This value gives a further reduction in the ratio of peak to average plate current, and represents the point at which further increase in inductance does not give correspondingly improved operating characteristics.

Swinging chokes — The formula for critical inductance indicates that the inductance required varies widely with the load resistance. In the case where there is no load except the bleeder (§ 8-4) on the power supply, the critical inductance required is highest; much lower values are satisfactory when the full-load current is being delivered. Since the inductance of a choke tends to rise as the direct current flowing through it is decreased (§ 8-4), it is possible to effect an economy in materials by designing the choke to have a "swinging" characteristic such that it has the required critical inductance value with the bleeder load only, and about the optimum inductance value at full load. Thus, in the case where the bleeder resistance is 20,000 ohms and the full-load resistance (including the bleeder) is 2500 ohms, a choke which swings from 20 henrys to 5 henrys over the full output-current range will fulfill the requirements.

Resonance — Resonance effects in the series circuit across the output of the rectifier which is formed by the first choke (L_1) and first filter condenser (C_1) must be avoided, since the ripple voltage would build up to large values (§ 2-10). This not only is the opposite action to that for which the filter is intended, but also may cause excessive rectifier peak currents and abnormally high inverse peak voltages. For full-wave rectification the ripple frequency will be 120 cycles for a 60-cycle supply (§ 8-4), and resonance will occur when the product of choke inductance in henrys times condenser capacity in microfarads is equal to 1.77. The corresponding figure for 50-cycle supply (100-cycle ripple frequency) is 2.53, and for 25-cycle supply (50-cycle ripple frequency), 13.5. At least twice these products should be used to ensure against resonance effects.

Output voltage — Provided the input-choke inductance is at least the critical value, the output voltage may be calculated quite closely by the equation:

$$E_o = 0.9E_t - \frac{(I_b + I_L)(R_1 + R_2)}{1000} - E_r$$

where E_o is the output voltage; E_t is the r.m.s. voltage applied to the rectifier (r.m.s. voltage

between center-tap and one end of the secondary in the case of the center-tap rectifier); I_b and I_L are the bleeder and load currents, respectively, in milliamperes; R_1 and R_2 are the resistances of the first and second filter chokes; and E_r is the drop between rectifier plate and cathode (§ 8-2). These voltage drops are shown in Fig. 804.

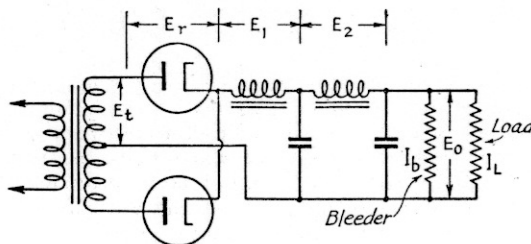


Fig. 804 — Voltage drops in the power-supply circuit.

At no load I_L is zero, hence the no-load voltage may be calculated on the basis of bleeder current only. The voltage regulation may be determined from the no-load and full-load voltages (§ 8-1).

Ratings of components — Because of better voltage regulation, filter condensers are subjected to smaller variations in d.c. voltage than in the condenser-input filter (§ 8-5). However, it is advisable to use condensers rated for the peak transformer voltage in case the bleeder resistor should burn out when there is no external load on the power supply, since the voltage then will rise to the same maximum value as with a condenser-input filter.

The input choke may be of the swinging type, the required no-load and full-load inductance values being calculated as described above. The second choke (*smoothing choke*) should have constant inductance with varying d.c. load currents. Values of 10 to 20 henrys ordinarily are used. Since chokes usually are placed in the positive leads, the negative being grounded, the windings should be insulated from the core to withstand the full d.c. output voltage of the supply.

§ 8-7 The Plate Transformer

Output voltage — The output voltage of the plate transformer depends upon the required d.c. load voltage and the type of rectifier circuit. With condenser-input filters, the r.m.s. secondary voltage usually is made equal to or slightly more than the d.c. output voltage, allowing for voltage drops in the rectifier tubes and filter chokes as well as in the transformer itself. The full-wave center-tap rectifier requires a transformer giving this voltage each side of the secondary center-tap (§ 8-3).

With a choke-input filter, the required r.m.s. secondary voltage (each side of center-tap for a center-tap rectifier) can be calculated by the equation:

$$E_t = 1.1 \left[E_o + \frac{I(R_1 + R_2)}{1000} + E_r \right]$$

where E_o is the required d.c. output voltage, I is the load current (including bleeder current) in milliamperes, R_1 and R_2 are the resistances of the filter chokes, and E_r is the voltage drop in the rectifier. E_s is the full-load r.m.s. (§ 2-7) secondary voltage; the open-circuit voltage usually will be 5 to 10 per cent higher.

Volt-ampere rating — The volt-ampere rating (§ 2-8) of the transformer depends upon the type of filter (condenser or choke input). With a condenser-input filter the heating effect in the secondary is higher because of the high ratio of peak to average current, consequently the volt-amperes consumed by the transformer may be several times the watts delivered to the load. With a choke-input filter, provided the input choke has at least the critical inductance (§ 8-6), the secondary volt-amperes can be calculated quite closely by the equation:

$$\text{Sec. V.A.} = 0.00075 EI$$

where E is the total r.m.s. voltage of the secondary (between the outside ends in the case of a center-tapped winding) and I is the d.c. output current in milliamperes (load current plus bleeder current). The primary volt-amperes will be 10 to 20 per cent higher because of transformer losses.

8-8 Voltage Stabilization

Gaseous regulator tubes — There is frequent need for maintaining the voltage applied to a low-voltage low-current circuit (such as the oscillator in a superhet receiver or the frequency-controlling oscillator in a transmitter) at a practically constant value, regardless of the voltage regulation of the power supply or variations in load current. In such applications, gaseous regulator tubes (VR105-30, VR150-30, etc.) can be used to good advantage. The voltage drop across such tubes is constant over a moderately wide current range. The first number in the tube designation indicates the terminal voltage, the second the maximum permissible tube current.

The fundamental circuit for a gaseous regulator is shown in Fig. 805-A. The tube is connected in series with a limiting resistor, R_1 , across a source of voltage which must be higher than the starting voltage, or voltage required for ionization of the gas in the tube. The starting voltage is about 30 per cent higher than the operating voltage. The load is connected in parallel with the tube. For stable operation, a minimum tube current of 5 to 10 ma. is required. The maximum permissible current with most types is 30 ma.; consequently,

the load current cannot exceed 20 to 25 ma. if the voltage is to be stabilized over a range from zero to maximum load current.

The value of the limiting resistor must lie between that which just permits minimum tube current to flow and that which just passes the maximum permissible tube current when there is no load current. The latter value is generally used. It is given by the equation:

$$R = \frac{1000 (E_s - E_r)}{I}$$

Where R is the limiting resistance in ohms, E_s is the voltage of the source across which the tube and resistor are connected, E_r is the rated voltage drop across the regulator tube, and I is the maximum tube current in milliamperes (usually 30 ma.).

Fig. 805-B shows how two tubes may be used in series to give a higher regulated voltage than is obtainable with one, and also to give two values of regulated voltage. The limiting resistor may be calculated as above, using the sum of the voltage drops across the two tubes for E_r . Since the upper tube must carry more current than the lower, the load connected to the low-voltage tap must take small current. The total current taken by the loads on both the high and low taps should not exceed 20 to 25 milliamperes.

Voltage regulation of the order of 1 per cent can be obtained with circuits of this type.

Electronic voltage regulation — A voltage regulator circuit suitable for higher voltages and currents than the gaseous tubes, and also having the feature that the output voltage can be varied over a rather wide range, is shown in Fig. 806. A high-gain voltage amplifier tube (§ 3-3), usually a sharp cut-off pentode (§ 3-5) is connected in such a way that a small change in the output voltage of the power supply causes a change in grid bias, and thereby a corresponding change in plate current. Its plate current flows through a resistor (R_5), the voltage drop across which is used to bias a second tube — the "regulator" tube — whose plate-cathode circuit is connected in series with the load circuit. The regulator tube therefore functions as an automatically variable series resistor. Should the output voltage increase slightly the bias on the control tube will become more positive, causing the plate current of the control tube to increase and the drop across R_5 to increase correspondingly. The bias on the regulator tube therefore becomes more negative and the effective resistance of the regulator tube increases, causing the terminal voltage to drop. A decrease in output voltage causes the reverse action. The time lag in the action of the system is negligible, and with proper circuit constants the output voltage can be held within a fraction of a per cent throughout the useful range of load currents and over a wide range of supply voltages.

An essential in this system is the use of a constant-voltage bias source for the control

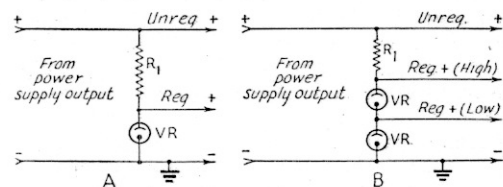


Fig. 805 — Voltage-stabilizing circuits using VR tubes.

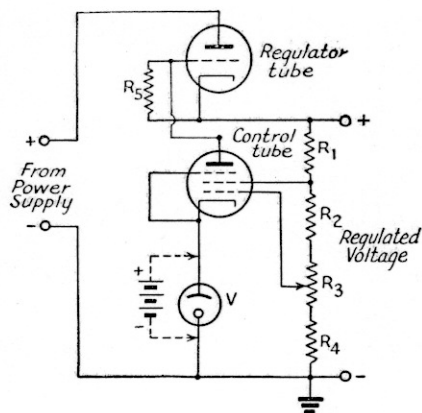


Fig. 806 — Electronic voltage regulator. The regulator tube is ordinarily a 2A3 or a number of them in parallel, the control tube a 6SJ7 or similar type. The filament transformer for the regulator tube must be insulated for the plate voltage, and cannot supply current to other tubes when a filament type regulator tube is used. Typical values: R_1 , 10,000 ohms; R_2 , 25,000 ohms; R_3 , 10,000-ohm potentiometer; R_4 , 5000 ohms; R_5 , 0.5 megohm.

tube. The voltage change which appears at the grid of the tube is the difference between a fixed negative bias and a positive voltage which is taken from the voltage divider across the output. To get the most effective control, the negative bias must not vary with plate current. The most satisfactory type of bias is a dry battery of 45 to 90 volts, but a gaseous regulator tube (VR75-30) or a neon bulb of the type without a resistor in the base may be used instead. This is indicated in the diagram. If the gas tube or neon bulb is used, a negative-resistance type of oscillation (§ 3-7) may take place at audio frequencies or higher, in which case a condenser of 0.1 μ f. or more should be connected across the tube. A similar condenser between the control-tube grid and cathode also is frequently helpful in this respect.

The variable resistor, R_3 , is used to adjust the bias on the control tube to the proper operating value. It also serves as an output voltage control, setting the value of regulated voltage within the existing operating limits.

The maximum output voltage obtainable is equal to the power-supply voltage minus the minimum drop through the regulator tube. This drop is of the order of 50 volts with the tubes ordinarily used (power triodes having low plate resistance, such as the 2A3). The maximum current also is limited by the regulator tube; 100 milliamperes is a safe value for the 2A3. Two or more regulator tubes may be connected in parallel to increase the current-carrying capacity, with no change in the circuit.

§ 8-9 Bias Supplies

Requirements — A bias supply is not called upon to deliver current to a load circuit, but simply to furnish a fixed grid voltage to set the operating point of a tube (§ 3-3). However, in most applications it is nevertheless true that current flows through the bias supply, because

such supplies are used chiefly in connection with power amplifiers of the Class-B and Class-C type, where grid-current flow is a feature of operation (§ 3-4). In circuit design a bias supply resembles the rectified-a.c. plate supply (§ 8-1), having a transformer-rectifier-filter system employing similar circuits. Bias supplies may be classified in two types, those furnishing only *protective* bias, intended to prevent excessive plate current flow in a power tube in case of loss of grid leak bias (§ 3-6) from excitation failure, and those which furnish the actual *operating* bias for the tubes. In the former type, voltage regulation (§ 8-1) is relatively unimportant; in the latter it may be of considerable importance.

In general, a bias supply should have well-filtered d.c. output, especially if it furnishes the operating bias for the stage, since ripple voltage may modulate the signal on the grid of the amplifier tube (§ 5-1). Condenser-input filters are generally used, since the regulation of the supply is not a function of the filter. The constants given in § 8-5 are applicable.

Voltage regulation — A bias supply must always have a bleeder resistance (§ 8-4) connected across its output terminals, to provide a d.c. path from grid to cathode of the tube being biased. Although the grid circuit takes no current from the supply, grid current flows through the bleeder resistor and the voltage across the resistor therefore varies with grid current. This variation in voltage is practically independent of the bias-supply design unless special voltage-regulating means are used.

Protective bias — This type of bias supply is designed to give an output voltage sufficient to bias the tube to which it is applied at or near the plate-current cut-off point (§ 3-2). A typical circuit is given in Fig. 807. The resistance, R_1 , is the grid-leak resistor (§ 3-6) for the amplifier tube with which the supply is used, and the normal operating bias is developed by the flow of grid current through this resistor. R_2 is connected in series with R_1 across the output of the supply, to reduce the voltage across R_1 , when there is no grid-current flow, to the cut-off value for the tube being biased. The value of R_2 is given by the formula:

$$R_2 = \frac{E_t - E_c}{E_c} \times R_1$$

where E_t is the output voltage of the supply with R_2 and R_1 in series as a load, E_c is the cut-off bias, and R_1 is as described above.

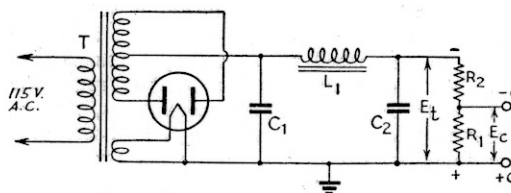
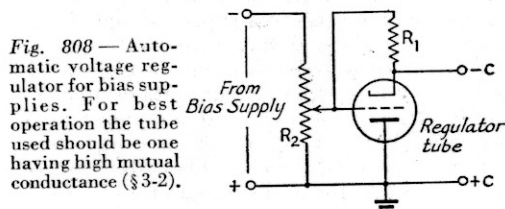


Fig. 807 — Supply for furnishing protective bias to a power amplifier. The transformer, T , should furnish peak voltage at least equal to the protective bias required,

When such a supply is used with a Class-C amplifier, the voltage across R_1 from grid-current flow will normally be higher than that from the bias supply itself, since the latter is adjusted to cut-off while the operating bias will be twice cut-off or higher (§ 3-4). In some cases the grid-leak voltage may even exceed the peak output voltage of the transformer (1.41 times half the total secondary voltage, in the circuit shown). The filter condensers in such a bias supply must, therefore, be rated to stand the maximum operating bias voltage on the Class-C amplifier, if this voltage exceeds the nominal output voltage of the supply.

Voltage stabilization — When the bias supply furnishes operating rather than simply protective bias, the value of bias voltage should be as constant as possible even when the grid current of the biased tube varies. A simple method of improving bias voltage regulation is to make the bleeder resistance low enough so that the current through it from the supply is several times the maximum grid current to be expected. By this means, the percentage variation in current is reduced. This method requires, however, that a considerable amount of power be dissipated in the bleeder, which in turn calls for a relatively large power transformer and filter choke.

Bias-voltage variation may also be reduced by means of a regulator tube, as shown in Fig. 808. The regulator tube usually is a triode



having a plate-current rating adequate to carry the expected grid current. It is cathode-biased (§ 3-6) by the resistor, R_1 , which is of the order of several hundred thousand ohms or a few megohms, so that with no grid current the tube is biased practically to cut-off. Because of this high resistance, the grid current will flow through the plate resistance of the regulator tube, which is comparatively low, rather than through R_1 and R_2 ; hence the voltage from the supply, across R_1 and the cathode-plate circuit of the regulator tube in series, can be considered constant. The bias voltage is equal to the voltage across the tube alone. When grid current flows, the voltage across the tube will tend to increase; hence the drop across R_1 decreases, lowering the bias on the regulator and reducing its plate resistance. This, in turn, reduces the tube voltage drop, and the bias voltage tends to remain constant over a fairly wide range of grid current values.

At low bias voltages it may be necessary to use a number of tubes in parallel to get sufficient variation of plate resistance for good

regulating action. The bias supply must furnish the required bias voltage plus the voltage required to bias the regulator tube to cut-off, considering the output bias voltage as the plate voltage applied to the regulator. The current taken from the bias supply is negligible. R_2 may be tapped to provide a range of bias voltages to meet different tube requirements.

Multi-stage bias supplies — Where several power amplifier tubes are to be biased from a single supply, the various bias circuits must be isolated by some means. If the grid currents of all stages should flow through a single bleeder resistor, a variation in grid current in one stage would change the bias on all, a condition which would interfere with effective adjustment and operation of the transmitter.

When protective bias is to be furnished several stages, the circuit arrangement of Fig. 809, using rectifier tubes to isolate the individual grid-leaks of the various stages, may be employed. In the diagram, two type 80 rectifiers are used to furnish bias to four stages. Each pair of resistors (R_1R_2) constitutes a separate bleeder across the bias supply. R_1 is the grid-leak for the biased stage; R_2 is a dropping resistor to adjust the voltage across R_1 to the cut-off value (without grid-current flow) for the biased tube. The values of R_1 and R_2 may be calculated as described in the paragraph on protective bias. In this case, the bias supply should be designed to have inherently good voltage regulation; i.e., a choke-input filter with appropriate filter and bleeder constants (§ 8-6) should be used, the bleeder being separate from those associated with the rectifier tubes. When the voltage across R_1R_2 rises because of grid-current flow through R_1 , the load on the supply will vary (hence the necessity for good voltage regulation in the supply), but there is no interaction of grid currents in the separate bleeders because the rectifiers can pass current only in one direction.

When a single supply is to furnish operating bias for several stages, a separate regulator-tube circuit (Fig. 808) may be used for each one. Individual voltages for the various stages can be obtained by appropriate taps on R_2 .

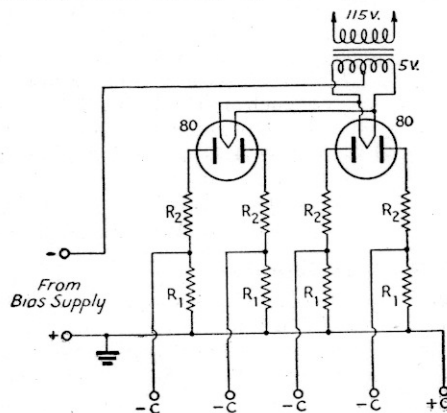


Fig. 809 — Isolating circuit for multiple bias supply.

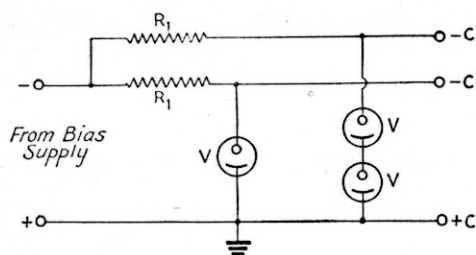


Fig. 810 — Use of VR tubes to stabilize bias voltage.

Well-regulated bias for several stages may be obtained by the use of gaseous regulator tubes, when the voltage and current ratings of the tubes permit their use. This is shown in Fig. 810. A single tube or two or more in series can be used to give the desired bias-voltage drop; the bias supply voltage must be high enough to provide starting voltage for the tubes in series. R_1 is the protective resistance (§ 8-8); its value should be calculated for minimum stable tube current. The maximum grid current that can be handled is 20 to 25 milliamperes with available regulator tubes.

8-10 Miscellaneous Power-Supply Circuits

Voltage dividers — A voltage divider is a resistance connected across a source of voltage and tapped at appropriate points, from which voltages lower than the terminal voltage may be taken (§ 2-6). Since the voltage at any tap depends upon the current drawn from the tap, the voltage regulation (§ 8-1) of such a divider is inherently poor. Hence, a voltage divider is best suited to applications where the currents drawn are constant, or where separate voltage-regulating circuits (§ 8-8) are used to compensate for voltage variations at the taps.

A typical voltage-divider arrangement is shown in Fig. 811. The terminal voltage is E , and two taps are provided to give lower voltages, E_1 and E_2 , at currents I_1 and I_2 respectively. The smaller the resistance between taps in proportion to the total resistance, the smaller the voltage between the taps. In addition to the load currents, I_1 and I_2 , there is also the bleeder current, I_b . The voltage divider may be the bleeder for the power supply. For convenience, the voltage divider in the figure is considered to be made up of separate resistances, R_1 , R_2 , R_3 , between taps. R_1 carries only the bleeder current, I_b . R_2 carries I_1 in addition to I_b ; R_3 carries I_2 , I_1 and I_b . For the purpose of calculating the resistances required, a bleeder current, I_b , must

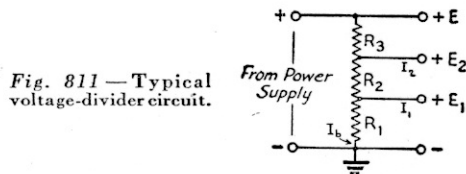


Fig. 811 — Typical voltage-divider circuit.

be assumed; generally it is low compared to the total load current (10 per cent or so). Then

$$R_1 = \frac{E_1}{I_b}$$

$$R_2 = \frac{E_2 - E_1}{I_b + I_1}$$

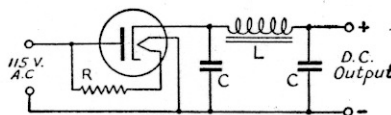
$$R_3 = \frac{E - E_2}{I_b + I_1 + I_2}$$

the currents being expressed in amperes.

The method may be extended to any desired number of taps, each resistance section being calculated by Ohm's Law (§ 2-6) using the voltage drop across it and the total current through it. The power dissipated by each section may be calculated by multiplying the same quantities together.

In case it is desired to have the bleeder resistance total to a predetermined value, the same method of calculation may be followed, but different values of bleeder current should be tried until the correct result is found.

Transformerless plate supplies — It is possible to rectify the line voltage directly, without using a step-up power transformer, for certain applications (such as some types of receivers) where the low voltage so obtained is satisfactory. A simple power-supply system of this type, using a half-wave rectifier, is shown in Fig. 812. Tubes for this purpose are provided with heaters operating at relatively high voltages (25, 35, 70, or 115 volts), which can be connected across the line in series with other tube filaments and/or a resistor, R , of suitable value to limit the current to the rated value for the tube heater. The rectifier often is

Fig. 812 — Transformerless plate supply with half-wave rectifier. Other filaments are connected in series with R .

incorporated in the same tube envelope with an audio power-amplifier tube.

The half-wave circuit shown has a fundamental ripple frequency equal to the line frequency (§ 8-4) and hence requires more inductance and capacity in the filter for a given ripple percentage (§ 8-5) than the full-wave rectifier. A condenser-input filter generally is used, frequently with a second choke and third condenser (§ 8-5) to provide the necessary smoothing.

A disadvantage of the transformerless circuit is that no ground connection can be used on the power supply, unless care is taken to insure that the grounded side of the power line is connected to the grounded side of the supply. Receivers using this type of supply generally are grounded through a low capacity (0.05 μ fd.) condenser, to avoid short-circuiting the

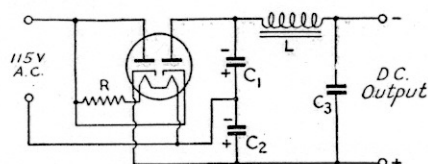


Fig. 813 — Voltage-doubling transformerless plate supply.

line should the line plug be inserted in the socket the wrong way, and the chassis is isolated from the power supply. The input condenser should be at least $16\ \mu\text{fd.}$ and preferably $32\ \mu\text{fd.}$, to keep the output voltage high and to improve voltage regulation.

Voltage-doubling circuits — The circuit arrangement of Fig. 813, frequently used in transformerless plate supplies, gives full-wave rectification combined with doubling of the output voltage. This is accomplished by using

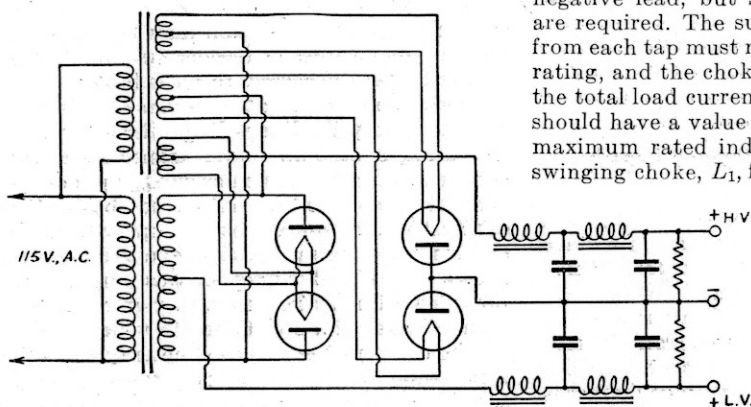


Fig. 814 — Duplex plate supply, in which a combination bridge and center-tap rectifier circuit is used to deliver two output voltages with good regulation. Only one plate transformer is required.

a double-diode rectifier, one section of which charges C_1 when the line polarity between its plate and cathode is positive while the other section charges C_2 when the line polarity reverses. Thus each condenser is charged separately to the same d.c. voltage, and they discharge in series into the load circuit. For effective operation of this circuit, the capacities of C_1 and C_2 must be at least $16\ \mu\text{fd.}$ each and preferably higher.

The ripple frequency with this circuit is twice the line frequency, since it is a full-wave circuit (§ 8-4). The voltage regulation is inherently poor and depends critically upon the capacities of C_1 and C_2 , being better as these capacities are made larger. A typical supply with $16\ \mu\text{fd.}$ each at C_1 and C_2 will have an output voltage of approximately 300 at light loads, dropping to about 210 volts at the rated current of 75 milliamperes.

No direct ground can be used on this supply or on the equipment with which it is used. If an r.f. ground is made through a condenser the capacity should be small (about $0.05\ \mu\text{fd.}$), since it is in shunt from plate to cathode of one rectifier. A large capacity (low reactance) would by-pass the rectifier, thereby nullifying its operation.

Duplex plate supplies — In some cases it may be advantageous economically to obtain two plate-supply voltages from a single power supply, making one or more of the components serve a double purpose. Two circuits of this type are shown in Figs. 814 and 815.

In Fig. 814, a bridge rectifier is used to obtain the full transformer voltage, while a connection is also brought out from the center-tap to obtain a second voltage corresponding to half the total transformer secondary voltage. The sum of the currents drawn from the two taps should not exceed the d.c. ratings of the rectifier tubes and transformer. Filter values for each tap are computed separately (§ 8-6).

Fig. 815 shows how a transformer with multiple secondary taps may be used to obtain both high and low voltages simultaneously. A separate full-wave rectifier is used at each tap. The filter chokes are placed in the common negative lead, but separate filter condensers are required. The sum of the currents drawn from each tap must not exceed the transformer rating, and the chokes must be rated to carry the total load current. Each bleeder resistance should have a value in ohms of 1000 times the maximum rated inductance in henrys of the swinging choke, L_1 , for best regulation (§ 8-6).

Rectifiers in parallel — Vacuum-type rectifiers may be connected in parallel (plate to plate and cathode to cathode) for higher current-carrying capacity with no circuit changes.

When mercury-vapor rectifiers are connected in parallel, slight differences in tube characteristics may make one ionize at a slightly lower voltage than the other. Since the ignition voltage is higher than the operating voltage the first tube to ionize carries the whole load, since the voltage drop is then too low to ignite the second tube. This can be prevented by connecting resistors in series with each plate, as shown in Fig. 816, thereby insuring that a high-enough voltage for ignition will be available.

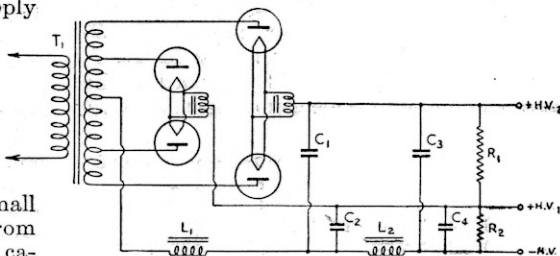


Fig. 815 — Power supply in which a single transformer and set of chokes serve for two different output voltages.

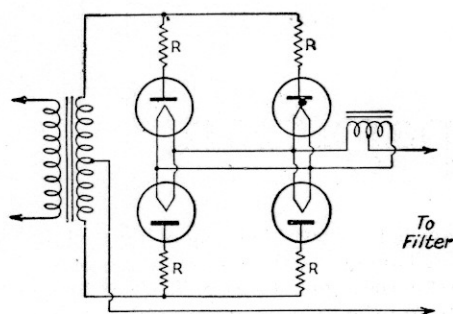


Fig. 816 — Operating mercury-vapor rectifiers in parallel. The resistors marked *R* should be 50 to 100 ohms.

Vibrator power supplies — For portable or mobile work, the most common source of power for both filaments and plates is the 6-volt automobile-type storage battery. Filaments may be heated directly from the battery, while plate power is obtained by passing current from the battery through the primary of a suitable transformer, interrupting it at regular intervals to give the changing magnetic field required for inducing a voltage in the secondary (§ 2-5), and rectifying the secondary output. The rectified output is pulsating d.c., which may be filtered by ordinary means (§ 8-5).

Fig. 817 shows two types of circuits used, both with vibrating-reed interrupters (*vibrators*). At A is shown the *non-synchronous* type of vibrator. When the battery circuit is open the reed is midway between the two contacts, touching neither. On closing the battery circuit the magnet coil pulls the reed into contact with the lower point, causing current to flow through the lower half of the transformer primary winding. Simultaneously, the magnet coil is short-circuited and the reed swings back. Inertia carries it into contact with the upper point, causing current to flow through the upper half of the transformer primary. The magnet coil again is energized, and the cycle repeats itself.

The synchronous circuit of Fig. 817-B is provided with an extra pair of contacts which rectify the secondary output of the transformer, thus eliminating the need for a separate rectifier tube. The secondary center-tap furnishes the positive output terminal when the relative polarities of primary and secondary windings are correct.

The proper connections may be determined by experiment, reversing the secondary connections if the first trial is wrong.

The buffer condenser, C_2 , across the transformer secondary is used to absorb surges which would occur on breaking the current, when the magnetic field collapses practically instantaneously and hence causes a very high voltage to be induced in the secondary (§ 2-5).

Its value usually is between 0.005 and 0.03 $\mu\text{fd.}$ and for 250-300 volt supplies it should be rated at 1500 to 2000 volts d.c. The proper capacity is rather critical, and should be determined experimentally. The optimum value is that which results in least battery current for a given rectified d.c. output from the supply.

Sparking at the vibrator contacts causes r.f. interference ("hash") when such a supply is used with a receiver. This can be minimized by installing hash filters, consisting of RFC_1 and C_1 , in the battery circuit, and RFC_2 with C_3 in the d.c. output circuit. C_1 is usually from 0.5 to 1 $\mu\text{fd.}$, a 50-volt rating being adequate. RFC_1 consists of about 50 turns wound to about half-inch diameter, No. 12 or No. 14 wire being required to carry the rather heavy battery current without undue loss of voltage. C_3 may be of the order of 0.01 to 0.1 $\mu\text{fd.}$, and RFC_2 a 2.5-millihenry choke of ordinary design. Equally as important as the hash filter is thorough shielding of the power supply and its connecting leads, since even a small piece of wire or metal will radiate enough hash to cause interference in a sensitive receiver.

Line-voltage adjustment — In some localities the line voltage may vary considerably from the nominal 115 volts as the load on the power system changes. Since it is desirable to operate tube equipment, particularly filaments and heaters, at constant voltage for maximum life, a means of adjusting the line voltage to the rated value is desirable. This can be accomplished by the circuit shown in Fig. 818, utilizing a step-down transformer with a tapped secondary connected as an autotransformer (§ 2-9). The secondary preferably should be

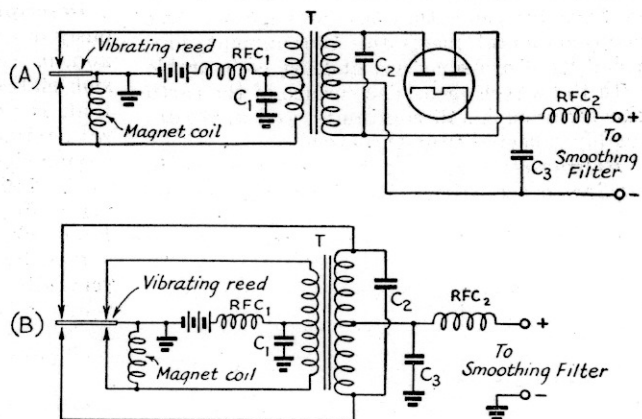


Fig. 817 — Basic types of vibrator power-supply circuits.

tapped in steps of two or three volts, and should have sufficient total voltage to compensate for the widest variations encountered. Depending upon the end of the secondary to which the line is connected, the voltage to the load can be made either higher or lower than the line voltage. A secondary winding capable of carrying five amperes will serve for loads up to 500 volt-amperes on a 115-volt line.