INTRODUCTION TO TRANSMITTER POWER SUPPLIES

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STUDY SCHEDULE NO. 26

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. Primary Power Sources . . . . Pages 1-2

This is a brief discussion of the primary sources from which power is drawn to operate transmitters on land, on shipboard, in aircraft, in automobiles, and on trains.

☐ 2. Filament Power Supplies . . . . Pages 2-8

Here you learn the various factors that must be considered in providing power for the filaments of transmitting tubes, and study the circuits used for the purpose. Answer Lesson Questions 1 and 2.

☐ 3. Grid Bias Power Supplies . . . . Pages 8-16

This section discusses the use of fixed bias, self-bias, and grid-leak bias in class A, class AB, class B, and class C amplifiers. Answer Lesson Questions 3 and 4.

☐ 4. Plate and Screen Power Supplies . . . . Pages 17-25

Here you learn how the high d.c. voltages needed for the plate and screen circuits of transmitters are secured from a.c. power lines. Universal power supplies and voltage multiplier circuits are also discussed. Answer Lesson Questions 5, 6, 7, and 8.

☐ 5. How High-Voltage D.C. Is Obtained from Low-Voltage D.C. Sources . . . . Page 26

This is a brief section outlining the methods that can be used to produce high-voltage d.c. from a low-voltage d.c. source.

☐ 6. Vibrator Power Supplies . . . . Pages 27-33

In this section you study synchronous and non-synchronous vibrator power supplies in detail. Answer Lesson Question 9.

☐ 7. Voltage Regulators . . . . Pages 33-36

This final section discusses various methods used to keep voltages constant in transmitter circuits. Answer Lesson Question 10.

☐ 8. Answer Lesson Questions.

☐ 9. Start Studying the Next Lesson.

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INTRODUCTION TO TRANSMITTER POWER SUPPLIES

Primary Power Sources

TRANSMITTER power supplies differ widely in size, construction, and power-handling ability. In their action, however, they are basically the same: each converts power from some primary source into the voltages and currents needed to operate a transmitter.

This Lesson is your introduction to transmitter power supplies. In it, we shall discuss both the supplies themselves and the primary sources from which they draw power. Since the subject is a big and an important one, it will be continued in later Lessons.

Let's start by studying the various primary sources of power.

LAND SERVICES

The primary power source for most land radio transmitters is the power line of the local electric company. In the United States, this power is generally 60-cycle a.c., although there are limited areas where the supply is d.c. or where the a.c. frequency is 25, 40, or 50 cycles. Transmitting equipment up to 1-kilowatt output is usually located close to a large city and is serviced by a 220/440 volt a.c. system. (The symbol 220/440 means that the power company can supply either of these voltages.) Most of these small transmitters operate from single-phase lines. Higher power equipment, which is generally located some distance from a populated area, is usually supplied by three-phase power at voltages ranging from 2300 to 34,000 volts. These high voltages are usually stepped down to the proper voltages to operate the secondary power supplies through a small transformer sub-station at the transmitter. Many stations whose main source of power is the a.c. line also have engine-driven auxiliary generating equipment for use in case of power failure.

SHIPBOARD SERVICES

On shipboard, the primary source of power is generally the ship's main supply, which is usually 115 or 230 volts d.c. Recently, however, the trend in shipboard electrical systems has been toward the use of a.c., and voltages up to 440 volts have been used.

Since one of the chief reasons for having a transmitter on a ship is to provide a way to send out a distress call, it is required by law that an auxiliary power supply be available in the event of a failure of the ship's main supply. This auxiliary supply is usually a storage battery kept continuously charged, although easy-starting engine-generator sets are coming into popular use.

AIRCRAFT SERVICES

In aircraft services, the primary power source is generally a d.c. system, either 12, 24, or 48 volts. A standard has not as yet been adopted either in military or commercial practice. The equipment is operated from storage batteries, which are kept charged by generators connected to the main engines.

Although most of the other equipment in an aircraft can be operated directly from the low-voltage d.c. line, radio equipment, however, requires higher voltages. These are sometimes furnished by d.c. generators driven by d.c. motors.

The trend, however, is to use a.c., generally 115 volts, 400 c.p.s., to power aircraft radio equipment. This a.c. can be obtained either directly from engine-driven a.c. generators or from "inverters" (d.c. motors that drive a.c. generators), which draw their power from the d.c. lines.

A 115-volt, 400-cycle source is preferable to 12 or 24 volts d.c., because the higher voltage permits the use of smaller cables for connecting the source to the transmitter, and the high frequency permits the use of smaller filter components in the secondary power supplies. For example, a 400-cycle transformer weighs only one-tenth as much as a 60-cycle transformer of equal power-handling capabilities.

AUTOMOBILE MOBILE SERVICES

In police cars, buses, public utility vehicles, taxis, and trucks, power for the radio equipment is taken from the car battery, which is usually a 6-volt type on the smaller vehicles, but may be a 12- or 24-volt type on larger trucks or buses. A heavy-duty battery, kept charged by a heavy-duty generator connected to the engine, is generally used. Instant-heating tubes have been developed that permit the transmitter to be kept ready for operation without a warm-up period, yet place no drain on the battery during stand-by periods.

TRAIN SERVICES

The sources of electrical power on trains are not particularly standardized. Both d.c. and a.c. are used. Generally, a steam train has a 32-volt generator driven by a steam turbine on the locomotive, and Diesel-powered equipment has a 64-volt generator driven by the main driving engines. The voltage output of a steam-driven generator is fairly constant at the nominal 32 volts. The Diesel units, however, may vary from 64 volts while idling to 72 volts at full speed. In the latter instance, the transmitter must be designed to accommodate the wide voltage variation without damage and without serious loss in power.

Filament Power Supplies

The purpose of secondary power supplies is to convert the power from the primary sources to the voltages necessary for the elements of the tubes used in transmitters.

Before discussing the various types of secondary power supplies, we shall see what factors must be considered in providing the voltages and currents to operate the tubes of the transmitter. From the operator's standpoint, these facts should be known so he will have a better understanding of what the meter readings indicate and how the equipment must be operated to prevent costly transmitter failure and interruptions of service. From the installation or maintenance man's viewpoint, these facts will make more clear the reasons for proper maintenance procedures and for the use of the circuits and devices employed in the installation.

The first purpose of a transmitter power supply is to heat the filaments of the tubes in the transmitter. The heated filament then provides the "emission current," which is the sum of the plate, screen, suppressor, and control grid currents. This current is

dependent on the character and temperature of the cathode emitting surface and the voltages on the electrodes of the tube.

The cathode of a transmitting tube may be either directly or indirectly heated. In the directly heated type, the cathode is a filament wire that is heated by current passing through it; electrons are emitted directly from this filament. In the indirectly heated type, a filament (generally called a heater) is heated by a current and, in turn, heats an insulated sleeve or vane coated with electron-emitting material; this sleeve is the cathode that emits the electron stream.

Three kinds of material are used for the filaments of directly heated tubes: a, pure tungsten; b, thoriated tungsten; and c, barium-strontium-calcium oxide-coated metals. The cathode material used depends on the service for which the tube is designed. In general, oxide-coated cathode emitters, both directly and indirectly heated, are used in small, low-power, low-plate-voltage tubes and in mercury-vapor rectifiers. Thoriated tungsten filaments are used in medium-power tubes at medium-high plate voltages (to 3000 watts plate input power) and in very high-plate-voltage rectifiers. Pure tungsten is used in all the large high-power forced-air and water-cooled tubes operating at high voltages.

The filaments of transmitting tubes can be operated from either a.c. or d.c. When a.c. is available, the filament voltage is generally obtained from voltage step-down transformers. When d.c. is used for high power tubes, it is generally obtained from a d.c. motor-generator. A battery source is generally used for low-power tubes.

Voltages used on the filaments of transmitting tubes depend on the design requirements. Only in the case of mercury-vapor rectifiers is the value of the filament voltage uniform, generally 2.5 volts or 5 volts. The reason for using such a low voltage for the filaments of mercury-vapor tubes is that the potential difference between the ends of the filament must be less than the voltage necessary to ionize the gas in the tube. In the case of mercury this voltage is about 15 volts.

TUNGSTEN FILAMENTS

Power supplies for tungsten filament tubes must be designed so that the voltage applied to the filaments of the tubes is kept within a few per cent of the rated filament value. The reason for this is that an increase of only 5% over rated voltage (although it greatly increases the emission current) results in a reduction of 50% in rated tube life.

The resistance of a tungsten filament when it is cold is only one-fourteenth of its resistance when it is hot. For this reason, if the full filament voltage were applied to a cold tube the initial surge of current might be large enough to damage the tube. Thus, when a cold tube is being started, the filament voltage must be increased gradually from a low value to limit the inrush of current to less than 150% of the rated filament current for large tubes and 250% for medium types. Manufacturers give maximum current ratings on starting in the specification sheets for their tubes.

When a filament is operated on d.c., one end of the filament is more negative with respect to the anode (plate) than the other and will supply more electrons. The extra quota of electrons causes an increase in current through this end with a resulting increase in filament temperature and consequent greater emission. This causes a rapid deterioration at the negative end.

Two methods are used to remedy this situation. The current can be equalized in each leg of the filament (the filament for some high-power tubes consists of many strands) by connecting the plate circuit return to the mid-tap of a potentiometer connected across the filament. Some manufacturers recommend a second method, which is to make all circuit returns to the negative terminal of the filament and to reverse the filament connections every 500 hours.

When a.c. is used, the circuit returns should be made to a center tap on the filament or to the mid-point of a potentiometer across the filament terminals. Voltage variations should not exceed 5% on either a.c. or d.c. In multiphase operation, the phase unbalance must not exceed 5%; however, a 15% unbalance may be tolerated during starting.

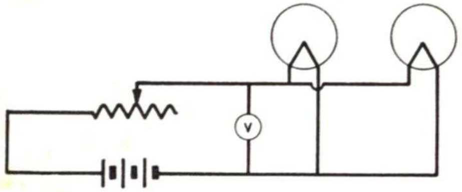


FIG. 1. How a rheostat is used to compensate for the decreasing voltage of a battery used for a filament power supply.

THORIATED FILAMENTS

Thoriated filaments are operated very much as are tungsten filaments. They may be operated from a.c. or d.c. If d.c. is used, the circuit return should be made to the negative filament terminal, and the filament leads should be reversed every 500 hours for longer life. If a.c. is used, the return should be to the mid-point of a potentiometer connected across the filament terminals. The filament voltage must not vary more than 5% from its rating; variation of greater magnitude tends to shorten the emission life. Thoriated filaments are rated at from 5 to 15 volts.

OXIDE-COATED FILAMENTS

Oxide-coated filaments are used in almost all receiving tubes; in certain high-transconductance power tubes; in the smaller sizes of high-vacuum rectifier tubes used in the voltage supplies for low-powered stages of transmitters and receivers; and in all mercury-vapor rectifiers. Except for the tubes designed specifically for battery operation, oxide-coated filaments are generally operated from a.c. Filament voltage regulation is not particularly important as far as tubes using oxide-coated filaments are concerned, except that the voltage applied to mercury-vapor rectifiers should not vary more than 5% from the nominal value.

In an indirectly heated tube it is essential that the voltage between the heater and the cathode be kept as low as possible. Generally the maximum permissible is 125 volts. The cathode or plate return should be connected to the center tap of the heater circuit if a.c. is used, or to either lead if d.c. is used. For best operation, the rated voltage should be applied to the heater; higher voltages materially shorten the cathode life. However, voltages as low as 95% of the rated value may be used on lightly loaded tubes.

► As we have noted, the filaments of transmitting tubes can be operated from either a.c. or d.c. Let us first study d.c. operation.

D.C. FILAMENT SUPPLIES

The simplest method of supplying d.c. power to the filament of a tube is to use a battery. This method is used extensively in portable and mobile transmitters.

Dry Cells. Such devices as the walkie-talkie and other strictly portable units use the primary (unrechargeable) type battery, which consists of one or more "dry cells," to supply the desired voltage and current. Dry cells have a nominal terminal voltage of 1.5 volts. Tubes used in portables are designed to operate from a single cell (1.4 volts), or from two cells in series (2.8 volts) and will operate satisfactorily until the terminal voltage of the cell decreases to 1.2 volts.

In some applications, such as portable field intensity meters, it is necessary to maintain the filament voltage at the nominal value at all times. This is done by using a circuit like that shown in Fig. 1, in which the rheostat controls the current flow and the voltmeter indicates the filament voltage.

Storage Batteries. In mobile transmitters like those used in police cars, aircraft, etc., lead-acid secondary-type (rechargeable) batteries are used. The nominal voltage of each cell of these batteries is 2 volts; they are commercially available connected in series as one unit of 3 or 6 cells giving a nominal voltage of 6 or 12 volts. The tubes used in these transmitters generally have filament voltage ratings of 6.3 or 12.6 volts, so the filaments are usually connected directly across the storage battery.

When a storage battery is being charged, the terminal voltage may increase to as much as 2.4 volts per cell, that is, 7.2 volts for a three-cell battery. A series of receiving-type tubes, also used in the lower power stages of mobile transmitters, has been developed to operate over the whole range of battery voltages (from 6 to 7.2 volts). These are the well-known lock-in tubes—7A4, 7A5, 7A6, etc.

Continuous operation of either a 6.3- or a 7.0-volt tube at its maximum rated voltage will quickly exhaust its useful life. However, in transmitter applications it is the practice to replace such tubes periodically long before their useful lives are over. This is done, in the interests of dependable service.

In one aircraft transmitter in which the filaments are directly connected to the battery, a relay cuts off the charging generator whenever the transmitter is operated. This reduces the filament voltage to the normal battery voltage (6.3 volts) during the time the tube is in actual operation.

When 12-volt batteries are used, the tubes are either 12.6-volt filament heater types or 6.3-volt tubes connected in series by pairs.

In aircraft equipped with 24-volt batteries, 12-volt tubes generally are used in a series-parallel arrangement like that shown in Fig. 2, although one tube manufacturer has developed a complete line of 26-volt tubes.

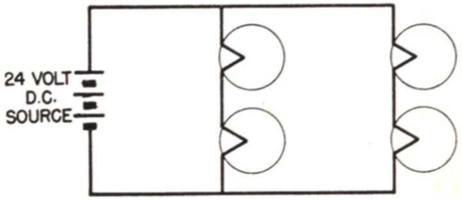


FIG. 2. How the filaments of four 12-volt tubes can be connected in series parallel across a 24-volt source.

In other applications where batteries are used as the primary source of power, such as on trains, pleasure craft, shipboard, etc., the cathode power is supplied indirectly through an inverter and transformer. These methods will be taken up later.

Storage batteries were once used in land stations for power tube filament heating. This method is seldom used today because a.c. operation is more economical.

Batteries are used in portable speech amplifiers to heat the tube filaments. Their cells usually have sufficient capacity to carry on throughout the operating period and are recharged or replaced by a freshly charged battery.

Other D.C. Supplies. In land stations, vacuum tube rectifiers, dry rectifiers (such as the copper-oxide, copper sulfide, and selenium types), and rotary machinery (such as motor generator sets and rotary converters) are used as d.c. filament sources in place of batteries. Although vacuum tube rectifiers can be used, it is more convenient to use dry rectifiers. Their advantages are that they are capable of carrying very heavy currents, are reliable, easily replaced and serviced, reasonably inexpensive, and rugged. They can be connected to the a.c. line several different ways. Half-wave and full-wave bridge circuits for rectifying single-phase power are shown in Fig. 3.

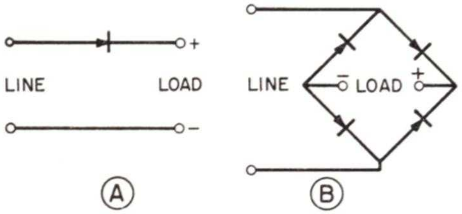


FIG. 3. Two methods of obtaining d.c. voltage from a single-phase a.c. line by means of dry disc rectifiers. In A is shown a half-wave rectifier circuit, in B, a full wave bridge rectifier.

A selenium rectifier consisting of a 4-inch bank of discs 1⅜ inches in diameter, connected as a single-phase bridge rectifier, will give a rated d.c. output of 600 ma. at 90 volts when connected to a 115-volt a.c. line. In both vacuum tube and dry rectifiers the output must be filtered to remove hum.

Selenium rectifiers are also used to provide the direct current used in the high-power stages of a transmitter. To obtain the large currents necessary, the rectifier is made of a number of banks in parallel.

A motor-generator set is frequently used for direct current operation of power tube filaments. The motor may be any type of single-phase or three-phase motor. The generator is usually a shunt-wound d.c. unit with a field control to adjust the output voltage and also to lower the voltage during the warm-up period. The generator is usually large enough to take care of all the power stages.

As an example, the power of the generator needed for a 5-kw. station using four 889 tubes, each of which requires 11 volts at 125 amperes each, is 5.5 kilowatts. To provide reserve capacity, a 10-kw. generator would probably be used. In addition, a duplicate standby generator set would have to be available for emergency use. This means a total installed capacity of 20 kw., which is a distinct disadvantage in view of the investment necessary. Another disadvantage of the motor-generator is the maintenance involved.

A.C. FILAMENT SUPPLIES

Filament heating by alternating current is most generally used in land equipment and on shipboard transmitters because of its simplicity and economy. The desired a.c. voltage is obtained by stepping the line voltage down through a transformer. The filaments of the smaller tubes can be connected to the power source with no warming-up period. However, the filament voltage for the larger tubes is dropped by a series rheostat or by taps on the transformer primary or secondary so that it can be kept constant despite line voltage variations. In some cases the tube filaments in speech equipment are connected in series and directly to the line; a voltage-dropping resistor is added to the filament string if needed. This eliminates a transformer and thereby helps reduce the possibility of hum pickup. We will study transformerless power supplies in greater detail later in this Lesson.

Almost universally, the filaments of rectifier tubes are heated with a.c.

A.C. Hum. In the large transmitting tubes the filament is designed to have sufficient heat retention so that its temperature remains nearly constant even though the amount of current varies throughout the a.c. cycle. Thus the amount of emission current also remains nearly constant and very little hum is produced. The filaments of some of the larger transmitting tubes are arranged so that different strands are heated by different phases of a polyphase source.

To prevent the a.c. filament voltage from producing hum by effectively varying the bias during the a.c. cycle, the grid and plate return leads are connected to a point having the same potential as the mid-point of the filament. This is done either by connecting these leads to the center tap of the filament transformer (Fig. 4A) or by connecting them to the center tap of a resistor connected across the filament leads (Fig. 4B).

Inverse feedback is used in many radio transmitters to reduce the hum produced by a.c. operation. A part of the output r.f. signal is rectified and fed back into the signal. Any hum in the circuit will thus tend to cancel itself.

By these means, the hum level in a broadcast transmitter, even one that uses a.c. on directly heated tubes in several stages, can be kept about 60 db below the 100 per cent modulation level of the transmitter.

Filament Circuit Isolation. In transmitters, especially in the power stages, each stage is supplied by its individual power supply. This is done for three reasons: (1) frequently the filament voltages of the various tubes are not the same; (2) closer control of tube voltages and currents can be maintained with separate metering in each stage; and (3) doing so prevents coupling between stages through the power supply.

To prevent the radio frequency currents from being circulated in the filament power source, a condenser is connected from each side of the filament to the ground circuit as is shown in Fig. 4. The condensers provide a low impedance path for the r.f. currents to ground. They are usually placed as close to the tube filament as possible. In crystal oscillator stages one side of the filament of a heater-cathode tube, such as the 807, is connected to the cathode either directly or through a condenser.

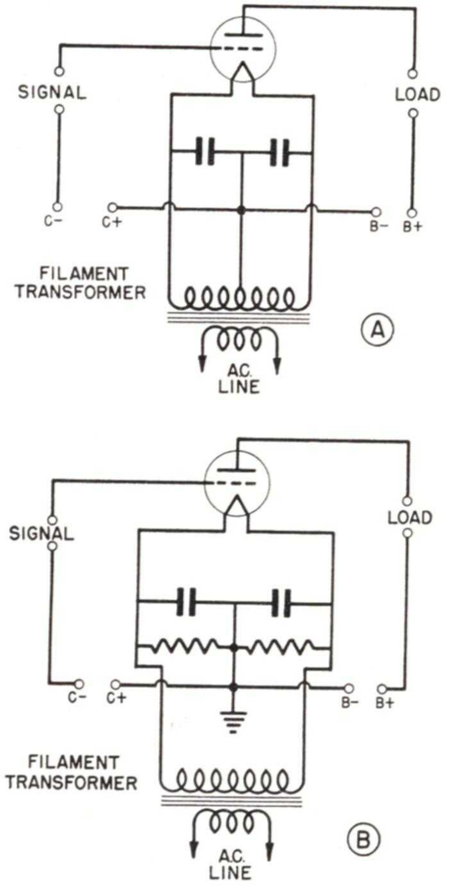


FIG. 4. Methods of preventing hum in transmitter stages using directly heated tubes.

Miscellaneous Methods of Obtaining A.C. for Filaments. On board ship where the transmitter is operated from the ship's d.c. supply, the usual method of generating a.c. is to use a dynamotor (a kind of motor-generator in which the generator windings are wound on the same form as the motor armature). Transformers in the transmitter itself step down the dynamotor voltage to the required value for the filaments of the tubes. Usually the oscillator and buffer stages are fed from one transformer, the output stage (the one usually keyed) from a second one, and the audio and receiver stages from a third.

One kind of marine transmitter uses the 110-volt d.c. ship's supply directly with all the filaments connected in series with a ballast tube.

Shipboard auxiliaries that you may be required to service and maintain are the direction finders. Since these units are of small power, the tubes are almost always wired in series with a ballast tube.

On aircraft using 400-cycle a.c., the same methods of heating the cathode are used as with standard 60-cycle supplies except that greater care is exercised to keep out the hum modulation, because a 400-cycle supply will produce a more audible hum than 60 cycles.

On one military version of an aircraft transmitter, an inverter in the transmitter itself supplies 400 cycles for the high-voltage rectifier, and the filaments of the tubes are connected in a series-parallel arrangement across the 24-volt battery.

Grid Bias Power Supplies

Secondary power supplies must also provide grid bias for the tubes in the transmitter. The grid bias needed for the various tubes used in the transmitter depend on the class of service in which the tube is used. There are four distinct classes of operation (classes A, AB, B, and C) and the grid bias varies for each one of these. Since the subject of grid biasing is tied up with these classes of amplifiers, we will now review them, the biasing required for each, and the practical means of obtaining the bias.

CLASS A GRID BIAS

In a class A amplifier the grid bias is adjusted so that plate current will flow at all times when the signal is impressed on the grid. Ordinarily, the grid is never driven positive and therefore no power is required in the grid circuit and no current is taken from the grid bias supply.

Grid bias for class A operation may be obtained in two ways: (1) from a separate d.c. voltage source, such as a battery or bias cell; and (2) by means of a cathode bias resistor.

Fixed Bias. Practical forms of the first type, known as fixed bias, are shown in Fig. 5. In Fig. 5A the battery used is called a "C" battery. In Fig. 5B a bias cell, which has a long life under open-circuit conditions, is used. This type of cell cannot be used, however, when the grid bias circuit must supply power. The circuit of Fig. 5B, with the bias cell close to the grid, is used extensively in microphone amplifiers because it permits the cathode and input circuit to be at ground potential. Bias cells are available in either 1.0-volt or 1.25-volt types. These cells may be connected in series for higher voltages.

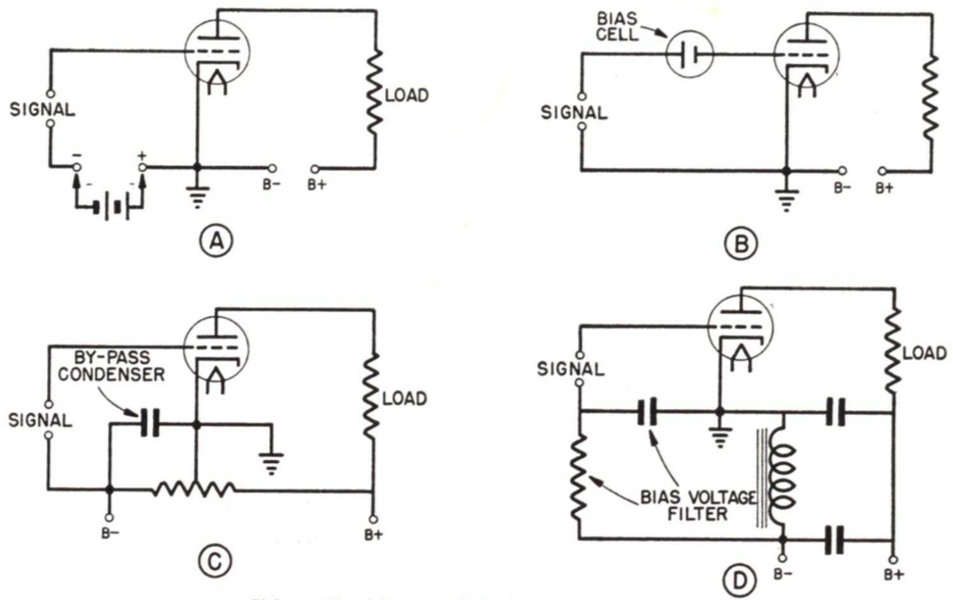


FIG. 5. Fixed-bias methods for class A operation.

A biasing method that uses a part of the plate supply voltage for bias is shown in Fig. 5C. A bleeder resistor across the "B" supply (either a battery or a power pack) is tapped as shown to provide a negative voltage with respect to ground. A grid circuit by-pass condenser is necessary to shunt the alternating grid signal voltage past the section of the bleeder that develops the bias voltage.

When the choke of a power supply filter is placed in the negative power lead, the voltage drop across it (d.c. drop in the choke resistance) can be used for grid bias as shown in Fig. 5D. This practice is not used extensively because a certain amount of ripple is by-passed through the rectifier transformer secondary. This ripple can be reduced by the filter network shown.

Cathode Resistor Bias. Methods of producing cathode (self) bias are shown in Fig. 6. In these circuits, the grid is at ground potential with respect to d.c., and the cathode is raised above ground by passage of plate current through R_c. Since the average plate current does not vary, and does not depend on the signal amplitude, the voltage across R_c will be constant. When the cathode is positive with re-

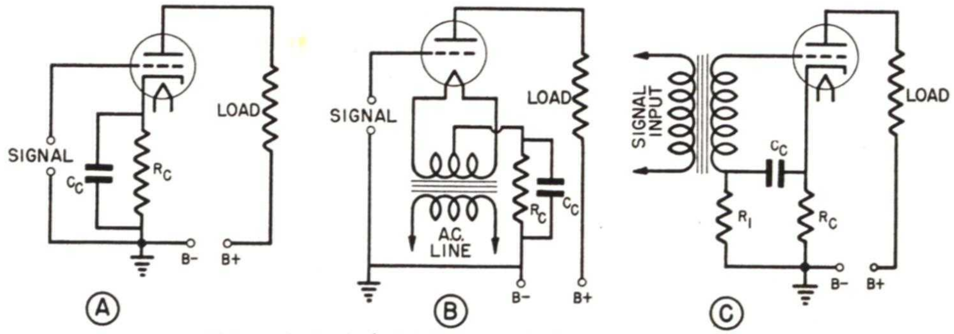


FIG. 6. Cathode (self) bias methods for class A operation.

spect to ground, the grid is negative with respect to the cathode, giving the desired bias.

The voltage furnished by the power supply to the plate circuit must be high enough to equal the desired plate voltage plus the drop in the cathode resistor. In small tubes the cathode drop is insignificant, but it can be rather large in high-power tubes. An 845, for example, requires a bias of 200 volts and a normal cathode-plate voltage of 1200 volts; to use self-bias on this tube, the plate-to-ground voltage would have to be 1400 volts. This is the reason why self-bias is not generally used in high-power class A amplifiers.

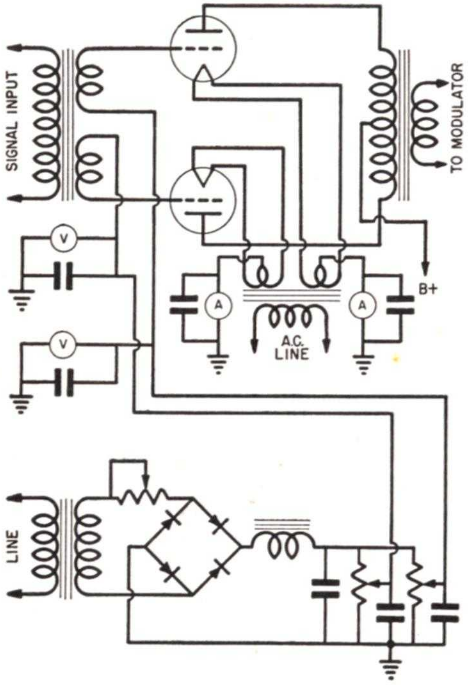


FIG. 7. Dry disc rectifier as a fixed bias for push-pull operation. Note that the two tubes are biased individually. This arrangement can be used for class A, AB, and B operation.

► One of the disadvantages of the circuits in Figs. 6A and 6B is that hum ripple in the plate power supply is applied to the grid. By-pass condenser C_c is supposed to remove such ripple, but it cannot do so completely unless it is an uneconomically large condenser. The circuit in Fig. 6C does not have this disadvantage. In this arrangement, R_1 and C_c act as a decoupling filter; if R_1 is made high in value, the required filtering is obtained with a much smaller condenser than is required with the arrangement shown in Figs. 6A and 6B.

The circuits shown in Figs. 5 and 6 show the bias applied to only one tube. A fixed bias can be applied to more than one stage from a common source. However, when self-bias is used, each stage usually has its own cathode resistor to prevent undesirable interstage coupling.

CLASS AB GRID BIAS

In class AB operation, the grid bias is adjusted so that plate current flows for appreciably more than a half-cycle of signal voltage but for less than the entire cycle. This class of amplifier is divided into two groups—AB_1, in which no grid current flows, and AB_2, in which a grid current flows during the positive peaks.

The grid bias for class AB operation must be obtained from a fixed voltage source. Self-bias from a cathode resistor cannot be used. The reason is that the amount of current in a class AB stage depends on the amplitude of the input signal; therefore, if a cathode resistor were used, the voltage developed across it would vary in accordance with the input signal. Naturally, a varying voltage cannot be used as a bias.

► In transmitters it is usual to adjust the bias individually for each tube as shown in the circuit arrangement in Fig. 7. Each bias-adjusting potentiometer is by-passed by a large condenser to reduce degenerative effects. Although a dry disc rectifier is shown as the fixed bias source in this example, vacuum tube rectifiers, batteries, or motor-generators may also be used.

CLASS B GRID BIAS

A class B amplifier is biased so that the plate current is practically zero when no signal is applied to the grid and flows only during the positive half of each cycle of signal voltage. Since the grids draw current on the positive half of the input cycle, power is taken from the preceding stage and the grid bias supply. Thus the grid bias supply must have good regulation; that is, it must not vary in voltage more than a fraction of a per cent when current is drawn from it.

Bias for Audio Frequency Class B Amplifier. Bias for class B operation in audio-frequency service should always be obtained from a fixed bias source, such as a battery. Bias may be obtained from a rectifier if the output is loaded to give good regulation or is regulated by a vacuum tube or gas regulator tube, methods we will study later in this Lesson. Cathode bias should *never* be used.

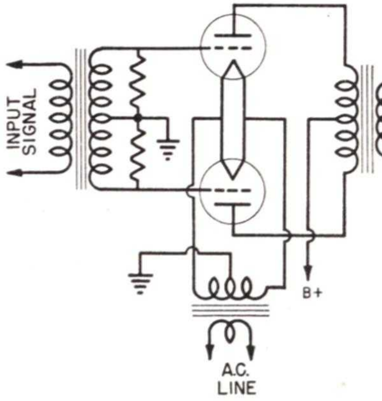


FIG. 8. A class B modulator using zero bias tubes.

Tubes of high amplification factor may be operated with zero bias, thus eliminating the need for a well-regulated supply. The 811, 838, 862, 892, GL146, HY1231Z, RK52, and HY51Z are examples of tubes that can be operated with zero bias for class B operation.

Bias for Radio Frequency Class B Amplifiers. Bias for class B operation in radio-frequency service may be obtained from a fixed source as in audio frequency service or from a cathode resistor by-passed for both audio and radio frequencies (self-bias). (As you learned in an earlier Lesson, the average plate current in a class B r.f. amplifier is constant; therefore, the voltage drop across a cathode resistor in such an amplifier is constant and can be used as a bias). The power supply for fixed bias must have good regulation but not necessarily as good as for audio service. Zero bias tubes for r.f. class B amplifiers have been designed (892-892R); a typical circuit using them is shown in Fig. 8. A typical r.f. class B amplifier using self bias is shown in Fig. 9.

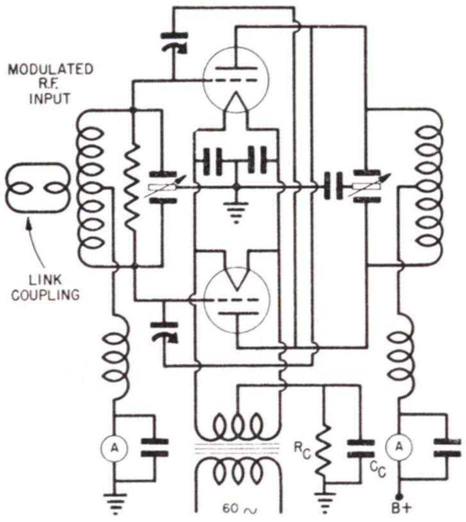


FIG. 9. A class B r.f. amplifier using cathode (self) bias.

We have mentioned the regulation of the grid bias source. Regulation of any rectifier power source is defined as the difference between the no-load output voltage and the full-load output voltage divided by the full-load output voltage. It is generally expressed in per cent. Where E_1 is the voltage output with no load and E_2 is the output voltage under load, the formula for regulation in per cent is:

$$\text{Regulation} = \frac{E_1 - E_2}{E_2} \times 100$$

As an example, let us calculate the regulation of a power supply whose output is 500 volts under no load but drops to 400 volts under load.

$$\text{Regulation} = \frac{500-400}{400} \times 100$$
$$= \frac{100}{400} \times 100$$
$$= 25\%$$

CLASS C AMPLIFIERS

A class C amplifier is biased so that the plate current is zero when no signal is applied and the plate current flows for appreciably less than one-half of each cycle of alternating grid voltage. It should be borne in mind that amplifiers of this class are used only in r.f. amplifier services. The bias is usually set at about two or more times "cut-off" value of plate current. The value of the bias depends on the use to which the amplifier is put; it is higher in plate-modulated amplifiers than in unmodulated amplifiers.

In general, there are three methods of biasing the grid of a class C amplifier. These are: (1) fixed bias, (2) grid-leak bias, and (3) self-bias. You learned in an earlier Lesson that the bias supply of a plate-modulated class C amplifier should be poorly regulated; for this reason, grid-leak bias is preferred in this application. If fixed bias is used, it should also have poor regulation.

For other class C amplifier uses such as in unmodulated stages, the regulation of the bias supply should be good. Either fixed bias or self-bias, or a combination of the two, can be used.

Fixed Bias. The advantage of fixed bias is that the tube is protected against overloading or burn-out in the event of removal of the r.f. excitation. Fixed bias may be supplied from any d.c. voltage source having good regulation, such as a battery, a d.c. generator, or a rectifier. Possible connections between the fixed bias source and the grid circuit are shown in Fig. 10. A radio-frequency choke and by-pass condenser are necessary in the bias lead to prevent the r.f. current from entering the bias supply. If a rectifier and filter are used as the bias source, a bleeder resistor is always connected across the filter output to improve the regulation. One way in which this is done is shown in Fig. 11. As you can see, the bleeder forms part of the return path for the grid current; it must therefore be low in resistance to prevent self-bias.

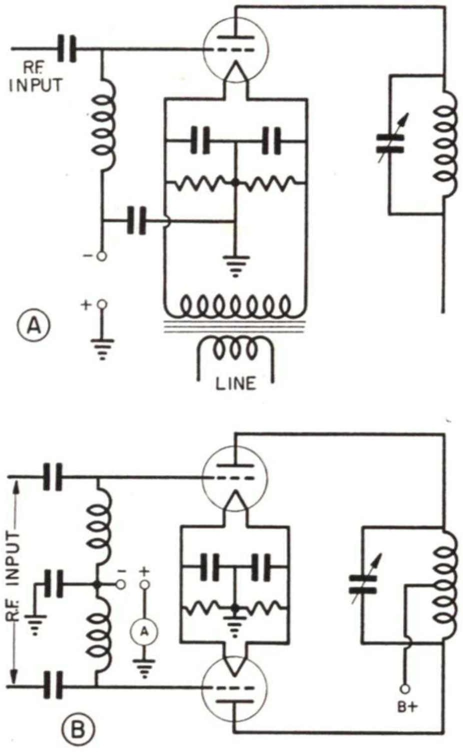


FIG. 10. Examples of fixed bias class C r.f. amplifiers.

Grid-Leak Bias. In grid-leak bias the voltage on the grid depends on the flow of grid current. This means that the stage must be sufficiently excited so that grid current will flow. Failure to provide this excitation would result in removal of the bias and possible burn-out of the tube; therefore, overcurrent relays must be used in the plate or cathode circuit to prevent damage if the excitation fails.

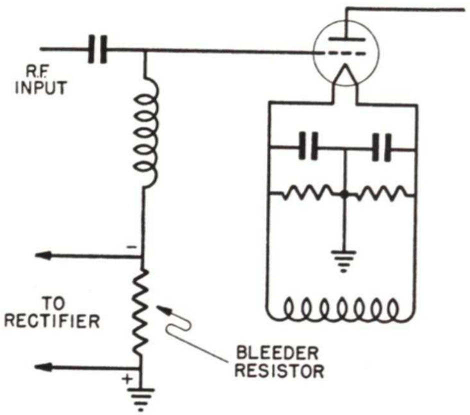


FIG. 11. When a rectifier is used as the bias source, a bleeder resistor is connected across the rectifier output in the manner shown above.

Fig. 12A shows a typical grid-leak-biased class C amplifier. The operation is as follows: when the grid swings positive, grid current flows through grid-leak resistor R_1, producing a voltage drop across it having the polarity shown. The condenser across the grid-leak resistor charges to this voltage. Once charged, this condenser acts as the bias source. It is not a constant-voltage bias source, because it discharges through resistor R_1 to some extent when the grid excitation swings negative; however, the value of R_1 is so high that only a small amount of charge is lost before the signal voltage drives the grid positive again. As soon as the grid becomes positive, grid current flows and C_1 recharges. Thus, we can consider C_1 to be a bias source with poor regulation (that is, one whose voltage varies somewhat during a cycle). As we said earlier, this is the kind of bias source that is desired for a plate-modulated class C amplifier.

Fig. 12B shows an alternate connection that can be used to obtain grid-leak bias; the action of this circuit is similar to that of the one just described.

The grid-leak resistor is usually made variable so that when the tubes are initially adjusted the amount of bias can be varied to give the proper operating point.

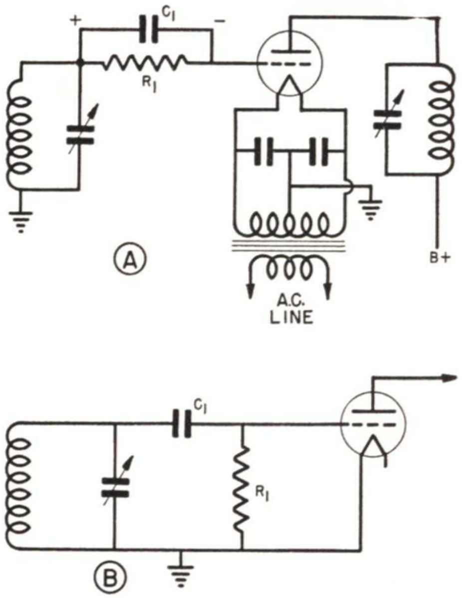


FIG. 12. Two methods of connecting grid bias resistor and condenser in a class C r.f. amplifier.

► This simple method of obtaining grid bias cannot be applied to tubes whose grids emit an excessive number of electrons. A grid may become emissive for either of two reasons—because it is so close to the filament that it becomes hot enough to emit (this is apt to occur in high-power tubes, in which the filaments run at high temperatures); or because, when it becomes positive, it is bombarded so heavily by electrons from the cathode that secondary emission occurs. It is also possible for a combination of these effects to occur.

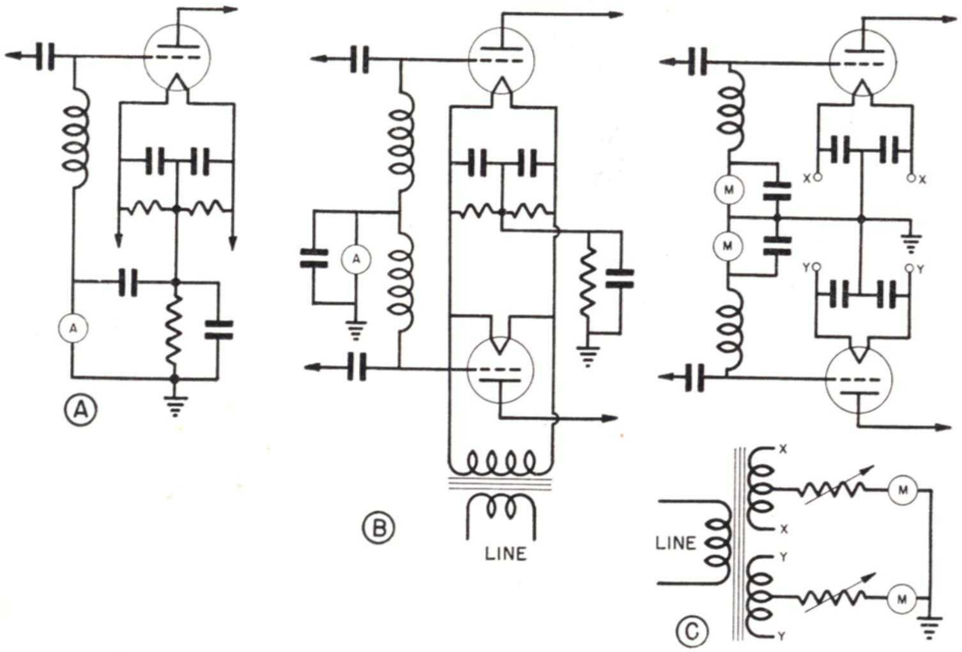


FIG. 13. Cathode bias methods for class C r.f. amplifiers. Note in C that the two tubes may be biased individually.

The result of excessive grid emission is that current flows toward the grid in the grid circuit—in other words, in the direction opposite to that in which it flows in the circuits in Fig. 12. If this reverse flow were to occur in either of these circuits, its effect would be to reverse the polarity of the bias voltage. That is, the grid would become positive with respect to the cathode. This would have the effect of pulling more electrons out of the cathode; in fact, there would very likely be such a heavy drain on the cathode that it would quickly be ruined.

Cathode Bias. The third method of obtaining grid bias for a class C amplifier is to use a cathode resistor. The total tube current—plate, screen (if used), and grid currents—flowing through the resistor builds up a voltage drop that makes the cathode positive with respect to ground. The grid, being at ground potential with respect to the d.c. voltages, is negative with respect to the cathode. The advantage of this system is that it automatically protects the tube against overload currents, since any increase in plate current makes the cathode more positive or the grid more negative.

A disadvantage, especially in class C amplifiers, is that additional plate voltage must be added to make the effective plate-to-cathode voltage the same as in other methods. In class C amplifiers these voltages are sometimes on the order of 1000 to 1500 volts and run as high as 2400 volts.

Typical cathode bias circuits for class C amplifiers are shown in Fig. 13. The cathode resistor must be by-passed for the r.f. currents, and, if the stage is a modulated stage, by-passed for audio frequencies also. Cathode bias is used mostly in r.f. stages; in modulated stages, it is always used in combination with other grid biasing methods.

Fixed bias in combination with grid-leak bias is used to a large extent in high-power plate-modulated class C amplifiers. A typical circuit is shown in Fig. 14A. The amount of fixed bias used determines the maximum loading of the tube in case of accidental failure of the r.f. excitation. For this service, the fixed bias is designed to have poor regulation.

Grid-leak bias is sometimes used in combination with cathode bias. Fig. 14B shows a typical circuit. In this method, if excitation fails, the tube current is reduced to a safe value by the automatic voltage drop across the cathode resistor. Also, this combination method has the advantage that less additional plate voltage need be applied.

Either of the combination methods of securing bias shown in the circuits in Fig. 14 improves the linearity of the plate-modulated amplifier, producing greater fidelity.

► Extensive use of harmonic generators in f.m. transmitters brings about the problem of biasing the grid of class C stages for proper harmonic generation. The bias is generally about 10 times cut-off for a frequency doubler and 20 to 25 times for a tripler. Because of the high grid voltages required, fixed bias sources having good regulation are almost universally used with large tubes; cathode and grid-leak bias are used to some extent with smaller tubes. The circuits are identical with the ones already shown for the various kinds of bias with the exception that the values of the cathode and grid-leak resistance are much higher. With fixed bias, greater control over the harmonic output can be maintained.

MISCELLANEOUS GRID BIAS METHODS

There are two other methods of obtaining grid bias for a tube, called convection current biasing and filament biasing. These methods are generally not used in transmitters but in equipment associated with transmitters, such as portable receivers, field strength meters, and signal generators.

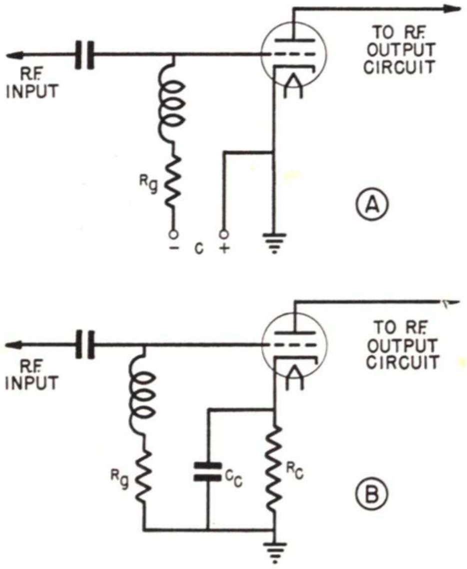


FIG. 14. In A is shown how grid-leak bias is used with fixed bias, in B, with self bias.

Except for oscillators, the majority of these applications operate class A.

Convection Bias. Convection current bias depends on the fact that some of the electrons emitted from the cathode strike the grid. These electrons return through the external circuit to ground (cathode). If the external circuit is of sufficiently high resistance.

a voltage drop will appear across the external circuit and thus bias the tube. In most tubes in which this is practical, the grid resistor must be on the order of 5 to 15 megohms. Fig. 15 shows a typical circuit.

Filament Bias. Since battery-operated equipments can have their filaments in series, it is possible, by making proper connections, to use the filament drops of the various tubes to provide bias. Fig. 16 shows an example. Here, four 1.4-volt tubes are connected in series with a 6-volt battery supplying the filament power; this makes 1.5 volts appear across each tube. Tube VT_1 has a zero bias, since its grid is tied directly to the negative end of the filament (which, in battery-operated tubes, is considered to be the bias reference point). The grid of tube VT_2 is tied to this same point; therefore, it has a bias equal to the drop in the filament of VT_1 or 1.5 volts. Similarly, the grid of VT_3, connected to the negative filament terminal of VT_2 is biased at 1.5 volts. The grid of VT_4 is connected to the negative filament terminal of VT_1, and therefore has a bias equal to the sum of the drops in the filaments of the other tubes, or 4.5 volts.

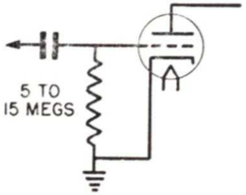


FIG. 15. Method of obtaining convection current bias.

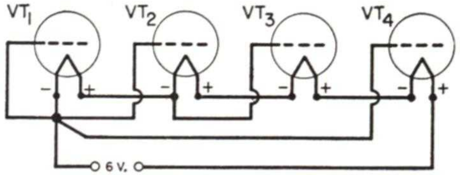


FIG. 16. The filament voltage in series connected tubes can be used to obtain various amounts of grid bias for the different stages.

Plate and Screen Power Supplies

The third purpose of transmitter power supplies is to provide the high d.c. voltage needed in the plate circuits and screen grid circuits of the transmitter. Let's see what is needed and how it is supplied.

SCREEN GRID SUPPLIES

Before we begin our discussion of the various types of power supplies for plate and screen circuits, let us review the use of screen grid tubes (tetrode, pentode, and beam power tubes) in transmitters and the requirements of screen grid supplies. A five-element tube connected as a pentode is used in the following classes of service:

audio—classes A, AB_1, AB_2
r.f.—classes B and C

Five-element tubes connected as tetrodes and pentodes are used as follows:

audio—little, if at all, nearly always supplanted by pentodes.
r.f.—classes B and C

In class A audio amplifiers the operating voltage for the screen grid is usually obtained either through a series resistance from the anode power supply, as shown in Fig. 17A, or from a voltage divider across the anode power supply, as shown in Fig. 17B. In each case a suitable by-pass condenser is connected between the screen and cathode.

In class AB_1 and AB_2 amplifiers the screen voltage is obtained in the same manner as in class A.

The power rating of the series screen-voltage dropping resistor should always be in excess of the power dissipated in it. When a potentiometer is used across the plate power supply to furnish the proper screen voltage, the amount of power dissipated in it is usually about five times that required by the screen; this is done to provide better voltage regulation. Designers sometimes resort to an existing voltage drop in a filter to supply screen voltages, especially in class AB or AB_2. An example of this is shown in Fig. 18.

In class B r.f. service the screen voltage is preferably obtained from a separate source of power. In the smaller tubes, however, it may be obtained from a voltage divider across the plate supply.

In class C r.f. service the type of screen voltage applied depends on whether the stage is a plate-modulated, screen-modulated, or straight class C stage used in telegraphy. Most tube manufacturers recommend that fixed screen voltages be used in class C power amplifiers and oscillators and that series-dropping resistances from the anode supply be used in plate-modulated set-ups.

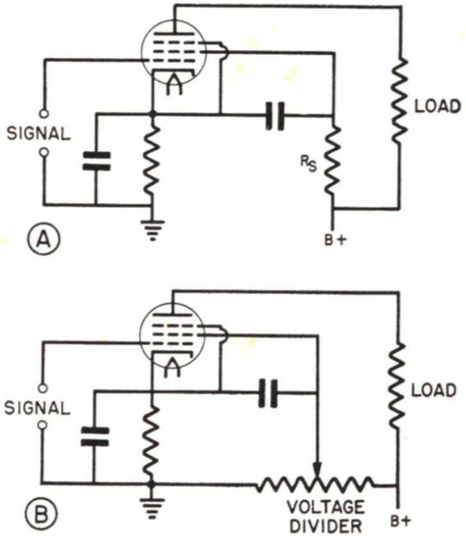


FIG. 17. Methods of obtaining screen grid voltages.

SUPPRESSOR GRID SUPPLIES

In nearly all audio circuits, the suppressor is operated at cathode potential. There are a few designs using cathode bias, however, in which the suppressor is connected to ground and therefore operates slightly negative with respect to the cathode.

In class B r.f. amplifiers, the suppressor is sometimes operated at a positive voltage.

HIGH-VOLTAGE D.C. FROM A.C. SOURCES

Before the advent of mercury-vapor tubes, a motor-generator set was commonly used to supply d.c. for the various tubes of the power stages of the transmitter. Some installations had two or even three generators connected to the driving motor to supply the various potentials required by the transmitter. These motor-generator sets were very satisfactory on two counts: they supplied almost ripple-free voltages that required little or no filtering, and they seldom needed replacement. However, they were expensive in initial cost and upkeep, and their commutators and brushes gave considerable trouble. A few older stations still have these generators.

RECTIFIER POWER SUPPLIES

The use of rectifiers to convert a.c. to d.c. has become practically universal in transmitter installations operating from a.c. primary sources. There are four types of rectifiers: (1) high-vacuum thermionic (kenotrons), (2) hot-cathode mercury vapor (phanotrons and thyratrons), (3) mercury-arc (ignitrons), and (4) dry-disc (copper-oxide, selenium, and copper-sulphide). Each has particular uses for which it is best suited.

High-vacuum thermionic types are used for small power supplies furnishing d.c. voltages up to 500 volts and current up to 125 milliamperes. These tubes are usually used as full-wave rectifiers for oscillators and low-power audio stages of transmitters.

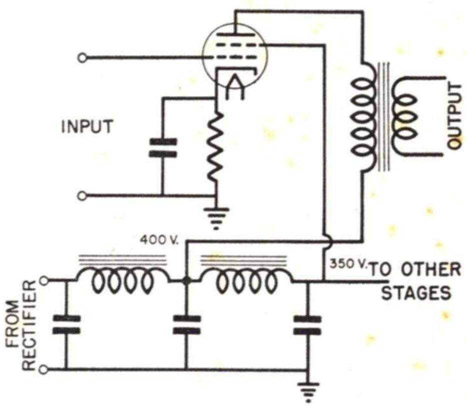


FIG. 18. The voltage drop across a filter choke can be utilized to obtain the proper screen grid voltage for a tube.

The hot-cathode mercury-vapor rectifiers are used where d.c. voltages from 500 to 20,000 volts and currents up to 30 amperes are needed. Mercury-vapor tubes are also generally used whenever power supply regulation is important, because, in contrast to high-vacuum rectifiers, the voltage drop in a mercury-vapor tube is very low due to the ionization of the vapor in the tube. This ionization action that occurs in a hot-cathode mercury-vapor rectifier tube also permits high conduction currents to flow.

Mercury-arc or pool-cathode rectifiers are adapted for industrial uses in which high current at comparatively low voltage is required. Ignitrons are not as yet used in transmitting equipment.

Dry-disc rectifiers are used in transmitters to some extent for low-voltage supplies, such as grid bias supplies.

Various types of rectifier connections are shown in Fig. 19. The single-phase half-wave circuit is seldom used because considerable filtering is necessary to filter the d.c. output adequately. Also the d.c. flows through the secondary winding in this circuit, allowing magnetization of the core.

The most popular rectifier circuit for single-phase sources using either high-vacuum or mercury-vapor tubes is the single-phase full-wave circuit shown in Fig. 19B.

The bridge circuit of Fig. 19C is frequently used in high voltage power supplies because the voltage output of a bridge circuit is double that of a full-wave rectifier for a given transformer. Notice that the bridge circuit, however, requires four rectifier tubes and two additional filament transformers. This circuit is used almost exclusively in dry-disc type rectifiers, where no filament transformers are required.

Polyphase rectifier circuits are used where the d.c. power required is 1 kw. or more. Because of the extra tubes and transformers necessary, it is not economical to use polyphase circuits in low-power supplies. One of the advantages of a polyphase rectifier is that the output requires less filtering than that of a single-phase system. This advantage is very important, for it is costly to filter large amounts of d.c. power.

Several types of polyphase power supplies are shown in Fig. 19D to 19H inclusive. The circuits of Figs. 19E, 19F, and 19G are designed to operate

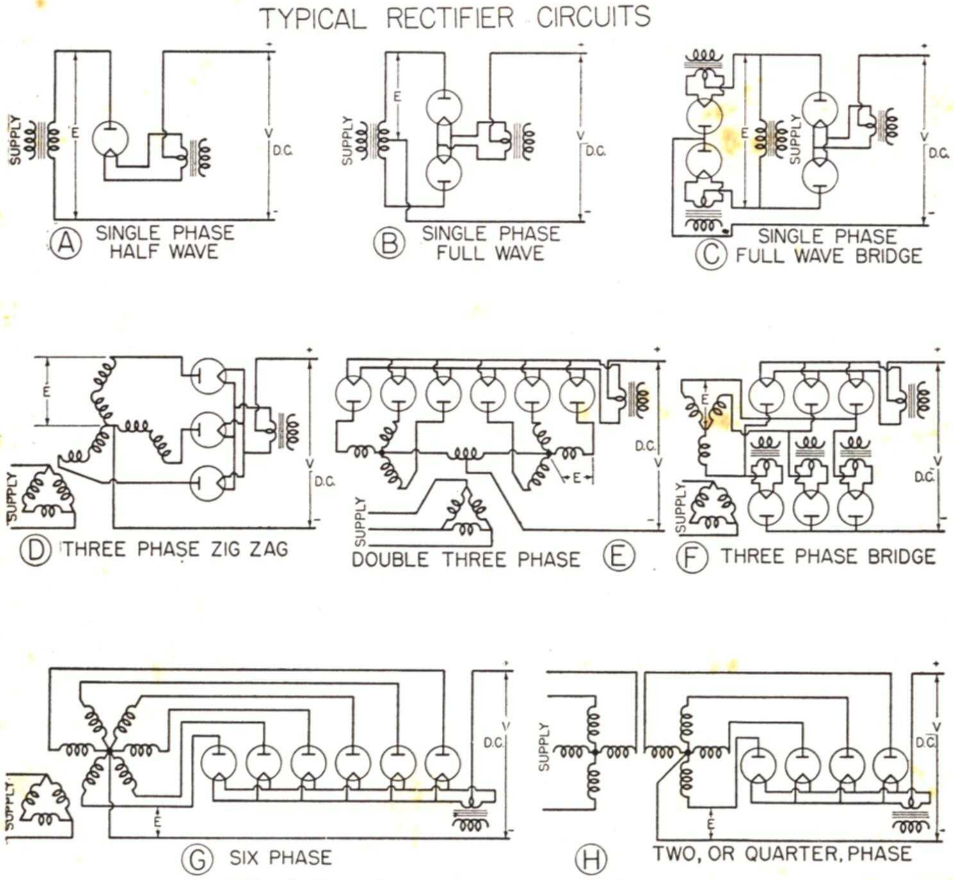


FIG. 19. Several types of transmitter rectifier circuits.

from a three-phase a.c. supply; the circuit of Fig. 19H is used where a two- or four-phase source is available.

The operation of these polyphase rectifier systems is a very important subject; however, since a later Lesson is devoted to it, we will not go into their operation at this time.

A high-power transmitter generally has polyphase rectifier systems for the modulator and final r.f. stages, single-phase, full-wave rectifier circuits using mercury-vapor tubes for the intermediate stages, and high-vacuum rectifier circuits for the oscillator and low-level audio stages. To balance the load on the incoming power line, the single-phase circuits are connected across different phases.

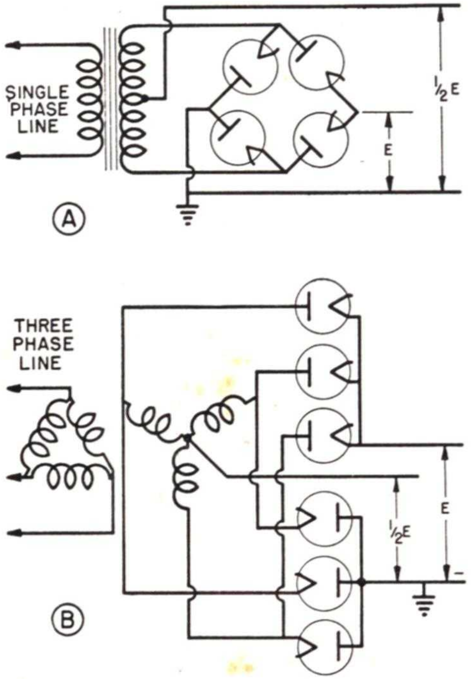


FIG. 20. Combination power supplies that provide two different voltages at the same time from a single transformer.

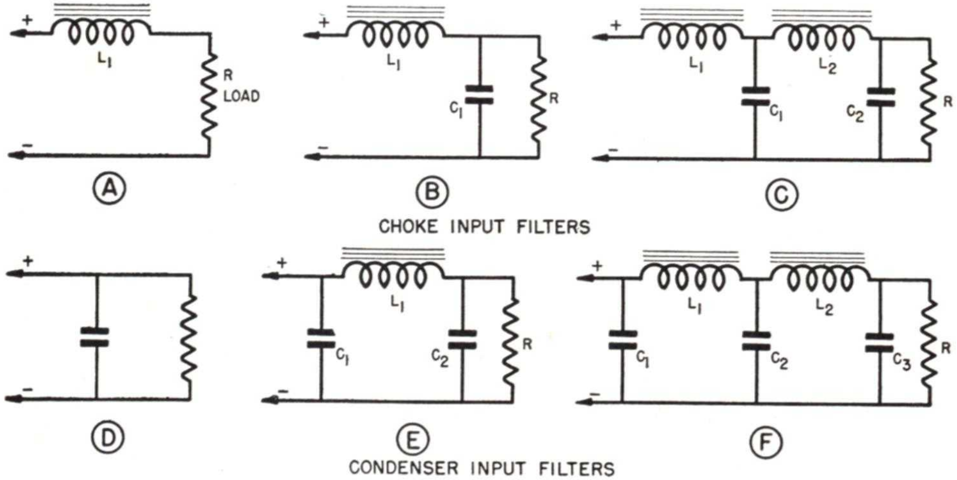
It is often desirable to have two voltages available from one power supply—a fairly low voltage for use in the intermediate stages of a transmitter and a higher voltage for use in the final stages. Of course, it is possible to use a voltage divider network to provide the two voltages. However, since considerable power loss occurs in such a network, the more economical arrangements shown in Figs. 20A and 20B are generally used instead.

The circuit of Fig. 20A combines the full-wave bridge circuit of Fig. 19C with the full-wave center-tapped arrangement of Fig. 19B. The output voltages developed are in a ratio of 2-to-1. In a similar manner the arrangement of Fig. 20B uses the three-phase bridge star connection of Fig. 19F to give two output voltages, one of which is twice the other.

Filters. Each of the rectifier circuits we have studied has a pulsating d.c. output—that is, its output consists of a d.c. voltage plus an a.c. ripple. This ripple is most predominant in the single-phase half-wave circuit and least noticeable in the polyphase circuits using six tubes; even in the latter, however, the amount of ripple is usually too great to be tolerated in transmitters, so some means must be used to reduce it. Filter systems are used for this purpose.

Filters are designed for specific purposes and are not interchangeable. For instance, a filter designed for a three-phase bridge cannot be used with a single-phase full-wave circuit.

Filters can be divided into two classes: (1) those having an inductance (choke) input, and (2) those having a condenser input. Fig. 21 shows the basic types of commonly used filters of both classes.



CHOKE INPUT FILTERS

CONDENSER INPUT FILTERS

FIG. 21. Commonly used filter circuits.

Filters with choke inputs are always used in polyphase rectifiers because these filters utilize the tubes and transformers more effectively than do condenser input systems. Choke input filters also have much better voltage regulation than do condenser input filters, and are therefore always used in applications in which the demand on the power supply varies.

Graded filters in which various output voltages are taken from different points in the filter network are sometimes used in equipment associated with radio transmitters. Fig. 22 shows a typical speech amplifier power supply filter circuit using a multisection graded filter.

► Filters are used to remove the commutator ripple from d.c. generators and dynamotors. The amount of ripple, however, is generally much less than that of the a.c. power supplies we have studied, so very simple filters suffice. You will learn more about d.c. generators in another Lesson.

TRANSFORMERLESS POWER SUPPLIES

The chief use of transformerless power supplies is in inexpensive radios. They are also used, however, in some transmitting equipment, so we will study them here.

The transformerless power supply in its most simple form is shown in Fig. 23. Note that the power line connects directly to the rectifier tube, eliminat-

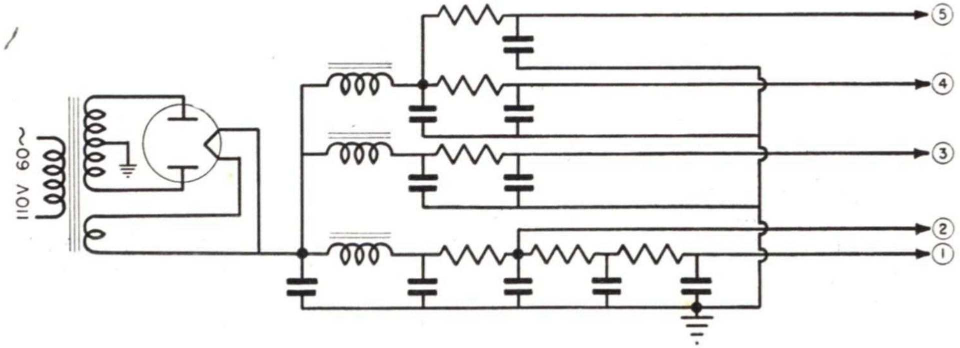


FIG. 22. Western Electric type 23C speech amplifier power supply, and filter. Note that each of the five outputs are individually filtered.

ing the power transformer. This is done in midget receivers primarily to reduce costs; in broadcast equipment, the chief reasons for dispensing with a transformer are to reduce weight and to minimize the possibility of hum pickup in low-level amplifiers for remote control pickups.

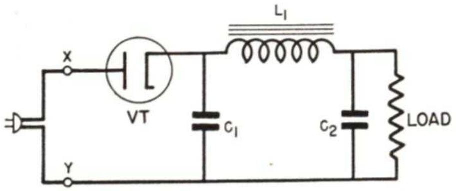


FIG. 23. Basic transformerless power supply circuit. The inductance L_1 may be a speaker coil.

The circuit in Fig. 23 is a standard half-wave rectifier with a condenser-input filter. The choke used may be replaced by the field coil of a speaker or by an R-C network. (The latter arrangement is often used in broadcasting equipment to reduce hum.) The high-capacity condensers that are now available (several hundred microfarads at 150 volts) produce very efficient filtering from a simple R-C circuit.

A large electrolytic input condenser draws a very high current while it is charging up when the unit is first turned on. In power supplies operating from transformers, the initial current is limited to some extent by the voltage drop in the transformer windings; however, since the universal pack is connected directly to the primary power source, these initial currents may be so high that the tubes are ruined. To prevent this, a 20 to 30-ohm resistance is placed in series with the tube cathode. This limits the peak current to less than 2 amperes.

Since the usual line voltage is 117 volts r.m.s., the peak voltage across the input filter condenser C_1 is 1.4 times this value, that is, 164 volts. Under no-load conditions, the d.c. voltage across C_1 in Fig. 23 will be practically this voltage. However, as Fig. 24 shows, the voltage output decreases under load. The larger the value of the input filter condenser C_1, the better the regulation of the power supply. Notice, however, that the output voltage is limited to only a little more than 100 volts under normal load conditions.

So far we have considered the operation of a transformerless power supply when a.c. is applied to it. Let us investigate what occurs when such a power supply is connected to d.c. line. Assume that we connect the cord plug to the d.c. receptacle so that terminal X in Fig. 23 is connected to the positive side of the line. The rectifier tube will then conduct and the set will operate as usual. The filter will remove any ripple in the d.c. voltage source.

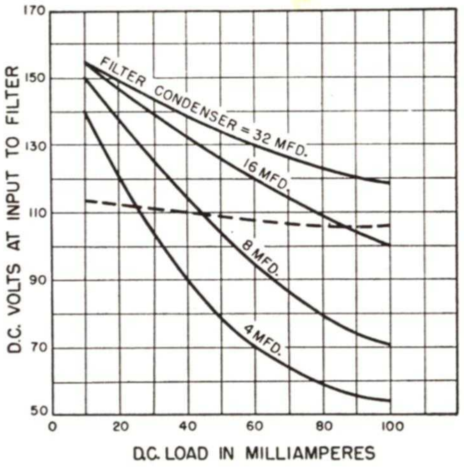


FIG. 24. Regulation curves for the universal power supply.

Suppose, however, that the line cord is plugged into the receptacle with terminal X connected to the negative side of the line. Because the plate of the rectifier is negative with respect to its cathode, no current will flow through it, and the set will be inoperative. It is necessary to reverse the plug for proper operation. Because this type of power supply can operate from either a.c. or d.c., it is sometimes called a "universal power supply."

The dotted line in Fig. 24 shows the regulation of a universal power supply when it is connected to a 117 volt d.c. line.

Filament Supply in Universal Power Supplies. In a transformer power supply, the proper filament voltage is obtained from a winding on the transformer. When a universal supply is used, however, some other method of securing filament voltage must be chosen.

The filaments of the tubes fed by a universal power supply designed for operation from a 115-volt line, are generally connected in series, as shown in Fig. 25. If the filaments of the five tubes draw 0.3 amperes at 6.3 volts, the total voltage drop across them should be about 32 volts. The portion of the line voltage applied to the tubes can be reduced to this value by connecting a 280-ohm resistor in series with the line, as shown. Then the voltage drop across this resistor will be 85 volts and the voltage drop across the tubes will be the desired 32 volts. The power loss in this series resistor is 25 watts. The resistor may be either a line cord resistor or a ballast tube.

Manufacturers have developed a series of low-current-drain, high-voltage tubes in regular and miniature sizes. A properly chosen series of these tubes can be connected directly across the 115-volt line without the need for a series resistor. For example, equipment containing a 35Z5 (rectifier), a 50L6 (power tube), a 12SA7 (converter), a 12SQ7 (diode-triode), and a 12SK7 (remote cut-off amplifier) connected in series would require no series resistor, for the total filament drop of these tubes is 121 volts.

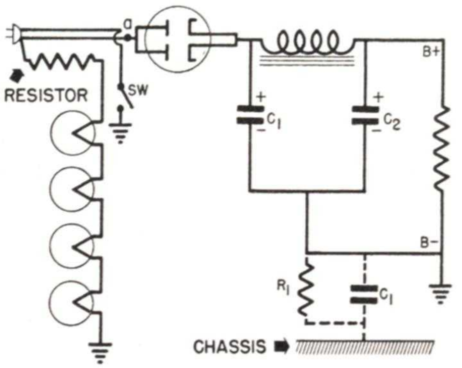


FIG. 25. Series operation of filaments in a universal power supply. In practical circuits of this type, you may find a protective resistor in series with the rectifier plates; also, there may be a speaker field connected across input filter condenser C_1.

Switch SW in Fig. 25 (the ON-OFF switch of the set) is shown as opening the filament and B supply circuits simultaneously by opening one side of the power line. Notice that one end of the switch, one end of the filament string, and the B— terminal are shown going to ground terminals; that is, all three are connected together electrically. The metal set chassis should not be used as this common ground point, because one side of the power line is usually grounded, and, if the line plug were put into a wall receptacle the wrong way, the chassis would be 115 volts a.c. above ground. This is very dangerous; it could produce a serious or even a fatal shock if the operator were standing on wet concrete or other ground and accidentally touched the set chassis. Therefore, the Underwriters Code requires that the chassis not be an electrical part of the circuit in such a set. Instead, points marked with a ground symbol are connected by a wire (often called a "bus"). If the chassis has electrical significance in the circuit, it is indicated by a different symbol, as shown in Fig. 25. Here the chassis is connected to the ground bus by a condenser and resistor combination C_1 and R_1.

VOLTAGE MULTIPLICATION

In the universal transformerless power supply, the maximum voltage obtainable is about 85% of the line voltage (about 100 volts for a 115-volt line). This voltage is often not sufficient for proper operation of reliable, high-fidelity studio and remote equipment; and yet we wish to dispense with the power transformer because of its extra weight and because it may pick up hum. The problem can be solved by using a circuit that will double, triple, or quadruple the d.c. voltage available for a given line voltage.

Let us first study a basic voltage doubler circuit. If we can charge two condensers, then put them in series so that the positive plates of one condenser are connected to the negative plates of the other condenser, the voltage of the combination will be the sum of the individual voltages of the condensers. The full-wave voltage doubler shown in Fig. 26 operates in this manner.

The circuit consists essentially of two half-wave rectifiers with their a.c. inputs connected in parallel and their d.c. outputs connected in series. The easiest way to understand its operation is to trace the flow of electrons.

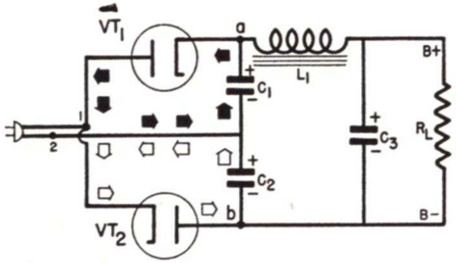


FIG. 26. This circuit doubles the line voltage without using a transformer.

Assume point 2 to be negative with respect to point 1. There are two possible paths for electron flow between point 2 and point 1, C_1-VT_1 and C_2-VT_2. However, when point 2 is negative with respect to point 1, electrons cannot flow through VT_2 because they cannot flow from plate to cathode. Instead, electrons flow into condenser C_1, charging it with the polarity shown. The flow continues through VT_1 from cathode to plate to point 1. This circuit is shown by black arrows.

When the a.c. line polarity reverses, electrons that leave point 1 cannot flow through VT_1, but pass through VT_2, charge condenser C_2 to the polarity shown, and return to point 2. This circuit is shown by the outline arrows.

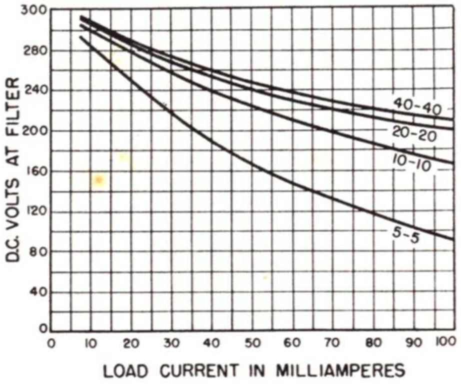


FIG. 27. The regulation of a full-wave voltage doubler.

If no load were connected across points a and b, the total voltage across these points would be the sum of the voltages across the individual condensers, or, in this case, twice the peak line voltage (whence the term *voltage doubling*). However, when a load is connected to the circuit one condenser discharges while the other one is charging, so the output is less than double. The actual voltage across the load depends on the size of the condenser and the current drain.

Fig. 27 shows the volt-ampere characteristic of a full-wave voltage doubler using condensers C_1 and C_2 of equal capacity. Curves are shown for values of 5, 10, 20, and 40 microfarads for each condenser. 16 microfarads is the minimum capacitance recommended for practical power supplies.

Notice that in the full-wave doubler circuit there is a voltage difference between either output terminal and either input terminal. Since one side of the a.c. line is generally grounded, this means that the d.c. output cannot be grounded. This is a disadvantage in many circuits.

Half-Wave Voltage Doubler. The half-wave voltage doubler circuit in Fig. 28 overcomes this disadvantage, because one terminal of the output voltage is connected to one side of the input a.c. line.

Let us see how the half-wave doubler operates. Assume that point 2 is negative with respect to 1. Electrons will flow from point 2 into condenser C_1, charging it to the peak of line voltage with the polarity shown, then flow to point 3, through VT_1, and back to point 1. (Electron flow is blocked by VT_2 because the plate is negative.) This electron path is shown by the outline arrows. When the cycle reverses, electrons flow from point 1 into condenser C_2 through VT_2, into condenser C_1, and back to point 2. (This time, the path through VT_1 is blocked.) However, since C_1 was already charged to the peak line voltage, the voltage across it is added to the line voltage; thus the voltage across C_2 after the first complete cycle is approximately twice the peak of the a.c. input voltage. Again the output is not exactly double, because C_2 discharges into the load during the entire cycle.

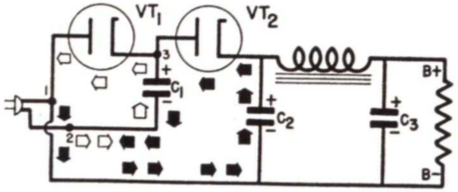


FIG. 28. The half-wave voltage doubler.

Since the current passes through C_2 only on alternate half cycles, this circuit is defined as a half-wave rectifier. This circuit has slightly poorer regulation than the full-wave doubler has, but in many applications the advantage of a common connection between the input and output circuit outweighs this.

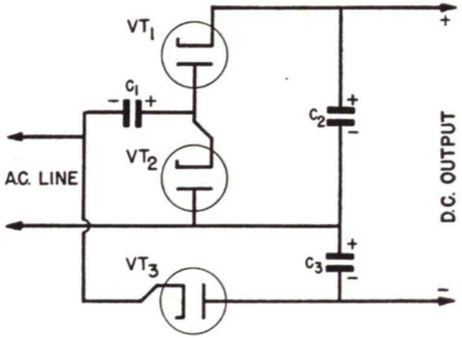


FIG. 29. Voltage tripler circuit.

This principle of individually charging condensers that are connected in series can be further extended to obtain still higher voltages. For example, Fig. 29 shows how a half-wave doubler can be combined with a half-wave rectifier to form a voltage tripler circuit. VT_1, VT_2, C_1, and C_2 form the voltage doubler and VT_3 and C_3 the half-wave rectifier. The voltages across C_2 and C_3 combine to provide a voltage output three times the peak line voltage.

► Notice that voltage multipliers can be operated on a.c. only. No output will be obtained if they are connected to a d.c. power line.

How High-Voltage D. C. Is Obtained from Low-Voltage D. C. Sources

In land installations where d.c. is the only primary source, and on shipboard, in aircraft, and in automobiles, where the primary source is a battery, there are three methods of changing the low-voltage d.c. to the high-voltage d.c. necessary for the operation of the plate circuits of transmitters. These methods are: (1) a d.c. motor driving a d.c. generator; (2) mechanical vibrator systems; and (3) a d.c. motor driving an a.c. alternator. In this last case the a.c. output is transformed to higher voltage a.c. and rectified and filtered to obtain the desired d.c. voltage.

Let us consider examples of these systems. In a typical shipboard installation, a motor operating from the 110- or 220-volt d.c. ship's power line is used to drive a 500-cycle alternator and a 1000-volt d.c. generator to operate a 200-watt transmitter. Power for the low-voltage stages of the transmitter is obtained from the 500-cycle alternator, the output voltage of which is fed into a transformer, stepped up, rectified, and filtered. The 500-cycle frequency is used in the a.c. power supply for two reasons: (1) rectifier-filter systems can be constructed of smaller and lighter weight components than would be needed if the frequency were lower, and (2) an available source of modulating voltage is on hand for modulated continuous-wave telegraphy. The power for the final and buffer stages is obtained from the d.c. generator. Emergency service is supplied from a 60-volt storage battery with a dynamotor that has a 110- or 220-volt d.c. output to operate the regular generator set in case of failure of the ship's d.c. supply.

Another commonly used marine transmitter merely uses a d.c. motor and d.c. generator with slip rings on the motor so that it also operates as an a.c. source to supply filament power. The lower voltage d.c. required for stages other than the final output are obtained from voltage dividers.

A typical aircraft transmitter operates from a 28-volt battery or engine generator and has two plate voltage supplies furnished by dynamotors, one a 500-volt supply for the receiver and transmitter oscillator and a 1050-volt supply for the final and buffer stages. A recent trend in aircraft units is to supply a.c. from a 400-cycle, 115-volt a.c. generator operated by a 28-volt d.c. motor. The a.c. is stepped up as required, rectified, and filtered with light-weight 400-cycle units. The generator supplies power for several of the radio frequency units on board the plane, such as the direction-finder, the homing device, the blind landing systems, the beacon radio and transmitter, and the voice receiver.

On an automobile, train, or other vehicle in which a battery is the primary power supply, power for the receiver and low-power stages of the transmitter is obtained from a vibrator power supply, and power for the final stages of the transmitter is obtained from a dynamotor that operates when the "push-to-talk" button on the microphone is pressed or the microphone is lifted from a hook. The primary power source is kept charged by an engine-driven generator while the vehicle is running; when not running, the battery reserve will operate the equipment.

Vibrator Power Supplies

Transmitter-receiver installations on police cars, aircraft, and other mobile equipment depend, as we just said, on low-voltage storage batteries for their operation. The voltage output of such a battery is adequate for filaments but seldom high enough for plate operation. Early installations used "B" batteries, but the development of the vibrator step-up system has now made them unnecessary. Let us see how a vibrator power supply works.

As you know, there will be no voltage induced in the secondary of a transformer if a battery is connected to the primary, because d.c. produces no changes in flux linkages. However, if we start and stop the current in the primary, a pulsating flux will be set up and a voltage will be induced in the secondary. As you will recall from your study of coils, when d.c. is first applied to a coil, the current builds up rapidly (not instantaneously, as in a resistor) from zero to a steady value. The flux linkages change as long as the current changes. If the circuit is then opened, the current flow is interrupted instantaneously and again the flux linkages change, this time in the opposite direction.

Suppose, for example, we connect a storage battery to the primary of a transformer through a switch as in Fig. 30A. When the switch is first closed, current will flow through the primary; the resultant change in flux linkage will induce a large voltage across the secondary, as shown by 1-2 in Fig. 30B. The primary current will rise rapidly until it reaches its maximum value (determined by the resistance of the wire with which the transformer primary is wound), then remain constant until the circuit is broken. When the primary current becomes constant, the secondary voltage will drop to zero (2-3) and stay there, since voltage is induced only when there is a change in flux linkage.* When the primary circuit is opened, the current will cease flowing and the magnetic field of the coil will quickly collapse. This will cause other change in flux linkage, this time in the opposite direction, and a secondary voltage pulse will appear, as shown by 4-5-6 in Fig. 30B. This voltage will also drop to zero when changes in flux linkage cease.

By using a step-up transformer and repeating this opening and closing regularly, we can get a series of alternate pulses from the secondary with high peak voltages.

From this, you can see that d.c. voltage can be stepped up with a transformer and changed into a.c. voltage if the primary circuit of the transformer is opened and closed fast enough with a switch. This allows the d.c. to flow in pulses that rise from zero to maximum and then decrease to zero again. Of course, if we could make the d.c. reverse in the primary, we would get more a.c. secondary pulsations, closer together—and thus obtain a greater a.c. output average. This is what happens in a vibrator power supply.

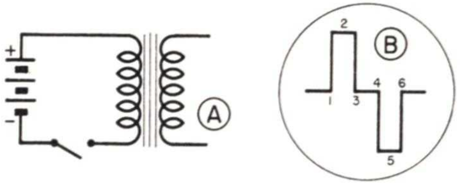


FIG. 30. A.C. can be produced by regularly interrupting a d.c. circuit.

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* The primary current would probably be great enough to burn out the primary winding, if allowed to flow long.

FULL-WAVE VIBRATORS

Fig. 31A shows how we can make the d.c. reverse. Notice that the primary is center-tapped. One battery terminal is connected to this tap; the other battery terminal is connected to a switch arm that can be connected to either outside primary lead.*

Suppose the switch is thrown from position X to position Y. When the contact at X is broken, the current through P_1 drops to zero, as shown by line 1-2 in Fig. 31B. During the time it takes the switch arm to travel to position Y, the primary current remains zero. Then, as the switch arm makes contact at Y, we have current flow 3-4 through P_2.

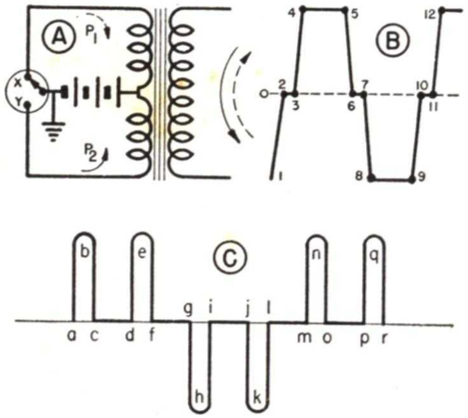

FIG. 31. Double voltage peaks are produced by using a full-wave interrupter.

Since current flows in opposite directions through the windings P_1 and P_2, a decreasing current in one produces a flux in the same direction as an increasing current in the other; therefore, the flux linkage change produced by current 1-2 decreasing through P_1 is in the same direction as the flux linkage change produced by current 3-4 increasing through P_2. The change 1-2 produces a secondary voltage pulse like a-b-c in Fig. 31C. Then the change 3-4 produces pulse d-e-f in the same direction.

Between 4-5 in Fig. 31B, the current through P_2 is constant and there is no change in flux linkage. When the switch arm is thrown from Y to X, the current through P_2 drops to zero, as shown at 5-6, and when contact at X is made, current P_1 rises as shown by 7-8.

The changing flux caused by currents 5-6 and 7-8 produces voltage pulses g-h-i and j-k-l. Then currents 9-10 and 11-12 produce pulses m-n-o and p-q-r. Thus, we now get double pulses in the secondary instead of the single ones of Fig. 30.

We could apply the secondary voltage shown in Fig. 31C to a rectifier tube, pass the tube output through a filter, and get a fair d.c. voltage output. However, there are several things wrong with these voltage pulses.

One is that the voltage consists of narrow double pulses in each direction, while we'd rather have pulses that are broader and not as high. We can get them by speeding up the switch shown in Fig. 31A, and by moving its contacts closer together, so that very little time elapses while the switch moves from one contact to the other. This means that the flat parts of the curve in Fig. 31B, where the current is zero (2-3, 6-7, etc.) are practically eliminated, so the primary current change will be almost a straight line between points 1 and 4, 5 and 8, 9 and 12, etc. As a result, each pair of secondary pulses will merge together, and there will not be much of a gap between opposite pairs of secondary pulses.

Even so, these pulses are very high, sharp peaks. This makes the filtering job difficult. It also produces sparking at the switch contacts, because each rapid change in flux in the transformer induces a back-electromotive force (back e.m.f.) in the primary that tends to cause arcing between the contact and the switch arm. This will burn and soon ruin the switch contacts.

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* One battery lead is grounded; it does not matter which one. The ground is shown because one terminal of a storage battery usually connects to the frame of the car or other device with which it is used.

The Buffer Condenser. The sparking problem is easily solved by connecting a low-capacity condenser (called a buffer condenser) between the secondary terminals.* Now, when the secondary voltage starts to rise, the condenser charges. This tends to reduce the sharpness of the peak in the secondary circuit, thus cutting down the back e.m.f. and thereby reducing the sparking at the vibrator contacts. Further, the discharge of the condenser when the secondary voltage begins to reverse helps to give us a secondary voltage more like that shown in Fig. 32, which has a shape approaching the one that would be fed to a standard rectifier circuit.

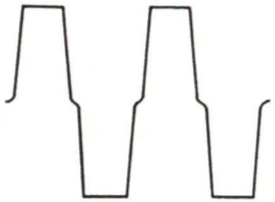

FIG. 32. The output of a vibrator-transformer-buffer condenser combination, that can now be rectified.

Fig. 33 shows how modern vibrators operate. The switch arm is a thin, flexible, spring-like metal reed. As it vibrates, it alternately closes contacts N and O, thus alternately closing the circuit through halves of the primary.

The shaded area shows the "motor" used to drive the reed. This motor is somewhat like the buzzer in an electric doorbell. Two types are used—the separate driver type and the shunt type.

Separate Driver. The separate driver type is shown in Fig. 33A. The vibrating reed is between K and R. Contact M is a spring contact that touches the reed when the reed is at rest. When the ON-OFF switch S is closed, electrons flow through contact M and electromagnet L_1. This energizes the electromagnet, which pulls up the soft iron bar K fastened to the end of the reed. This moves the reed, opening contact M and so breaking the circuit through the electromagnet. Since the electromagnet is no longer energized, the reed moves back to its original position, again closing M. Current again flows through L_1, and the cycle repeats as long as the battery is connected. The period of vibration of the reed depends on its mechanical characteristics—its length, springiness, etc.

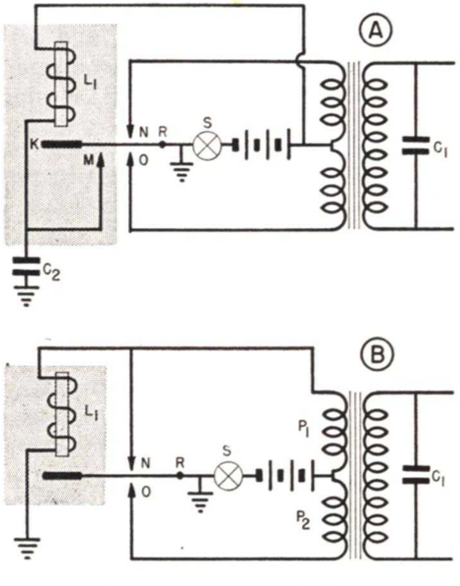

FIG. 33. Separate driver and shunt vibrator motor units. One or the other of these will be found on practically all commercial vibrators.

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* The condenser is chosen to work with a particular transformer and a certain rate of switch closure. Its capacity is quite important. When replacing a defective condenser, use the capacity and working voltage originally used by the manufacturer.

In moving back and forth, the reed closes contacts N and O alternately. Each closure completes the circuit through one of the primary winding sections. The buffer condenser C_1 in the secondary prevents arcing at contacts N and O. This does not affect the motor circuit and so does not protect M; for this reason, a separate condenser C_2 is used across this contact.

The contacts are large and flat-surfaced, made from a hard grade of tungsten to reduce pitting and burning to a minimum.

The Shunt Motor. The shunt motor shown in Fig. 33B does not require a separate contact and is more widely used than the separate driver motor. When switch S is closed, electrons flow through the chassis (shown by ground symbols), electromagnet L_1, and primary winding P_1. The electromagnet then pulls the reed upward, closing contact N and connecting the battery directly across primary P_1. Contact N shorts the coil L_1, and the current now flows through N and the reed instead of through coil L_1, so the electromagnet releases; the reed springs back. Its springiness carries it beyond the resting position—this overshooting causes it to close contact O. Then current flows through P_2. When contact N is broken the current again starts to flow through L_1 and soon builds up enough magnetic pull to jerk the reed back and close contact N. This cycle of action is repeated as long as S is closed. We always have current flowing through P_1 (it flows through P_1 and L_1 when N is open), but this current is much smaller than that when N is closed and does not have any appreciable effect on the wave form of the secondary voltage.

Rectification. Now that we know how a high a.c. voltage may be obtained from a d.c. source, let us see how this a.c. voltage is rectified. Fig. 34 shows a typical full-wave rectifier circuit commonly used for this purpose. The only real difference between this and an ordinary power pack is that the filament of the rectifier tube is supplied from a battery. Since one battery terminal is grounded, the filament is at the same potential as B—. This means good insulation is needed between the cathode and heater of the rectifier tube, for as much as 400 volts may exist between them.

Also, the voltage pulses that result from rectification are still rather sharp and the rectifying process generates r.f. noise signals. R.F. filters, consisting of r.f. coils and small capacity condensers, in the filament and B+ supply leads, prevent this interference (called "hash") from being fed to the other tube circuits. Direct radiation is prevented by complete shielding, as shown by the dotted lines.

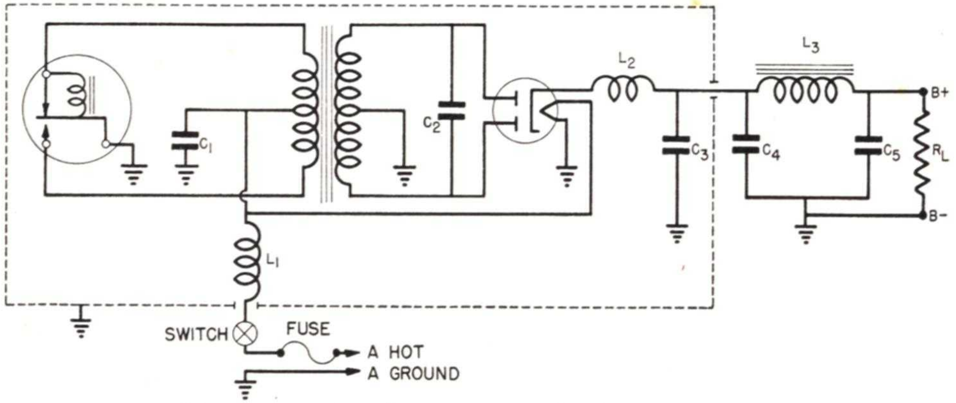

FIG. 34. A complete vibrator power supply using a tube rectifier.

Notice that the two battery leads are marked A-hot and A-ground. The one marked A-ground connects to the grounded side of the battery. In power packs using the tube rectifiers, it makes no difference whether A+ or A— is grounded.

If the filament current drawn by the rectifier tube can be eliminated, the drain on the battery can be reduced. For this reason, cold-cathode rectifier tubes are sometimes used in battery-operated radios. To refresh your memory of these tubes, refer to Fig. 35, which shows the structure of a typical full-wave cold-cathode rectifier. The tube is filled with gas that, on ionization, becomes an excellent conductor.

Rectification is caused by the physical structure of the tube. When one of the pointed plates is positive it can pull many electrons out of the large cathode. But when the cathode is positive with respect to a plate, the cathode can pull only a few electrons from the small surface of the plate; as a consequence, only a comparatively small current flows in the undesired direction. In other words, the cold-cathode tube is a two-way conductor that conducts far better in one direction than the other.

The ionization of the gas in the tube causes a brilliant purplish glow that continually flickers as current through the tube changes. The cold-cathode tube has a serious disadvantage in that it generates a large amount of r.f. noise signal—much more than the mercury-vapor tube that it resembles. Often this interference is difficult to eliminate because of poor joints at shield contacts to the chassis, changes in the tube characteristics, etc. If you meet this difficulty, the easiest way to solve it is to rewire the circuit for a heater type rectifier. Usually it is only necessary to wire in the filament circuit, retaining the original tube socket.

Synchronous Vibrators. Sometimes it is desirable to eliminate the rectifier tube altogether, particularly where space limitations are important. Let us see how we can do so.

Basically, a rectifier tube is just an electronic switch that reverses a circuit connection every time the a.c. cycle reverses, and so keeps current flowing always in the same direction through the circuit. We can replace this electronic switch with a mechanical one—a vibrator—and get the same effect. Of course, this vibrator must be synchronized with the vibrator in the primary circuit so that both of them open and close their circuits at the same time. We can get this synchronization by mounting both sets of vibrator contacts on the same vibrating reed. This also helps to save space, by making two reeds unnecessary.

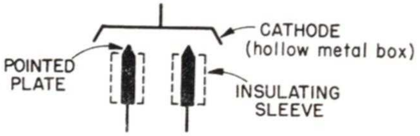

FIG. 35. The elements of a gaseous or cold-cathode rectifier tube.

Fig. 36A shows the fundamental operation of such a circuit. Switch SW is synchronized with the vibrator, and replaces the rectifier tube. Notice that more is involved than a simple replacement of the tube by the switch; the circuit is also changed around, with the rectifying element in the negative side of the output circuit. This is necessary because one side of the battery is grounded, which means that the vibrating reed is also grounded. Since the same reed is used in SW, if we connected the switch in the positive side of the output (as we do with a tube), we would be grounding $B+$.

When current flows through the primary in the direction shown by the solid arrow, the polarity of the secondary voltage is that shown by the solid arrows drawn between the secondary terminals. Current flow through the other half of the primary reverses the secondary voltage polarity, as shown by the dotted arrows.

Notice that the center tap c on the secondary will be positive with respect to a when current flows one way through the primary, and positive with respect to b when current flows the other way. Obviously, switch SW must connect a to ground when a is negative with respect to c, and b to ground when b is negative with respect to c, in order to maintain the right polarity for the load R_L. Therefore, it must be synchronized with the primary vibrator. This is the reason these types are called "synchronous" vibrators, while the other type is known as the "non-synchronous" type.

Fig. 36B shows the complete circuit of a practical synchronous vibrator, with both switch units operating from a common vibrator reed. Either a separate driver or a shunt motor unit may be used; the shunt type is more common. Notice that the whole unit is enclosed in a shield (dotted lines) and that r.f. filters are used in both the $B+$ and filament leads.

You must be careful about the battery connections when you use one of these synchronous vibrators. When the battery polarity is reversed, the direction of current flow in the primary windings reverses, thus interchanging the secondary polarities. Battery connections do not matter in a vibrator power pack that uses a rectifying tube —the tube automatically passes current in the proper direction, since whichever plate is made positive will pass current.

The synchronous vibrator pack is put together with a particular polarity in mind. Should the battery polarity be reversed, the secondary contacts would be closing to the positive terminals (with respect to c in Fig. 36A) instead of to the negative terminals. This would reverse the $B+$ and $B-$ terminal polarities, and so prevent operation of the radio device. Further, this reversed polarity would ruin the electrolytic condensers if it existed for more than a few seconds.

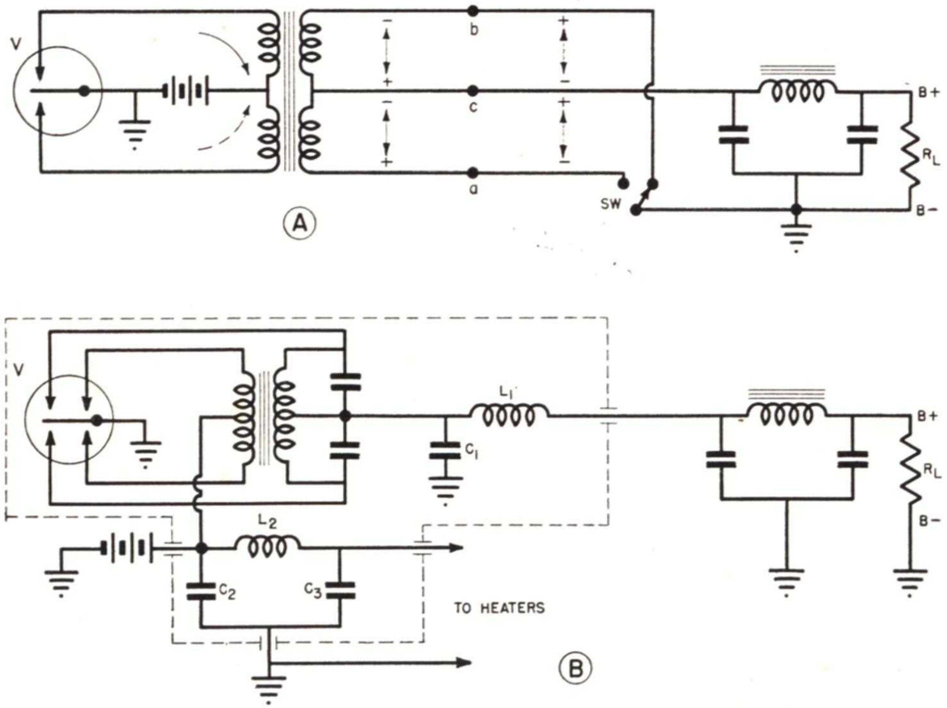

FIG. 36. The elements of a synchronous vibrator which uses mechanical rectification.

Voltage Regulators

The voltages applied to transmitting equipment must often be controlled precisely. For example, a 10% increase in line voltage will cause the power output of a broadcast transmitter to increase more than the 5% permitted by the FCC. In addition, this increased filament voltage will greatly shorten the operating life of expensive high-power tubes.

Rapid voltage surges on the a.c. power line may cause voltage peaks of several thousand volts on the plates of the tubes in a radio transmitter. These surges may cause flash-overs in the power amplifier tubes from plate to cathode and burn out the tubes.

Voltage regulators of various kinds have been developed to solve these problems. Let's see how they work.

A.C. VOLTAGE REGULATORS

One type of a.c. voltage stabilizer (or regulator) is shown schematically in Fig. 37. It consists essentially of two transformers with secondaries connected so that their voltages are opposed. T_1 is an ordinary transformer, whereas T_2 is designed so that its core will be saturated over the range of input voltages that is to be regulated.

The output e_4 of T_2 is considerably larger than the output e_3 of T_1; therefore, the net output voltage E_2 of the regulator is equal to e_4-e_3. When the input voltage increases, output voltage e_3 increases in proportion. Output voltage e_4 also increases, but, since the core of T_2 is saturated, the increase in e_4 is not proportionately as high as the increase in e_3. Therefore, the net output voltage E_2 remains nearly constant.

These units are available in 100-watt to 25-kw. ratings.

Neon Tube A.C. Voltage Regulator. A simple voltage regulator for a.c. can be made using two glow discharge voltage regulator tubes as shown in Fig. 38. These tubes maintain a constant voltage drop over a wide range of current. This fact is used in this regulator by placing two of them connected back-to-back across the primary of a transformer (two are necessary because the tubes conduct in only one direction). The voltage drop across the tubes, and therefore the voltage across the primary, remains practical-

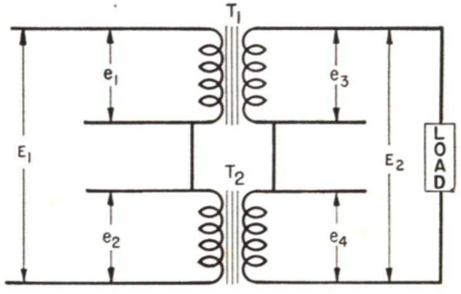

FIG. 37. Magnetic saturation type of voltage regulator.

ly constant; any variations that occur in the line voltage result only in a change in the drop across series resistor R.

The wave shape of the secondary voltage is rich in harmonics; therefore, this circuit is used only in instruments in which the harmonics of the a.c. supply frequency do not interfere or can be filtered out.

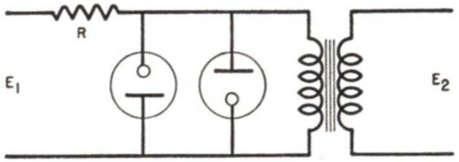

FIG. 38. Glow discharge a.c. voltage regulator.

Ballast Tubes. For some special purposes, ballast tubes are widely used for regulation of a.c. *current*. Certain metals, like iron, exhibit a considerable change in resistance when the temperature increases. When a resistor made of these metals is placed in series with the load, any increase in current will heat up the resistor; the resistance of the resistor will then increase, causing a decrease in the circuit current.

A ballast tube consists of one of these resistors enclosed in an envelope like that of an ordinary tube. The volt-ampere characteristic of one type of commercial ballast tube is shown in Fig. 39A and a typical circuit connection is shown in Fig. 39B.

Ballast tubes are available in a variety of ratings in current ranges from ¼ amp. to 5.5 amperes and voltage ranges from 1-3 volts to 165-185 volts.

D.C. VOLTAGE REGULATION

There is frequent need for close regulation over low-current, low-voltage circuits in communication equipment. Grid bias voltages and the plate supply voltages for the master oscillator and low-level amplifiers of many transmitters are regulated.

Two methods of d.c. voltage regulation are in common use. One uses the constant voltage characteristic of the discharge through a gaseous tube to maintain a constant output voltage, the other uses the variable resistance property of a vacuum tube for the same purpose.

D.C. Regulator Using VR Tubes. Voltage regulator (VR) tubes have been developed to supply regulated d.c. outputs of 75, 90, 105, and 150 volts.

The basic circuit using a VR tube is given in Fig. 40A. The load is connected in parallel with the VR tube and a current-limiting resistor R is placed between the regulator and the voltage source.

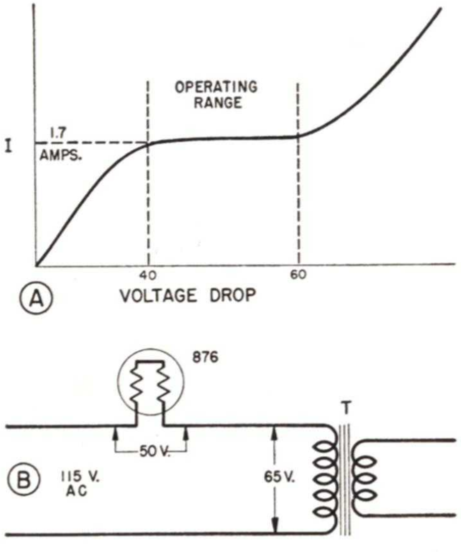

FIG. 39. A, characteristics of a type 876 current regulator tube, and B, its use in a power supply circuit.

The voltage-regulating action of a VR tube depends on the fact that, as shown in the typical VR tube characteristic in Fig. 41, a small voltage change across the tube produces a large change in the current flow through the tube. Thus, if the voltage across the load and across the VR tube in the circuit in Fig. 40A should increase a small amount, the current through the VR tube will increase a large amount. This will cause an increased voltage drop across resistor R, thereby reducing the voltage applied to the load to something near the original value. Conversely, a slight decrease in the applied voltage will cause a large decrease in current through the VR tube. This will produce a smaller voltage drop across R and thus increase the fraction of the circuit voltage that is applied to the load.

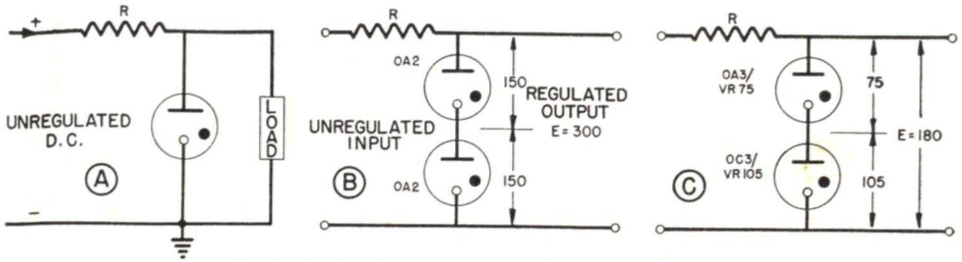

FIG. 40. D.C. voltage regulating circuits using VR tubes.

Although this circuit is very simple, its voltage-regulating ability is excellent. A VR tube can be used in this manner to keep the voltage applied to the load constant within 1% when either the input voltage or load current vary as much as 50 per cent.

Most VR tubes are designed to operate for tube current variations from 5 to 30 ma. In fact, below 5 ma., as shown in Fig. 41, the regulating action stops. The value of R must be chosen so that the VR current is in the middle of this range (about 18 ma.) for normal input voltage and normal load current.

Various values of regulated voltage output can be obtained by connecting two or more VR tubes in series as shown in Figs. 40B and 40C.

When the load current variation is more than the 25 ma. that can be handled by one tube, two or more VR tubes can be connected in parallel provided a 100-ohm resistor is placed in series with each tube to equalize the current distribution.

► Incidentally, the no-load input voltage must be at least 30 per cent higher than the regulated output voltage in order to ionize the VR tubes and thus start the regulating action.

Electronic D.C. Regulator. If closer regulation and adjustment of output voltage over a wide range is desired, an electronic regulator of the type illustrated in Fig. 42 is used.

Note that a conventional tube VT_1 is placed in series with the positive lead of the power supply. Regulation is obtained by using this tube as a variable resistance. Briefly, when the output voltage varies, this variation is fed back through VT_2 to change the operating bias of VT_1 and thus correct the original voltage variation.

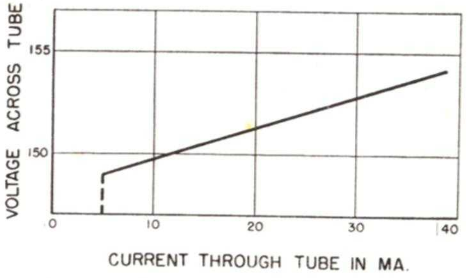

FIG. 41. Typical regulation curve of a OD3/VR150 tube.

Let us study this regulating process in detail. The circuit can be divided into three parts: (1) the regulator tube VT_1; (2) the control tube VT_2; and (3) the load. Tube VT_3 is used merely to supply a regulated bias for the control tube VT_2.

Tube VT_2 (any sharp cut off pentode, such as a 6SJ7) has a bias equal to the difference between the voltage drop across VT_3 (which remains constant over a very wide current range) and a fixed bias (E_1) taken from a voltage divider across the output of the regulator. The screen voltage for VT_2 is obtained from resistor R_1. The plate of the tube is connected directly to the grid of the regulator tube. When the circuit is adjusted for the desired output voltage, the effective bias on the regulator tube (VT_1) is slightly negative.

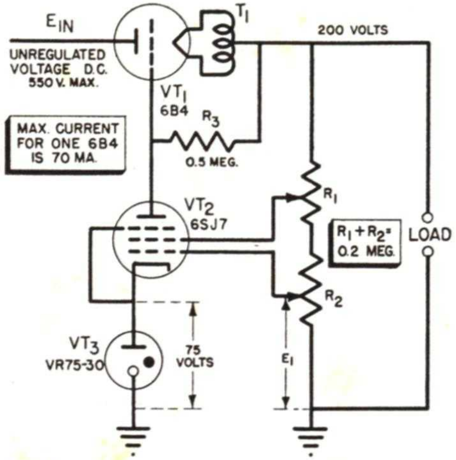

FIG. 42. An electronic voltage regulator using a 6B4 tube as a variable resistor.

Now let us suppose that the output voltage decreases because of a change in the load or a change in the d.c. input voltage to the regulator. The bias of VT_2 is *increased* proportionately; this increase in bias reduces the plate current of VT_2, causing less voltage drop across R_3. The negative bias of VT_1 therefore *decreases*, reducing its d.c. plate resistance and therefore reducing the voltage drop across it. This permits the voltage across the load to rise to its former level. Conversely, any tendency for the output voltage to increase is opposed by the regulating action of the circuit in a similar manner.

The d.c. output voltage of this regulated supply can be changed simply by varying R_2. The amount of voltage that can be regulated depends on the current-carrying abilities of VT_1. If a higher load voltage is needed than can be regulated by VT_1, one or more other tubes can be connected in parallel with VT_1.

Lesson Questions

Be sure to number your Answer Sheet 26RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. Show how four 12-volt tubes can be connected in series parallel across a 24-volt source.
2. Why are condensers sometimes connected to ground from each side of the filament of a transmitting tube used as an r.f. amplifier?
3. If the no-load output of a power supply is 400 volts and the regulation of the supply is 15%, what is the full-load output voltage?
4. What protects the tube if excitation fails in a class C r.f. amplifier using combination grid-leak and cathode bias?
5. What action permits the high-conduction currents of a hot cathode mercury-vapor rectifier tube?
6. Why are bridge rectifier circuits frequently used in high-voltage power supplies?
7. Does the output of a d.c. generator generally require more filtering, or less filtering, than the output of a rectifier system?
8. What is the advantage of a half-wave voltage doubler when compared to a full-wave doubler?
9. Why are buffer condensers used in vibrator power supplies?
10. The voltage regulating action of a VR tube depends on what fact?

AT THE END OF THE RAINBOW

The only pot of gold you'll find at the end of the rainbow is the one that you put there yourself.

Now, when your best earning years are still ahead, is the time for you to fill that pot of gold. You're an NRI student—you're carrying the ball down the field right now for a touchdown—and everything favors you to make the goal you have in mind.

Will you falter now and be thrown for a loss, or will you keep right on going? Will you complete your training Course just as steadily as you started it, with no losses, no set-backs, preparing yourself for that rainbow trail to success—or will you let minor successes now lure you from your planned path to a sound future in Radio?

There is no royal road to anything. Steady progress step by step will get you anywhere, and bring you a success that endures. The only failure you need to fear now is failure to stick to the goal you know is best.

J. E. SMITH