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SPECIAL POWER SUPPLY CIRCUITS

ASSIGNMENT 24

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In the preceding assignment, we learned the underlying principles of all rectifiers. That is, we found how alternating current is changed to pulsating direct current and then, how the pulsations are smoothed out, leaving almost pure d-c. In that assignment, we discussed in detail the operation of the half-wave rectifier circuit and the full-wave rectifier circuit. In this assignment, we will apply the principles which we have already learned to special power supply circuits. Among these circuits are the a-c d-c power supply, the voltage-doubler power supply, and vibrator power supplies. We shall discuss other considerations of power supplies, such as the type of rectifier used, the type of choke, etc.

Transformerless Power Supplies

In the power supplies discussed in the preceding assignment, power transformers were used to change the voltage from the 115 volt a-c supply to some desired value of voltage. (Higher voltages are usually required in vacuum-tube equipment and lower voltages in transistorized equipment.) However, a great number of vacuum-tubes have been developed which operate very satisfactorily with plate voltages of approximately 100 volts. By incorporating these tubes in the circuit design, manufacturers have been able to produce equipment which does not use a power transformer. This has had several advantages. It lowers the price of equipment considerably, since the power transformer is one of the most expensive components in electronics equipment. Also, the power transformer is a large heavy item and its elimination has made the construction of smaller, light weight equipment possible. Also, as we shall see, it is possible to operate this equipment from a d-c source such as is still present in some localities. (Of course, it is not possible to operate a transformer type of power supply from a direct-current source.)

Figure 1 shows the basic schematic diagram for a transformerless power supply, or a-c d-c supply as it is often called. This power supply is designed to give satisfactory operation for small radio sets and other low-powered electronic equipment. The filament circuits of such sets have been discussed in previous assignments, and will be reviewed later in this assignment. Let us now see how the "B" supply voltage is obtained from this power supply.

As can be seen from the schematic diagram in Figure 1, no power transformer is used with this type of circuit. The 115 volt a-c line is connected directly into the input of this rectifier circuit. The rectifier tube operates as a half-wave rectifier and is followed by the standard pi-type capacitor-input filter with which we are already familiar.

The operation of the rectifier circuit is identical with that of the half-wave rectifier which we have studied in a previous assignment. When the polarity of the a-c voltage, applied to the rectifier, is such that point A is positive in the respect to point B, current will flow from point B, through the load R_L and the filter choke to the cathode of the rectifier tube. It then flows from the cathode to the plate and back to the source. This produces a voltage drop across the load R_L with polarity as indicated in Figure 1. This charges the filter capacitors. On the next half of the a-c input cycle, when point A is negative in respect to point B, no current will flow through the rectifier tube due to the fact that its plate is negative in respect to its cathode. During this half cycle, the filter capacitors begin to discharge through the load resistance R_L. This maintains a fairly constant flow of current through R_L. Of course, the action of the filter is to remove the pulsations from this current flow and produce a steady d-c current. Thus, we see that the only difference between this type of circuit and the half-wave rectifier which we have studied previously is the fact that the power transformer has been eliminated.

It will be recalled from the preceding assignment that the input filter capacitor will charge approximately to the peak value of the a-c input to the rectifier circuits. The peak value of a 115 volt a-c rms input will be approximately 165 volts. Therefore, the **maximum** voltage which may be obtained from this type of power supply is approximately 160 volts. However, this can be obtained only with very light values of load current. As the load current increases, the output voltage will decrease very sharply. In most cases, the power supplies are so designed that, when operating with their normal values of load current, the output voltage is approximately 100 volts.

In a circuit such as Figure 1, the regulation, and therefore the amount of output voltage under load, is almost entirely dependent upon the size of the filter capacitors. This is illustrated very clearly by the graphs for the 35W4 tube in Figure 4(B). Study this set of graphs very carefully, and you will discover that the regulation with the 40 microfarad input capacitor in the filter is within the limits of fair operation, but with the 8 microfarad capacitor in the input section, the regulation is very poor, dropping from approximately 160 volts to approximately 80 volts under full load. This regulation is so poor that proper operation of the vacuum-tube circuits is impossible. For this reason, the filter capacitors used in the half-wave transformerless type of power supply always have large values of capacity, ranging from 30 to 80 microfarads.

Figure 2(A) shows a graph with which we are already familiar. The light line illustrates the pulse of voltage which would exist across the output of the half-wave rectifier if no filter were used. The heavy line illustrates the voltage across the input capacitor of the capacitor-input filter. It has been pointed out previously that the capacitor charges to the peak value of the pulsating d-c and then discharges gradually through the load during the period when the rectifier tube is not conducting. Notice, in this graph, that the capacitors are actually charging only during the portion of X to Y, then discharging during the entire remaining portion of the graph. Thus, we see that the current flowing into the capacitor from the rectifier does not constitute a steady flow of current, but flows only during the short duration from X to Y in this graph. This is shown in Figure 2(B). In the portion of the graph labelled "current into input capacitor", we see that the current flowing into this capacitor flows only in sharp pulses. These sharp pulses of current then charge the capacitor to the full value of voltage. The capacitor then discharges through the load, supplying a fairly constant value of direct current to the load. Since the full current, which is drawn by the load, must be supplied from the rectifier tube to the filter capacitor, the value of current which flows in the pulses (as shown in Figure 2) is quite high. Thus, we see that, while the output from the circuit (shown in Figure 1) will be a fairly constant value of direct current, the actual rectifier tube is supplying pulses of current which have a much greater value than the average value supplied to the load.

This action of the rectifier tube, in supplying current only on peaks as shown in Figure 2(B), occurs in the transformer type of supply as well as in the a-c d-c type of power supply which we are now studying. If a capacitor-input filter is used with a transformer, the resistance of the high voltage secondary winding limits the current to the rectifier tube to some degree; but in the a-c d-c type of power supply, there is no such limitation on the current. If this excess **peak** current is allowed to flow through the rectifier tube, the tube may be ruined. There are several things which may happen to the rectifier tube under these conditions. One of these is that the electron emitting material on the cathode will literally be **torn off,** and the tube will lose its electron emitting ability. Also, the plate may become hot and warp, thus touching the cathode and short-circuiting the tube. In a great number of cases, a metal lead which connects the tube elements (either the cathode or the plate) to the metal base of the tube may burn out. This lead is normally a very small piece of wire, particularly the one used for the cathode connection, and the excessive current will cause it to overheat and burn out. Of course, any of these conditions will cause the rectifier tube to be ruined.

There are two arrangements which are sometimes used for minimizing this condition. These are shown in Figure 3. Figure 3(A) shows a rectifier tube with two cathodes and two plates such as a 25Y5 or 25Z5 tube. The plates are connected in parallel and the cathodes are connected in parallel in this circuit so that they may be able to supply a higher value of current. Figure 3(B) illustrates another method which is superior as far as peak current conditions are concerned. In this case, a **current-limiting** resistor is connected between the rectifier tube and the input filter capacitor. This resistor is usually about 50 ohms. The action of this resistor is to limit the peak current which will flow into the filter capacitor and thereby reduce the damage to the tube. This resistor is sometimes connected at point X between the plate and the 115 volt line, instead of between the cathode and the filter capacitor as shown. Since it will be in series with the tube in either case, it makes no difference in the operation of the circuit. In case of defective filter capacitors if, for example, the input filter capacitor in the filter circuit shown in Figure 3(B) were to become shorted, the resistor will normally burn out.

Filament Circuit in A-C D-C Supplies

Figure 4(A) shows the schematic diagram of a power supply which is the same as that of Figure 3(B), except that the filament circuit of this receiver has been shown. The filament circuit in Figure 4(A) is indicated by the circuit using heavy lines. Such filament circuits have been discussed previously, but let us consider them now in conjunction with the entire power supply. This happens to be the filament circuit for a five tube radio using a 35Z4 as the rectifier and a 50L6, a 12SQ7, a 12SK7 and a 12SA7 as the other tubes in the radio. If the filament voltages for all of these tubes were added together (we should add them because they are in series), it will be found that the total voltage required by these filaments is approximately 120 volts, therefore no series resistor is needed with them. We see that we have two separate circuits in Figure 4(A), one is the filament circuit as shown in the heavy lines, and the other is the rectifier and d-c circuit. This type circuit is used in quite a few a-c d-c receivers; and in some cases, the high voltage filament tubes (the 35Z4 or the 50L6) are so placed that the light from their filament is used to illuminate the tuning dial, since the filament circuit makes no provision for using a pilot light. Figure 5 illustrates a similar circuit, but one which has provision for a pilot light. In this case, the 35Z5 tube is used as the rectifier tube. In this rectifier tube, the filament has a tap on it, and the pilot light is connected across this section of the tube. With the panel light connected as shown, in parallel with this section of the filament of the 35Z5 tube, the voltage drop across this section will be 5.5 volts. This will provide satisfactory operation for the rectifier circuit and also for the filament and pilot light circuit. However, this circuit is often modified as shown in Figure 6.

In Figure 6, the plate of the rectifier tube is connected to the tap on the filament of this tube. This connects the parallel combination, consisting of the pilot lamp and the low voltage section of the filament of the tube, in series with the plate circuit. This makes it unnecessary to use the series current-limiting resistor as illustrated in R of Figure 5. In this type of circuit arrangement, if either of the filter capacitors becomes shorted, the pilot light will burn out very quickly. If this power supply is left on after the pilot light burns out due to a shorted filter capacitor, the pilot light section of the filament on the rectifier tube will probably also burn out. In this type of receiver, if the pilot lamp burns out from any cause, the receiver should not be operated until the bulb is replaced. If the pilot lamp burns out from no other cause than the fact that the lamp's useful life has been exhausted, continued operation of the set will result in the rectifier tube being ruined. With the pilot light out of the circuit, the voltage drop across the pilot light section of the filament of the tube is higher than normal (about 7.5 volts) and the tube's life will be shortened.

At this point, let us clear up one question which may be present in your mind — that is, why the pilot lamp glows brilliantly when the set is first turned on, then grows dimmer. This initial glow is caused by the inrush of current when the set is first turned on. This is due to the fact that the resistance of the filaments of the various tubes in the set is much lower when they are cold than after the tubes have warmed up. For this reason, the current which flows through this filament circuit when the set is first turned on is much higher than it will be after the set is operating normally. This large amount of current which flows through the filament circuit initially, also flows through the pilot light, lighting it to a greater than normal brilliance; but after the filament current reaches its normal value, the current through the light bulb is normal and the bulb will light with normal brilliance. If a circuit such as that shown in Figure 6 is used, it will be found that, after growing dimmer, the pilot light will again grow brighter, but normally not so bright as the initial brilliance. This is because the d-c current which is drawn by the power supply also flows through the pilot light section of the 35Z5 rectifier tube and the pilot light as mentioned previously. Therefore, when the tube filaments in the receiver have "warmed up" and the tubes in the receiver start to draw plate current, this plate current in flowing through the pilot light, will cause it to glow more brightly.

The power supplies, which we have been discussing, are commonly called a-c d-c power supplies. We have seen how these power supplies operate on a-c, now let us see how they operate on d-c. If any of the power supplies illustrated so far in this assignment are connected to 110 volts d-c, so that the plate of the rectifier tube is connected to the positive side of the source, the rectifier will deliver approximately 110 volts d-c from its output. This is possible because, with the plate of the rectifier tube positive in respect to the cathode, current will flow continuously through the rectifier tube. In other words, the tube is not rectifying at all, but merely allowing the current to flow from cathode to plate. If one of these power supplies is connected to a 110 volt d-c source, so that the plate is connected to the negative side of the supply, there will be no output from the d-c supply. If this occurs, the plug that connects the radio receiver to the power source should be reversed, and then the power supply will operate as explained previously. This was one selling point for these types of supplies; they could be operated from d-c such as is still found in some communities. Actually, however, the main reason which led to the widespread use of these supplies was due to the fact they were considerably cheaper than the transformer type of supply.

Grounding A-C D-C Supplies

Figure 7 shows the manner in which a great number of a-c d-c supplies are wired. The switch opens the "B" supply circuit and the filament circuit at the same time by opening one side of the circuit to the power line. This means that one side of the switch and one end of the filament string and the

"B—" all are connected to the **chassis** of the radio. Since the radio chassis is made of metal, this means that these points are tied together electrically.

You may or may not be familiar with the fact that one wire of the a-c supply to a home is grounded. Therefore, the radio receiver is connected to ground through the power cord connection to the power line. For this reason, a set wired like this should never be connected to ground by a separate wire. If such an external ground connection is made and the power line plug is so inserted in the wall socket that the ungrounded side of the 110 a-c supplied to your home is connected to the chassis, the a-c supply to your home will be short circuited through the radio chassis. This will blow out the fuses in the a-c power line. Let us repeat this precaution. **Never use a ground connection on an a-c d-c power supply unless a terminal is provided for this purpose by the manufacturer.** Also for your own protection, remember that the chassis of an a-c d-c receiver may be 110 volts above ground potential if the power cord happens to be plugged into the receptacle with the ungrounded side of the power line connected to the chassis. If such is the case, you will get a shock if you touch the chassis while standing on a damp floor or in contact with any other sort of ground such as a radiator, water pipe, etc.

Due to the hazard which results from having the chassis connected directly to one side of the 110 volt a-c line, some a-c d-c supplies use an arrangement similar to that shown in Figure 8. In this type of circuit, the chassis is not used as the B— connection in the equipment. Instead, all B— points are connected to one common wire called the **ground bus.** Some technicians refer to this type of circuit as having a **floating ground.** In this circuit, it will be noticed that the ground bus is connected to the chassis through a capacitor. The value of this capacitor is usually in the order of .05 micro-farads. In checking a circuit like this, it is necessary to connect one of the voltmeter test prods to the ground bus and the other to the various points of voltage in the circuit, rather than the common method of connecting one test prod to the chassis and the other to the points of the circuit where the voltage is to be checked.

Voltage Doublers

The output voltage which can be obtained from the transformerless type of power supply, which we have been discussing, is about 100 volts under normal load. It is sometimes desirable to obtain a higher voltage than this without using an expensive power transformer. This is made possible through the use of rectifier circuits knows as voltage doublers.

Before studying the circuit of the full-wave voltage doubler, let us consider the simple circuit shown in Figure 9. This circuit shows two capacitors connected in series and a 100 volt battery to which is connected a set of test leads. Let us first connect the test leads of the 100 volt battery to the top capacitor, connecting the positive lead to A and the negative test lead to B. If we allow this connection to remain for a few seconds, the top capacitor will be charged with the point A 100 volts positive in respect to point B. Now let us disconnect the battery from this circuit and connect it to the lower capacitor by connecting the positive test lead to point B and the negative test lead to point C. The lower capacitor will be charged to 100 volts also.

Now, let us disconnect the battery entirely. If we now connect a voltmeter across the **two** capacitors from A to C as shown in Figure 9(B), the reading of the voltmeter will be 200 volts. Let us see how we were able to obtain 200 volts when our supply voltage (the 100 volt battery) was only 100 volts. First one capacitor was charged and then the other capacitor was charged. The two capacitors are connected in series, and when the voltmeter is connected across them, the total voltage across the two will equal the sum of the two individual voltages, or in this case 200 volts. We shall see that a voltage doubler works on much the same principle as this, except that a rectifier is used to obtain approximately 100 volts d-c instead of the battery as shown in Figure 9(A). The d-c voltage output from the rectifier is used to charge first one capacitor and then another capacitor, and then the two capacitors are discharged in series. This is illustrated in Figure 10.

In Figure 10(A), we see a rectifier tube V_1 connected in series with a capacitor C_1, and the 115 volt a-c power line. When the polarity of the applied a-c voltage is such that the plate of the rectifier tube V_1 is positive, the rectifier tube V_1 will conduct current. Electrons will flow through the tube (as shown by the arrow), leaving the top plate of C_1 in this diagram positive. Electrons will flow from the negative terminal of the a-c input to the bottom plate of C_1, making it negative. This will charge the capacitor to the **peak** value of the applied a-c voltage with a polarity as shown in Figure 10(A). Remember, that the peak value of the applied a-c voltage is 1.41 times the rms value of 115 volts. In this case, the peak value of the applied a-c voltage will be 115 x 1.4 or approximately 163 volts. Thus, capacitor C_1 is charged to a value of 163 volts. Let us now connect the rectifier tube to capacitor C_2 as shown in Figure 10(B). On the other half of the a-c input cycle, the cathode of tube V_2 will become negative in respect to the plate, so current will flow through this tube in the direction indicated by the arrow making the lower plate of capacitor C_2 in Figure 10(B) negative. Electrons will flow away from the top plate of capacitor C_2 to the a-c supply line. Thus, capacitor C_2 will be charged to 163 volts with polarity as indicated in the diagram. We see that we have used a rectifier tube to charge two capacitors from the 115 volt a-c line similar to the manner in which the battery was used in Figure 9(A).

In Figure 10(C), the two capacitors are connected in series and two rectifier tubes V_1 and V_2 are used. The operation of the top half of this rectifier circuit V_1 and C_1 is identical to that of (A) in Figure 10, and the operation of the bottom half, consisting of V_2 and C_2, is identical with that of (B) in Figure 10. Thus, on one half of the input cycle, capacitor C_1 will become charged to 163 volts (with polarity as indicated in the diagram), and on the other half of the input cycle capacitor C_2 will become charged. These two capacitors are connected in series and the output voltage is taken off across the two capacitors. Thus, the output voltage will be the sum of the two voltages across the individual capacitors, and in this case, the maximum output voltage will be 326 volts. Thus, we see that it is possible to get a voltage of almost three times the rms line voltage from such a supply. However, the regulation of such a supply is very poor and the voltage will drop to approximately 225 volts under a normal load. This circuit is known as a **full-wave** voltage doubler circuit, since it operates on both halves of the a-c input cycle. It will have a ripple frequency of twice the a-c input frequency. Thus, with the a-c input of 60 hertz it will produce a ripple frequency of 120 hertz.

As mentioned previously, voltage doublers have inherently poor voltage regulation. The regulation depends on the size of the two capacitors C_1 and C_2. On the alternation when the capacitor is not charging, it is discharging through the load. As the capacitor discharges during this alternation, the voltage goes down. The only solution to limiting the amount to which this voltage will fall is to make the capacitance as large as practical, so that the quantity of electrons which leaves the capacitor to furnish current to the load is only a small portion of the total charge on the capacitor. As a guide in constructing a voltage doubler, if C_1 and C_2 are 16 microfarads each, the output voltage will be about 300 volts at 10 milliamperes of load current. The output voltage will be about 225 volts at 60 milliamperes load. This is based on a power line voltage of 115 volts a-c, 60 hertz.

Figure 11 shows the complete diagram of a full-wave voltage-doubler rectifier circuit. The tube used in this case is a 25Z5 rectifier tube. The dotted line shows the filament circuit for this tube and consists of the actual tube filaments in series with resistor R, which reduces the filament voltage to the proper value (25 volts) for this tube. The heavy line in this diagram indicates the current path when the a-c input cycle is such that the upper terminal in Figure 11 is positive. The light line indicates the current path on the other half of the a-c input cycle. Voltage-doubler power supplies were used rather widely in table model radio receivers and modifications of this circuit are used in many modern television receivers.

Half-Wave Voltage Doublers

Figure 12 illustrates the operation of a half-wave voltage doubler. In (A) of this figure, we see a capacitor and a rectifier tube connected in series across the 115 volts a-c power line. When the polarity of the applied voltage is such that the bottom line is positive, a positive voltage is applied to the plate of V_1. Electrons will flow through the tube (as shown by the arrow) leaving the right hand plate of C_1 positive. This capacitor will charge to the peak value of the applied a-c voltage (163 volts) with the polarity as indicated. On the next alternation of the a-c input cycle, the bottom line is negative. Thus, a negative voltage is applied to the plate of V_1. Current cannot flow in the circuit through the vacuum-tube when the plate is negative in respect to the cathode, so the capacitor will hold its charge. Figure 12(B) shows the polarity and magnitude of the instantaneous voltages at the peak of the second half of the cycle. **(Study this figure carefully.)** The cathode of V_1 is positive with respect to the plate. The magnitude of the voltage is twice the peak value of a-c (326 volts). To understand where this 326 volts comes from, let us add the instantaneous voltages present between the plate and the cathode. Starting at the plate of V_1 and going clockwise through the circuit, we find 163 volts (peak value of source voltage) and 163 volts (charge on the capacitor), both adding in the same direction to give 326 volts between the plate and cathode. Thus, we see that the plate of V_1 is 326 volts negative in respect to the cathode.

Figure 12(C) provides a load resistor and a path for the current to flow, so that this voltage (326 volts) can be used. V_2 is connected opposite to that of V_1, so current will flow through the load as indicated by the arrow. Current flows through the load resistor R_L and through V_2 when the plate of V_1 is negative in respect to its cathode. This produces a pulsating d-c voltage of 326 volts peak across the load resistor R_L. To summarize—when the bottom line is positive, V_1 will conduct, charging C_1 to 163 volts. V_2 will not conduct since its cathode is positive in respect to its plate. When the bottom input line is negative, C_1 will discharge in series with the source voltage, through V_2 and R_L, producing a peak d-c pulse across R_L of approximately 326 volts. This circuit is called a **half-wave** voltage doubler, and its ripple frequency will be the same as the input a-c frequency. The output voltage from this supply without the filter is shown in Figure 12(C).

In Figure 13 we see a half-wave voltage doubler, to which a filter circuit has been added.

Voltage Quadruplers

A d-c output voltage of four times the peak a-c input voltage is obtainable through the use of a voltage quadrupler circuit. A quadrupler consists of two half-wave voltage doublers, each of which is used to charge a capacitor; then, these capacitors are connected in series.

Figure 14(A) is a conventional half-wave voltage doubler. It is the same as Figure 13 without the complete filter. Figure 14(B) is another half-wave voltage doubler. The only difference between Figure 14(A) and 14(B) is that the tubes and capacitors are arranged so that the two circuits operate on alternate half cycles of the a-c input. Notice that C_1 will be charged to twice the a-c peak input, and C_2 will also be charged to twice the a-c input. Figure 14(C) is a combination of both 14(A) and 14(B), with the dotted lines connected and a resistor placed across both output capacitors. Each of these capacitors will charge 326 volts peak. The capacitors are connected in series and the output voltage is taken off from the series combination. The output voltage will be the sum of the two capacitor voltages, and will give four times the peak value of the applied a-c voltage or 652 volts. This 652 volts will be present across the load resistor, but the regulation will be very poor. It is possible through the use of rectifier tubes and capacitors to design circuits giving voltage tripling action, six or eight times the line voltage, or any desired amount. Generally speaking, however, when using power supplies to obtain voltage much in excess of twice the line voltage, it is just as cheap to use a power transformer to do the job.

One important fact, which should be emphasized, is that only alternating current sources can be used with voltage doublers, triplers, quadruplers, etc. No output can be obtained if a d-c power source is connected to any of these voltage multipliers, because the polarity of the d-c power line never reverses.

Rectifier Tube Considerations

One important factor which must be considered when dealing with rectifier tubes, is the ***peak inverse voltage.*** This is the maximum voltage which a tube can withstand when it is not conducting. Figure 15 is a diagram of a half-wave rectifier without a filter. As we have learned, when a plate is positive, current flows through the resistor and tube, developing a voltage drop across the resistor as shown. When the plate is negative however, no current will flow in the circuit, and the entire applied voltage will appear across the tube. Notice that the polarity of the voltage appearing across the tube when it is not conducting is such that the plate is negative and the cathode is positive. The voltage will appear across the tube, when it is not conducting, for the same reason the source voltage will be present across a switch when it is open. When point A is negative with respect to point B, the tube acts as an open switch so there will be no current through the resistor R_L.Since there must be a current through a resistor in order to have a voltage across it, there will be no voltage present across the resistor when the tube is not conducting. The voltage in the series circuit must "add up" to equal the source voltage, so the entire voltage is present across the rectifier tube. The peak value of this voltage will be 1.41 times the rms value of the secondary voltage of the transformer.

In actual operation of a rectifier, the filter will cause the inverse peak voltage to be much higher. Figure 16 is the same as Figure 15, except that a filter has been added. Now, when the tube conducts, C_1 will charge to almost the peak value of the a-c. The polarity of this voltage will be as shown in Figure 16. On the next alternation, when point A of the transformer is negative and the tube is not conducting, let us see how much inverse voltage is appearing across the rectifier tube. Remember, that the capacitor C_1 will hold its charge for some time, therefore adding around the circuit from the cathode of the rectifier tube to the plate, we will have two voltages in series. The capacitor voltage will add to the voltage across the transformer, and the inverse voltage across the rectifier tube will be almost twice the amount of the peak value of a-c secondary voltage. Let us repeat this statement for emphasis. **When a capacitor input filter is used, the inverse peak voltage to which the rectifier tube is subjected, is almost twice the value of the peak voltage across the secondary of the transformer.** When considering a full-wave rectifier, (one with a center-tapped secondary), the peak inverse voltage is twice the peak value of one half of the secondary voltage.

In the design of rectifier tubes, the plate is placed near the cathode to allow more current to flow through the tube. If the plate is too close to the cathode, however, the peak inverse voltage will cause an arc to occur between the plate and cathode. This will ruin the tube. To prevent this from happening, all rectifier tubes are rated as to the maximum peak inverse voltage they can withstand "without arcing over." For example, in a tube manual look up the 5Y3GT rectifier tube. Notice that the tube manual lists the peak inverse plate voltage for this tube to be 1400 volts. Likewise, the peak inverse voltage for a 5U4G tube is 1550 volts. Also, refer to the 35W4 tube, and you will find that the peak inverse voltage is only 360 for this tube.

Example: What should be the peak inverse voltage rating of a tube operating as a half-wave rectifier, if the a-c being rectified is 200 volts rms?

Solution: Peak inverse voltage $= 2 \times 1.41 \times E_{eff}$.
Peak inverse voltage $= 2 \times 1.41 \times 200$.
Peak inverse voltage = approximately 564 volts.

To find the peak inverse voltage of a full-wave rectifier (Figure 17), only one half of the transformer secondary voltage would be used. This is true, because each tube (or each section of the tube) is rectifying only one half the secondary voltage.

Example: What should be the peak inverse voltage rating of the tube in Figure 17, if the total high voltage secondary voltage is 600 volts?

Solution: Peak inverse voltage $= \dfrac{2 \times 1.41 \times E_{eff}}{2}$

Peak inverse voltage $= 1.41 \times E_{eff}$.
Peak inverse voltage $= 1.41 \times 600$
Peak inverse voltage = 846 volts.

If a choke-input filter is used in a power supply, the peak inverse voltage will not be as high as with a capacitor input type of filter. The amount this peak inverse voltage is lowered, is approximately equal to the difference in the amount of no load output voltage between a capacitor input filter and a choke input filter.

Another important rating when considering rectifier tubes is ***peak plate current***. This peak plate current was illustrated in (B) of Figure 2. Peak plate current is limited by the maximum emission of the cathode at normal cathode temperatures. Electrons cannot be attracted to the plate more rapidly than they are emitted, so the emission of the cathode limits the plate current. The amount of peak plate current, which a rectifier tube can safely deliver, is listed in the ratings on rectifier tubes in the tube manual. In addition to this rating, the average plate current which the rectifier tube can safely deliver is listed in the tube manual. Look up these ratings on the 5U4 tube, the 5Y3 tube, and the 35W4 tube in a tube manual.

Mercury-Vapor Rectifier Tubes

When a rectifier tube is conducting, there is current flow within the tube from the cathode to the plate. The electrons encounter some opposition in passing through this region, or to state it in another fashion, there is some resistance present in this path. Therefore, in flowing through this region, the current will cause a voltage to be developed. This voltage drop subtracts from the output voltage in a power supply. An ideal rectifier tube is one which has zero resistance from cathode to plate and an infinite resistance in the reverse direction; however, such tubes do not exist in practice. A certain amount of resistance is encountered by the electrons flowing from the cathode to the plate. The voltage drop across the tube varies with the current. Since this voltage subtracts from the output voltage, it will be a contributing factor in poor regulation in a power supply, since with an increase in current it will cause the output voltage to fall. In the small power supplies, such as are used in radio receivers, this is not serious, but in the power supplies used in electronic equipment where large amounts of power are to be handled, this may become a serious factor. In these high powered applications when tubes are employed, high vacuum tubes are not used. Instead of high vacuum rectifiers, **mercury-vapor tubes** are employed.

Mercury-vapor tubes are vacuum tubes into which a small amount of mercury has been added. As you probably know, mercury is a liquid metal. It is the only metallic element which is liquid at room temperatures. Due to the vacuum, which exists in the tube when the mercury is added, most of this mercury will be vaporized inside of the tube. Since it exists in the tube as a vapor or gas, the name mercury-vapor rectifier tube is used to designate these tubes. Since the mercury vapor in the tube causes a vacuum to be less perfect than in the plain vacuum tube, the term *high vacuum tube* or just vacuum rectifier tube is used to designate a rectifier tube which contains *no* mercury vapor.

The important advantage of a mercury-vapor tube over a high-vacuum rectifier tube is the fact that the mercury-vapor tube has a constant voltage drop across it when conducting. This voltage drop is *small* compared to the high-vacuum tube which has a relatively high voltage drop and which varies with an increase in current. This is a decided advantage, since it will improve the regulation of a power supply.

To understand the action of a mercury-vapor rectifier tube, let us recall a few of the things we have learned about vacuum tubes. In the normal vacuum tube, electrons are emitted from the cathode. Some of these electrons travel to the plate, while many of them form a cloud of electrons about the cathode. This cloud of electrons surrounding the cathode is called the *space charge.* When other electrons are being emitted from the cathode, they find difficulty in passing through this negative space charge region. This is the opposition, which was mentioned, that an electron will encounter in passing from the cathode to the plate. If through some means this space charge is eliminated, or practically eliminated, this opposition will be lowered and the voltage drop across the tube will be lower. Now, let us see how the mercury vapor does this particular thing.

If just a few volts are applied, the tube will act just as a vacuum tube. The space charge will build up around the cathode, and electrons will flow from this space charge to the plate. However, if the plate voltage is raised to about 15 volts, the electrons will be attracted to the plate more strongly, and the velocity of the electrons (the speed at which they are traveling) will be increased. In the mercury-vapor tube, these electrons must go *through* the mercury vapor to get to the plate. This mercury vapor consists of a large number of mercury atoms. In traveling through this region containing mercury atoms, some of the electrons collide with the mercury atoms. If the electron has a velocity greater than that which is attained when the plate voltage is 15 volts, in striking the mercury atoms, they contain enough energy to knock other electrons from the mercury atoms. Each time a high speed electron knocks an electron out of a mercury atom, the atom is left minus one electron. Since the atom is minus one electron, it now bears a positive charge. Such a mercury atom is called an *ion*. After the mercury atom has been *ionized*, two things will occur. The electrons which have been knocked out of the mercury atom, will move toward the plate, increasing the plate current flow, and also the positive ion will be repelled by the positive charge on the plate, and will move toward the cathode into the space charge region. This positive ion is many thousand times as heavy as an electron, so it will move into this region slowly. In so doing, it will attract the electrons from the space charge. These positive ions will be sufficient in number to just balance the number of electrons in the space charge. Thus, the space charge is effectively neutralized, and there is nothing to impede the electrons from traveling to the plate. Whenever there is sufficient voltage (about 15 volts) on the plate to cause positive ions to be formed, the space charge is neutralized, and the plate voltage will be sufficient to attract all of the electrons being emitted by the cathode. This produces a very advantageous characteristic of a mercury-vapor tube. It has a constant voltage drop across it of about 15 volts, regardless of the current drawn. This voltage drop is much lower than a high vacuum rectifier, in which the positive plate must not only attract electrons, but must attract them against a force of the negative space charge, forcing them back toward the cathode. Since the voltage drop in a mercury-vapor tube is constant, regardless of the current drawn, the mercury-vapor tube will give better regulation than a high vacuum rectifier tube. However, it is not as rugged as a high vacuum rectifier tube and requires more care in operation. For this reason, high vacuum-tubes are almost universally used in receiver supplies. Mercury-vapor tubes find wide application in industrial electronics equipment.

The symbol for the mercury-vapor rectifier tube is the same as that for other rectifier tubes, except there is a small round dot shown in the schematic symbol. When this dot is shown in any tube, it means that it is not a high vacuum-tube, but is a gas type tube. In this particular case, the gas within the tube is mercury vapor.

When operating, a mercury-vapor rectifier tube emits a brilliant blue glow which quickly distinguishes it from a vacuum-rectifier tube. This blue glow is produced by the ionized mercury atoms and is very similar to the light given off by a mercury-arc lamp.

Several precautions must be observed when operating a mercury-vapor rectifier tube. In the first place, it must be operated within certain specified temperature limits—a temperature range from 24 to 60 degrees centigrade being rather common. The reason a mercury-vapor tube should not be operated at too high a temperature is that as the tube becomes hotter, the gas pressure in the tube becomes greater. It might be said that there is a little less vacuum. The greater the gas pressure in the tube, the easier it is for the tube to "arc back" from plate to cathode when the plate is highly negative. In other words, if the tube becomes too hot, the inverse peak rating of the tube will be reduced. If the tube is operated too cold, not enough positive ions are formed to neutralize the space charge. At cool temperatures, some of the mercury vapor condenses and is deposited on the glass envelope as liquid mercury. There are not enough mercury atoms left in the form of a vapor for the electrons to collide with, so not enough positive ions are formed. Consequently, some of the space charge remains and the voltage drop across the tube will increase to a figure much higher than 15 volts. If this voltage rises above about 22 volts, the cathode of the tube will be destroyed. At voltages above 22 volts, the positive mercury ions have sufficient velocity that they travel on through the space charge region, striking the cathode. At voltages in excess of 22 volts, the velocity of these ions is great enough to damage the cathode when they hit it (they actually knock small chunks out of the cathode emitting material). This rapidly destroys the cathode. This is known as ***positive ion bombardment*** of the cathode and is serious if the tube is operated too cool.

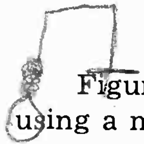
For the same reason, the cathode must be fully heated before plate voltage is applied. In all but a few mercury-vapor tubes, this is *very* important. If plate voltage is applied at the same time as heater power, then there will be a high voltage drop when the cathode is just warming up and emitting few electrons. The plate to cathode voltage will be much greater than 22 volts and again positive ion bombardment will destroy the cathode. Many power supplies employing mercury-vapor tubes have either separate filament and plate switches, or employ a time delay device so that when the switch is thrown, the heater power is applied but plate power is applied only after a time delay (usually about 30 seconds).

One disadvantage of mercury-vapor tubes is the fact that the output signal contains an r-f component which produces an undesirable noise in nearby radio receivers. To eliminate this noise, small air core choke coils are often connected in series with the plate leads of the rectifier tubes.

Mercury-vapor tubes must not be required to deliver more **peak** current than that for which they are designed. It will be recalled that capacitor-input filters require a high peak current, much higher than choke-input filters. For this reason, capacitor-input filters are never used with mercury-vapor tubes.

Let us summarize the action of mercury-vapor tubes.

1. When mercury-vapor tubes are used, much better regulation is obtained from a power supply.
2. A choke-input filter is always used with mercury-vapor tubes.
3. Mercury-vapor tubes must be operated within the proper temperature range.
4. Plate voltage should not be applied until after the cathode has reached full operating temperature.



Swinging Choke

Figure 18 shows the schematic circuit diagram of a full-wave rectifier, using a mercury-vapor rectifier tube and a two-section choke-input filter. This circuit will produce an output voltage which is fairly constant and which therefore has good voltage regulation. However, an increased current demand on this power supply will cause some drop in voltage since this increased current will be flowing through the chokes in the filter circuit and through the secondary winding of the power transformer. For this reason, the voltage will fall under increased loads. With the mercury-vapor tube shown, the amount the voltage will decrease is not as great as if a high-vacuum rectifier tube is used, but the regulation is still not as good as could be desired. To increase the regulation, a *swinging choke* is often used in the place of Ch_1 in Figure 18. A swinging choke is one whose inductance varies with the amount of d-c current being drawn. To get an understanding of the advantage of this, look carefully at Figure 18. Let us assume that we have some means of shorting out choke Ch_1 when desired. That is, let us assume that we can connect a lead from A to B at will. If the power supply is delivering some low value of current, let us leave choke Ch_1 in the circuit. In this case, the power supply will be operating as a choke-input filter and the output voltage will be lower than if we have a capacitor-input filter. Now let us assume that for some reason an increased amount of current is desired from our power supply. This increased current will flow through chokes Ch_2 and Ch_1 and also through the secondary of the power transformer, producing a d-c voltage drop which will lower the output voltage. This is undesirable. Now let us assume that we are able to connect our shorting wire from A to B at this instant. Now the power supply is operating with a capacitor-input filter. The output voltage would be higher than previously, and the amount of increase due to shorting out the choke will just about cancel out the amount of decrease produced by the d-c voltage drop in the chokes and transformer. For this reason, it would be highly desirable to have such a circuit that would operate as a choke-input filter with low values of current and capacitor-input filter with high values of current. It is not possible to design a power supply which would do just this, but the use of a swinging choke closely approximates this. The inductance of a swinging choke is high when the d-c current is low, and the inductance is low when the d-c current is high. Now let us look at Figure 18, assuming that the choke Ch_1 is a swinging choke. When a low value of current is being drawn by the load, the choke Ch_1 is a large inductance and the filter will operate very efficiently as a choke-input filter. However, as the current of the load increases, the inductance of choke Ch_1 will be decreased. Under these conditions, choke Ch_1 is not very efficient as a filter choke. In other words, the filter acts more like a capacitor-input filter, and the voltage increase due to the action of the capacitor-input filter cancels the voltage decrease produced by the added current drawn through the d-c resistance of the chokes and transformer. For this reason, the incorporation of a swinging choke as the input choke in the filter will greatly improve the regulation of a power supply. In almost all large power supplies where the load is varying (such as those used in large public address systems, radio and television transmitters, etc.), swinging chokes are used in conjunction with the mercury-vapor tubes to obtain good regulation.

Power Supplies Using "Solid-State" Rectifiers

Just as we have found that solid-state devices—transistors—are being used to replace vacuum-tubes in many of the more modern circuit designs, so will it be found that solid-state devices—diodes—are being used in place of vacuum-tube rectifiers in the majority of newly designed circuits.

There are three solid-state diodes which have been used to replace the diode vacuum tube. These are the **selenium** diode, the **germanium** diode, and the **silicon** diode. The first of these rectifiers to be developed was the selenium diode and a photograph of a typical selenium rectifier unit is given in Figure 19(A). These rectifiers are manufactured in a number of sizes, with current ratings of 100, 150, and 250 milliamperes at 130 volts rms input voltage being the most popular. These selenium rectifier units are manufactured by a process wherein crystalline selenium is deposited on a metal carrier plate. The rectifier units are then subjected to a voltage, and a film forms on the layer of the selenium. This film is called the barrier layer. When an alternating voltage is applied to a selenium rectifier, current will flow through the barrier layer to the metal carrier plate, but will not flow in any appreciable amount in the opposite direction. Thus, because the current flows in only one direction, the selenium unit will act as a rectifier.

Under operation, selenium type rectifiers generate heat; but high temperatures must be avoided since above a certain definite temperature, current will pass in either direction and the rectifying action will stop. Selenium rectifiers are made with a flange on alternate plates to increase the radiation of heat and keep the temperature of the rectifier unit below the critical point. These heat radiating flanges may be seen on the selenium rectifier shown in Figure 19(A).

Radio and TV receivers, and commercial electronics equipment designed during the period of ten years following World War II, utilized selenium rectifiers most frequently in half-wave rectifier circuits and in voltage-doubler circuits of various types. In such applications, the selenium rectifiers have several advantages over vacuum-tubes. One of these advantages is the reduction in the power consumption due to the fact that no filament power is required for the rectifier. Also, since these units operate cooler than a rectifier tube, much less damage is done to circuit components due to heat. Another advantage of the selenium rectifier over a high-vacuum rectifier tube is that it has a small voltage drop across it when conducting. The voltage drop across the selenium rectifier under its full rated load is approximately 5 volts. This will greatly improve the regulation of a power supply.

Figure 19(B) shows a half-wave power supply using a solid-state rectifier. The symbol for all solid-state rectifiers is the same, an arrowhead and straight line. The current flow is from the straight line to the arrowhead as indicated in Figure 19(B). The current-limiting resistor should always be used in series with these rectifiers and the input capacitor of the filter system. This will protect the rectifier from the high surge of charging current that flows through the rectifier from the input capacitor when the circuit is first energized. Normally, a resistor of about 50 ohms is used in this application. Since this is a series circuit (the source, rectifier, resistor, and capacitor), the limiting resistor may be connected between the rectifier and the capacitor or between the rectifier and the line (See Figure 20). In many of these power supplies, the filter choke is replaced by a resistor. The filtering action of the resistor will not be as good as that of a choke, but it is much cheaper.

Figure 20 shows the schematic diagram of a full-wave voltage doubler employing two solid-state rectifiers. In this case, one current-limiting resistor (R) is used to limit the current through the two rectifiers when the unit is first energized.

The selenium rectifier is not perfect. For one thing, it does not have infinite resistance in the reverse direction. Furthermore, the selenium rectifier will fail because of **excessive applied voltage, excessive cell heating,** or **gradual deterioration,** called aging. Also, selenium itself is one of the scarcest elements on earth and there is an acute shortage; so much so, that at the time these rectifiers were finding their widest use, most manufacturers would buy back defective rectifiers to reclaim the selenium.

The fact that selenium rectifiers offer definite advantages over vacuum-tube rectifiers but have certain disadvantages in themselves led to further development in the field of solid-state rectifiers. The two developments of this research are the **germanium rectifiers** and the **silicon rectifiers**. These rectifiers possess the desirable characteristics of low forward resistance and high reverse resistance.

Germanium Rectifiers

Germanium is a grayish-white, rare metal. A sandwich of **very pure** germanium and germanium with appropriate impurities added form the actual rectifier unit. In most germanium rectifiers, the actual rectifying element is no more than one-eighth inch square. However, since germanium is affected by humidity, the unit is customarily mounted in a hermetically-sealed metal container about the size of a pencil eraser. Also, because the germanium rectifier is affected by heat, some means is usually provided for dissipating the heat generated. Figures 21(A) and (B) show two germanium rectifier units. The hermetically-sealed section is labeled in each figure and the actual rectifying element is inside of this metal container. It will be noted that the bulk of the unit consists of the mounting and heat dissipating flanges.

The reverse voltage at which germanium cells will break down **increases** as the size of the actual rectifying element **decreases.** Thus, higher breakdown voltages can be obtained from germanium rectifiers by using small rectifier elements. Years of life testing of germanium rectifiers indicates that these rectifiers do not age with time as the selenium rectifiers do.

Germanium rectifiers fail for two principle reasons: 1. They fail if the inverse voltage exceeds the dielectric breakdown value of the rectifier, and; 2. They fail if the heat generated in the rectifier is not dissipated and the temperature exceeds the melting point of the germanium. For the latter reason it can be seen that high temperature is the enemy of germanium rectifiers. This accounts for the elaborate arrangement illustrated in Figures 21(A) and (B) to conduct the heat away from the rectifier unit.

Germanium rectifiers offer outstanding advantages over selenium rectifiers: 1. Low forward drop, unexcelled by **any other** type of rectifier with the same inverse voltage rating. 2. Reverse resistance so high that its effects are negligible for most applications. 3. No aging and, therefore, indefinitely long life; also, as compared to rectifier **tubes**, no filament burnout. 4. Ability to withstand shock and vibration—no moving parts, flimsy supports, or sensitive filaments.

As has been mentioned, the schematic symbol for a germanium rectifier is the same as that for a selenium rectifier. Thus, the circuit arrangements illustrated in Figures 19 and 20 could be those of a germanium rectifier, as well as a selenium rectifier.

The fact that a germanium rectifier is critical as far as its maximum temperature is concerned limits the current which such a rectifier can handle. Few germanium rectifiers have been made with current ratings in excess of 400 mA.

Silicon Rectifiers

Although the germanium rectifier is a very good and highly efficient rectifier, it has been largely superseded by the silicon rectifier. This is primarily because silicon rectifiers can withstand inverse voltages three times as high and temperatures twice as high as germanium units. As a result silicon rectifiers can be manufactured to handle much higher values of current.

Some silicon rectifiers are made in the low current range (100 to 500 mA) and, in such instances, may have an appearance similar to small resistors as illustrated in Figure 21(C).

High current silicon rectifiers usually are manufactured in shapes which differ from those which have been illustrated for selenium and germanium rectifiers. Figures 21(D), (E), and (F) show three high-current silicon rectifiers. The rectifier illustrated in Figure 21(D) will rectify 5 amperes of current; the one in Figure 21(E) will rectify 35 amperes of current; whereas, the unit pictured in Figure 21(F) will safely handle 75 amperes of current at 212°F. The nickel shown alongside the rectifier of Figure 21(F) will give an indication of the physical size. Single rectifiers up to 500 amperes are available and in appearance, are similar to Figure 21(F).

In the rectifiers illustrated in Figures 21(E) and (F), the base of the rectifier is silver-soldered to a copper mounting stud. The copper stud serves as one electrical connection and also provides a means for joining the cell to a heat "sink" to dissipate the heat produced by cell losses. (The term heat sink is used to refer to a relatively large piece of metal the purpose of which is to dissipate heat.) The other electrical connection is made to the flexible lead. The actual rectifier element is hermetically sealed so that it will not be affected by atmospheric conditions.

The forward voltage drop of a silicon rectifier is approximately 40 per cent higher than for a germanium rectifier of the same rating and the reverse characteristics of a silicon may be several hundred times less than that of germanium. Thus, it can be seen that the silicon rectifier is inferior to the germanium in some respects. However, the silicon rectifier's ability to operate properly under conditions of high temperature, and consequently high current, outweigh these disadvantages.

The silicon rectifier adapts itself to both parallel and series connections for higher current and voltage ratings. For instance, 10,000 volt peak inverse rectifiers are available and 300 volt, 100,000 ampere installations are already in use, in industrial electronic applications.

Vibrator Power Supplies

In the preceding discussion, we have dealt with power supplies which can be operated from the 115-volt a-c supply line, or in some cases, from the 110 volt d-c supply line. However, in certain applications such as automobile radio receiving sets, such supply lines are not available.

The very earliest of automobile radio receiving sets used the 6 volt storage battery in the car as a source of power for heating the filaments of the vacuum-tubes and provided space for carrying several 45 volt "B" batteries for the plate voltage supply. Since the 6 volt car battery is kept in a well charged condition by the car's generator when the motor is running, it was obvious that an attempt would be made to secure all of the needed power from this battery. At first, small dynamotors were used to furnish the plate power. A dynamotor consists of a d-c motor and a high-voltage d-c generator all in the same case. A typical dynamotor may operate from a supply voltage of 6 volts at a current of 4 amperes d-c, and deliver an output voltage of about 180 volts at 50 milliamperes direct current. Of course, this power does not equal the input power and the difference is used up in friction of the bearings of the motor generator and the resistance of the winding, etc. While dynamotors are very practical sources of higher values of d-c voltages from a low voltage d-c source, they are expensive, and for this reason have been seldom used in portable radio equipment since the development of less expensive and more efficient means.

As we learned in the assignment on transformers, a transformer cannot be used to step-up the 6 volts d-c to some higher value of d-c, since a **changing current** is required to produce a voltage across the secondary of a transformer. However, it was pointed out in the assignment on transformers that, if a d-c current was passed through the primary of a transformer, a pulse of voltage would appear across the secondary of the transformer during the interval that the current was building up from zero to its final fixed value. This is illustrated in Figure 22. The circuit in Figure 22 consists of a battery and switch connected in series with the primary of the transformer. At the instant the switch is closed, the current through the primary of the transformer increases from zero to some fixed value. In other words, during the instant that the switch is closed and for a fraction of a second thereafter, the current is **changing.** The graph in Figure 22(B) shows how the voltage across the secondary of this transformer would vary. During the instant the switch was closed, the voltage would increase as shown in the graph. If the switch were allowed to remain closed, the primary current would reach some constant value and the field would no longer be changing. Under these conditions, the voltage across the secondary would drop to zero as shown at B of Figure 22(B). Thus by closing the switch in the primary circuit, we have produced a **pulse of voltage across the secondary.** As long as the switch remains closed, the secondary voltage will remain at zero as shown from B to C in Figure 22(B).

When the switch is opened as shown at C in Figure 22(B), a voltage of the opposite polarity will be built up across the secondary of the transformer. This voltage is produced due to the collasping of the magnetic field which results when the switch is opened in the primary circuit. Thus, we see that by closing and then opening the switch in series with the primary circuit, an a-c voltage has been built up across the secondary winding of the transformer. Hence, if it were possible to open the switch at point B, so that B and C coincided on the graph in Figure 22(B), we would have a voltage across the secondary appearing as shown in (C) of Figure 22. This is an a-c voltage, but differs from a sine wave in that it is more of a flat-topped wave. A special type of magnetically controlled switch is used to open and close the circuit between the battery and the primary of the transformer. This unit operates at a high rate of speed and is called a **vibrator.** We will study the action of vibrators shortly, but before doing so, let us consider another practical method of producing this a-c voltage across the secondary of the transformer.

Figure 23 illustrates a circuit which can be used to cause a current to flow through the primary first one direction and then in the other direction. Thus, effectively, an a-c current is caused to flow through the primary of this transformer. When the switch is in position 1, as shown in Figure 23, current flows from the battery down through the lower half of the primary winding, back through the switch to the positive side of the battery. This will cause a voltage to be built up across the secondary between X and Y in Figure 23. In this case, as the switch is opened, the magnetic field built up due to current flowing in the lower portion of the primary collapses, but at the same time the switch is closed in position 2. Thus, a magnetic field is building up in the top half of the transformer (due to current flowing in the primary from A to C) at the same time. The dotted arrow in Figure 23 indicates the direction of current flow through this half of the primary winding. Notice, that it is opposite to the direction of current flow when the switch is in position number 1. **The magnetic field,** which is produced by the current increasing through the top half of the primary winding, is in the same direction as the **collapsing magnetic field** from the lower half of the transformer primary. Thus, the two fields are aiding one another and generating a voltage across the secondary X and Y which is equal to twice that which would be produced by either of the primary magnetic fields alone. Thus by using a double-throw switch as shown in Figure 23, an alternating current is made to flow through the primary and an alternating voltage will appear across the secondary.

By using the method illustrated in Figure 22(A) or Figure 23, an a-c voltage is obtained across the secondary winding. We could apply this secondary voltage to a rectifier, filter the output from the rectifier, and obtain a d-c output. However, it would be rather difficult to obtain a d-c comparable to that from a battery. One of the main reasons for this is the fact that a voltage across the secondary differs considerably from that of a sine-wave voltage. Actually, the voltage across the secondary consists of very sharp pulses of voltage. This makes the filter job quite difficult. This also produces sparking of the switch contacts, because the rapidly changing magnetic field in the transformer induces a counter emf in the primary winding, which causes arcing between the contacts of the switch. This will soon result in the switch contacts becoming pitted and the switch ruined. This condition, however, may be eliminated by connecting a capacitor across the secondary winding from X to Y in Figure 23. As the voltage from X to Y starts to increase, the capacitor will charge. This tends to reduce the sharpness of the peaks of voltage in the secondary circuit, thus reducing the counter emf, thereby reducing the sparking at the switch contacts. Also, as the secondary voltage begins to reverse, the capacitor discharges and helps to give a secondary voltage which is much less peaked. This capacitor, which is connected across the secondary winding of such a transformer, is called a **buffer** capacitor. It is shown as C_1 in Figure 24.

The size of the buffer capacitor is quite critical. The size of this buffer capacitor is determined by the design of the particular transformer and the rate of closure of the switch. Only one size capacitor will work effectively with a given transformer and vibrator. In replacing a defective buffer capacitor, the capacity of the replacement capacitor should always be identical with that of the original capacitor. Also, the buffer capacitor voltage rating should be quite high, normally 2000 volts, since the voltage surges across the secondary will reach quite high values on the peaks.

Vibrators

Figure 24 shows the circuit for a popular type of vibrator and Figure 25 shows a drawing of the construction of this vibrator. Examine Figure 25 to get a clear picture of the construction of a vibrator in your mind. A vibrator consists fundamentally of three parts; the coil (which forms the electromagnet), the reed (which vibrates and upon which is mounted two contacts), and two fixed contacts (against which those on the reed operate). As the reed vibrates, contact will be made first between the right-hand fixed contact and that on the reed, and then between the left-hand fixed contact and that on the reed. Let us examine Figure 24 to see why the reed vibrates and how the unit is connected in the circuit. When the switch SW is first closed, there will be a current path as indicated by the dotted line. This current flow will be through the top half of the primary winding, through the coil of the electromagnet to ground, and from ground back to the positive side of the battery. This current flow will energize the electromagnet and cause it to draw the reed to it. As the reed is drawn toward the electromagnet, it will close the contact between the movable contact on the reed and the fixed contact A. This will cause a high value of current to flow through the top half of the primary winding, through contact A to the reed, and back to the battery, which induces a voltage in the secondary. Also, at this same time, current will cease flowing in the electromagnet due to the fact that the electromagnet is shorted out by the wire leading from the top connection on the primary winding of the trans former to contact A. Since the path through this wire is of much lower resistance than that of the electromagnet, very little current flows through the electromagnet and it becomes de-energized. Therefore, the electromagnet releases the reed, and the reed springs back toward its original position. However, the reed is made of spring steel, and its degree of springing carries it beyond its original resting position until it comes in contact with fixed contact B. When this occurs, the current will no longer be flowing through the top half of the primary winding, but will be flowing through the bottom half of the primary winding through contact B, and back to the battery. Thus, we have caused current to flow first through the top half of the primary winding and then through the bottom half of the winding, as in Figure 23. After the contact has been broken between contact A and the reed, the electromagnet will again be energized, and the magnetic field soon builds up to a sufficient value to pull the reed back toward it, breaking contact B and closing contact A. This cycle of operation continues as long as the switch SW is closed. The rate at which the reed vibrates is determined primarily by the stiffness of the steel of the reed spring and other physical dimensions (for example, the spacing of the contacts, etc.). Most vibrators operate at a frequency of about 115 cycles per second.

Rectifiers For Vibrator Supplies

We have seen how it is possible to apply pulsating direct current to the primary of a transformer and obtain a-c voltage across the secondary of the transformer. Let us now see how this a-c is rectified. Figure 26 is a schematic diagram of a complete circuit of a very common type of vibrator supply. The rectifier circuit is that of a full-wave rectifier and there are very few differences between this circuit and that which we have already studied. One difference is the fact that the heater power for the tube is obtained from the storage battery of the automobile. Typical examples of tubes which are used in this application are the 6X4 and 6X5 rectifier tubes in cars with 6 volt ignition systems, and the 12X4 for cars with 12 volt ignition systems.

Due to some sharp voltage pulses, which result even with the buffer capacitor C_3 connected as shown, additional filtering is needed in a vibrator type of supply. The characteristics of these voltage pulses are such that they will produce radio-frequency interference or noise. It is common practice to use an r-f filter, consisting of a small coil L and a small value of capacitor C, before the pi-type filter. This filter (LC) effectively removes a large portion of this radio-frequency interference. To prevent direct radiation from the vibrator supply into the r-f circuits in the radio, the vibrator unit is usually mounted in a metal container that is grounded. This noise which is produced by a vibrator supply is commonly called **hash** by technicians.

It can be seen from Figure 26, that the vacuum-tube filament circuit draws power from the battery in addition to the power which is drawn to supply the high voltage. If this filament could be eliminated, the drain on the battery would be reduced. Before the advent of transistorized power supplies (which we will study in a later assignment), there were two methods to eliminate the use of filament power. These two methods are the synchronous vibrator and the cold-cathode rectifier tube.

Synchronous Vibrator

Basically, a synchronous vibrator consists of one vibrating reed on which are located two sets of contacts. One set of these contacts is used in the primary circuit just as in the type of vibrator which we have discussed. Incidentally, the type of vibrator which we have discussed previously is often called the non-synchronous vibrator, to differentiate it from the synchronous type. The other set of contacts on the synchronous vibrator is connected in the secondary circuit of the vibrator transformer and is used for rectifying the output voltage. Figure 27 shows the schematic diagram for a synchronous vibrator type of power supply. The electromagnet circuit for this vibrator is the same as that shown for the vibrator in Figure 26, and has been omitted for the sake of simplicity in the diagram of Figure 27. The vibrator transformer is so wound that, when the vibrating reed has been pulled up by the electromagnet so that it is making contact with the top primary contact A and the top secondary contact B, the polarity of the voltage drop across the secondary winding is as indicated in Figure 27. Under these conditions, the secondary current will flow from the top of the secondary winding, through contact B and through the reed to ground. The complete path then continues from ground, through the load resistance R_L, through the filter circuit and back to the center tap of the secondary. The polarity of the voltage drop across the load resistor is also indicated in Figure 27. As the vibrator swings away from contact A and contact B and swings against contact C and contact D, the current through the primary will be in the opposite direction, as was shown in Figure 23. Under these conditions, the polarity of the voltage drop across the secondary winding will be opposite to those indicated in Figure 27, making the bottom terminal on the transformer negative. In this case, current flows from this bottom terminal, through the contact D, to the reed and to ground. The path is then completed from ground, through the load, through the filter, and back to the center tap of the transformer. Notice that, in this case, the current flowing through the load resistor is in the same direction as in the former case. Thus, a pulsating d-c current flows through the load resistor R_L. Thus, we see that the vibrating reed has been used to replace the rectifier tube. The coil L and capacitor C are used as the hash filter. Two buffers are shown in Figure 27. Such a circuit arrangement is often employed. The pulsating d-c output is filtered by the pi-type filter.

In the non-synchronous type of vibrator circuit, it makes no difference if the polarity of the battery voltage is reversed. This is due to the fact that the rectifier tube automatically passes current in the proper direction, because whichever plate is made positive will pass current. However, in the synchronous type of vibrator, care must be exercised regarding the polarity of the battery. When the battery polarity is reversed, the direction of current flow in the primary winding also reverses, which interchanges the secondary polarities. If the battery polarity in Figure 27 is reversed, the top terminal on the secondary will be positive when the reed contact is against contact B. In this case, current flow will be in the opposite direction, from the center tap of the transformer, through the filter chokes, down through the load resistor to ground, and then back from ground through the reed to the top connection on the secondary. Likewise, on the next swing of the reed, when contact is being made with contact D of the secondary circuit, current will again flow in the opposite direction through the chokes and load resistor, causing the voltage drop across the load resistor to be opposite of that shown in Figure 27. Thus, any radio equipment which would be connected to this d-c output would have the wrong polarity and would not operate. Also, it was pointed out in the assignment on capacitors, that electrolytic capacitors must be connected with the proper polarity as the reversed polarity which would result would ruin the capacitors in a few seconds. For this reason, any time a synchronous vibrator supply is connected to a battery source, the polarity of the output voltage should be checked immediately, and if it is incorrect, the proper changes should be made. It would seem that the simple thing to do would be to reverse the battery, but such is not always possible. In a great number of cases, such as cars, boats, etc., where the battery is used for ignition in addition to operating the radio equipment, the battery cannot be reversed. Most synchronous vibrator supplies provide some means for correcting this trouble. Usually a means is provided for reversing the leads to the secondary contacts on the vibrator. This is generally accomplished by reversing the two leads on a terminal board, but is sometimes accomplished by reversing the vibrator in its socket.

Vibrators are housed in metal containers which plug into a socket similar to that used for vacuum-tubes. This makes the replacement of vibrators a simple matter. Vibrators are one source of trouble, due to the fact that the contacts become pitted after continued operation. When this occurs, the operation of the unit will be erratic. This is particularly true of synchronous vibrators since the high voltage contacts are a source of trouble. Also, the synchronous vibrators are quite expensive. For these reasons, synchronous vibrators were not used very widely in mobile equipment. Instead, cold-cathode rectifier tubes were used more extensively.

Cold-Cathode Rectifier Tubes

Figure 28(A) shows the construction of a cold-cathode rectifier tube and Figure 28(B) shows the schematic symbol for this tube. In the cold-cathode rectifier tube, the cathode consists of a hollow metal disc and the plates are pointed rods or wires. These tubes are gas filled as indicated by the schematic symbol, and rectification is caused by the physical construction of the tube. When one of the pointed plates is positive, it is able to draw some of the electrons from the gas within the tube, thus ionizing the gas. The positive ions then move toward the cathode, striking the cathode, causing it to emit more electrons which also go to the positive plate. When the cathode is positive, current cannot flow in the opposite direction due to the fact that the cathode is such a large element (compared to the pointed plates) that whatever charge appears on it, is spread out and does not have enough to draw electrons from the gas and thus ionize it. Since the cold-cathode tube is a gas filled tube, it will emit a purple glow when operating.

Figure 29 shows the diagram of the rectifier section of the vibrator supply using an OZ4 rectifier tube. The capacitors C_1 and C_2 are hash filter capacitors since this gas tube is subject to hash similar to that which is encountered in the mercury-vapor tubes.

While the use of cold-cathode rectifier tubes reduces the drain on the battery, it introduces some disadvantages. One of these is that since the cold-cathode rectifier tubes are gas filled tubes, the temperature of the tube is important. For this reason, these tubes are rather critical in operation and were not used nearly as widely as the vacuum rectifiers such as the 12X4 rectifier tube as was shown in Figure 26.

Voltage-Regulator Tubes

We have seen that through the use of mercury-vapor rectifier tubes and swinging chokes that the voltage regulation of a power supply can be improved, but in most cases it will still be far from perfect. For example, if the line voltage should change and cause the power supply output to change, the mercury-vapor rectifier tube, swinging choke, and even a heavy bleeder current are unable to correct this condition. It is sometimes desirable to maintain a voltage very close to a given value. For such purposes, voltage-regulator tubes may be used. These tubes are generally called **VR** tubes and are available in several ratings: VR75, VR90, VR105 and VR150 are the common types in use. The VR part of the number indicates **voltage regulator,** and the number indicates the amount of voltage which will be maintained across the tube. Thus, a VR75 will regulate the voltage at 75 volts; whereas, a VR90 will regulate the voltage at 90 volts.

A voltage-regulator tube is a gas filled tube which has no filament. When the voltage applied to this tube is sufficiently high, the gas within the tube ionizes and the tube will conduct current. Figure 30 shows the usual circuit used with a VR tube. The resistor R in Figure 30 is a current-limiting resistor and must be used in a circuit containing a voltage-regulator tube.

The action of a voltage-regulator tube depends upon the fact that it does not have a constant value of resistance. Its internal resistance is determined by the number of gas ions between the two elements in the tube. If the voltage from the power supply increases, the number of ions within the tube will increase, the resistance of the tube will drop, and the tube will draw more current. If the output voltage from the filter decreases, there are fewer ions within the tube, the tube resistance increases, and less current flows through the tube.

Thus, if the output voltage from the filter increases, an increased current will flow through the VR tube which is in series with the limiting resistor R. Therefore, a larger voltage drop occurs across the resistor R. The polarity of the voltage drop across resistor R is shown in Figure 30. The regulated output voltage is the difference between the output voltage from the filter and the voltage drop across resistor R. Since the drop across R increases with an increased output from the filter, the regulated voltage remains very nearly constant.

In a similar manner, if the output voltage decreases, the VR tube will cause a smaller amount of current to flow through resistance R, thereby reducing the voltage drop across this resistor and maintaining a constant voltage across the voltage-regulator tube.

In a properly designed circuit employing a voltage-regulator tube, the voltage-regulator tube will maintain the voltage within one or two volts of the proper value. The current which can be handled by a VR tube ranges from a few milliamperes to a maximum of 30 milliamperes. If it is desired to regulate higher values of voltage than can be obtained from one VR tube, two or more VR tubes may be operated in series. Such a circuit is shown in Figure 31. In this circuit, a VR75 and a VR150 are connected in series. Regulated outputs of 150 volts and 225 volts are obtainable. There are also solid-state voltage regulation devices. We will consider these in a later assignment.

Summary

This assignment has been included to familiarize you with some of the specialized power supplies which are used in certain types of electronic equipment. These include the voltage-doubler power supplies which are being used in a great number of relatively inexpensive television receivers, and vibrator supplies. In the wide variety of types and makes of electronic equipment on the market today, various modifications will be found of the basic circuits explained herewith, but if the operation of these basic circuits is well understood, little difficulty will be encountered with these modified circuits.

You are advised to study each of the fundamental circuits carefully to make sure you understand the operation of the circuit. Also, each of the fundamental schematic diagrams should be drawn several times so that a good mental picture of each circuit is obtained.

Test Questions

Use a multiple-choice answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer, except in cases where two answers are required, as indicated. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that answer (A) is correct for Question No. 1, indicate your preference on the answer sheet as follows:

1. [✓ (A)] (B) (C) (D)

Submit your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. Two advantages of solid-state rectifiers over vacuum-tube rectifiers are: (CHECK TWO)
   - [✓ (A)] The solid-state rectifiers require no heater power.
   - (B) Heat presents no problem with solid-state rectifiers.
   - (C) The solid-state rectifiers have higher voltage drops across them while conducting.
   - [✓ (D)] The solid-state rectifiers have lower voltage drops across them while conducting.
2. The main purpose of the resistor, R, in Figure 19 is:

   Wrong
   - (A) To take the place of a swinging choke.
   - (B) To provide better regulation of the output voltage.
   - [✓ (C)] To limit the peak current that will flow, to reduce damage to the rectifier.
   - (D) To reduce the d-c potential difference fed back to the power lines from the rectifier circuit.
3. In the circuit of Figure 6, if the pilot lamp burns out:
   - [✓ (A)] Continued operation of the receiver, without replacing the bulb, will cause part of the rectifier tube filament to burn out.
   - (B) It is a positive sign that a filter capacitor is shorted.
   - (C) It is a positive sign that part of the rectifier tube filament is burned out.
   - (D) The receiver may continue to operate safely, without replacing the bulb.
4. Referring generally to all types of a-c d-c power supplies:
   - (A) An external ground should be connected to the chassis because this will assure proper operating voltages.
   - [✓ (B)] An external ground should never be used unless a "floating ground" bus is employed in the circuit.

(C) An external ground may be used except when a "floating ground" bus is employed in the circuit.

(D) It is never safe to connect an external ground to the chassis even if a ground terminal is provided.

5. A full-wave voltage doubler circuit:

(A) Will deliver approximately twice the peak value of the input a-c voltage, or 326 volts, under normal full load conditions.

(B) Has better regulation than a simple half-wave rectifier power supply.

(C) Will operate equally well on a-c or d-c power sources.

[✓ (D)] Will deliver approximately 225 volts under full load conditions.

6. In the operation of mercury-vapor rectifier tubes, the voltage drop across the tubes:

(A) Is small at first, but increases with changes in load.

(B) Is high at first, but decreases with changes in load.

[✓ (C)] Is fairly constant and is small (about 12-15 volts).

(D) Is fairly constant and is high (about 100 volts).

7. In the operation mercury vapor rectifier tubes particularly in high power applications:

[✓ (A)] The plate voltage should not be applied until the cathode is hot.

(B) The filament voltage should not be applied until after the plate voltage has been applied.

(C) The filament voltage should not be applied until after a blue glow is observed.

(D) The plate and filament voltages are usually applied at the same time.

8. Two types of vibrators can be used to interrupt the flow of d-c through the primary of a transformer, to produce a-c pulses of voltage across the secondary. There are (1) synchronous vibrators and (2) non-synchronous vibrators. Select the true statement below:

(A) The use of a synchronous vibrator necessitates the use of a rectifier.

[✓ (B)] The use of a non-synchronous vibrator necessitates the use of a rectifier.

(C) In a synchronous type of vibrator circuit, it makes no difference if the polarity of the battery voltage is reversed.

(D) In a non-synchronous type of vibrator circuit, if the battery polarity is reversed, the polarity of the rectifier d-c will be reversed.

9. A capacitor, called a "buffer capacitor," is connected across the secondary of the transformer in a vibrator type power supply. Select the true statement below:

(A) The function of a buffer capacitor is to increase the amplitude of the pulses of voltage.

(B) The buffer capacitor is usually an electrolytic capacitor because the voltage across it is d-c.

(C) The buffer capacitor is seldom rated higher than 6 volts when the vibrator is operated at that voltage.

[✓ (D)] The buffer capacitor is normally rated at 2,000 volts.

10. Recently designed power supplies for electronics equipment having **very** heavy current demands will use:

(A) Selenium rectifiers.

(B) Germanium rectifiers.

[✓ (C)] Silicon rectifiers.

(D) Cold-cathode rectifier tubes.

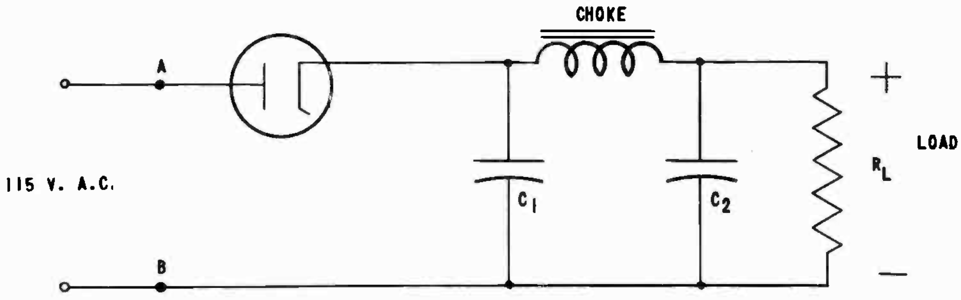
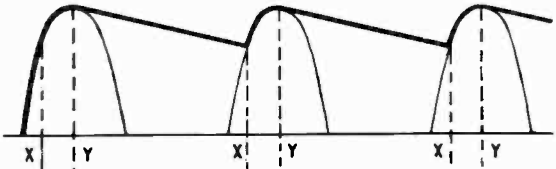
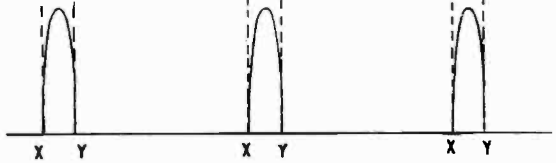


FIGURE 1



(A)

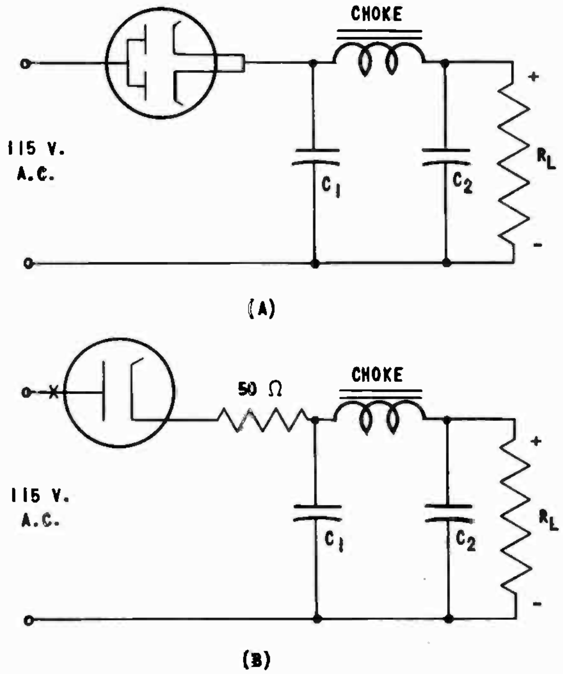
VOLTAGE ACROSS INPUT CAPACITOR



CURRENT INTO INPUT CAPACITOR

(B)

FIGURE 2



(A)

(B)

FIGURE 3

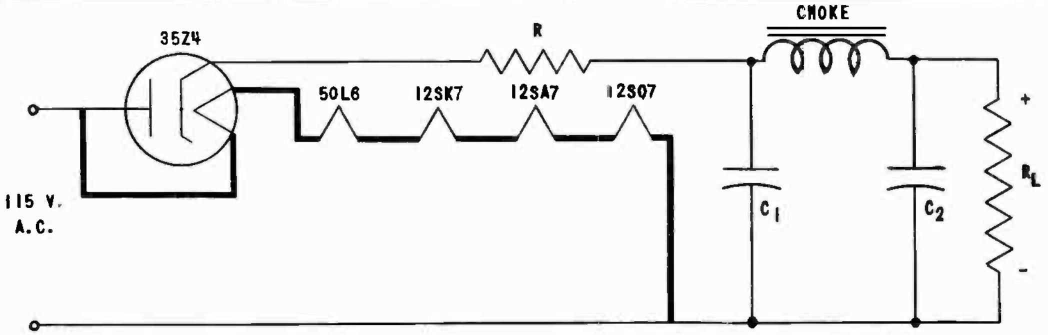


FIGURE 4(A)

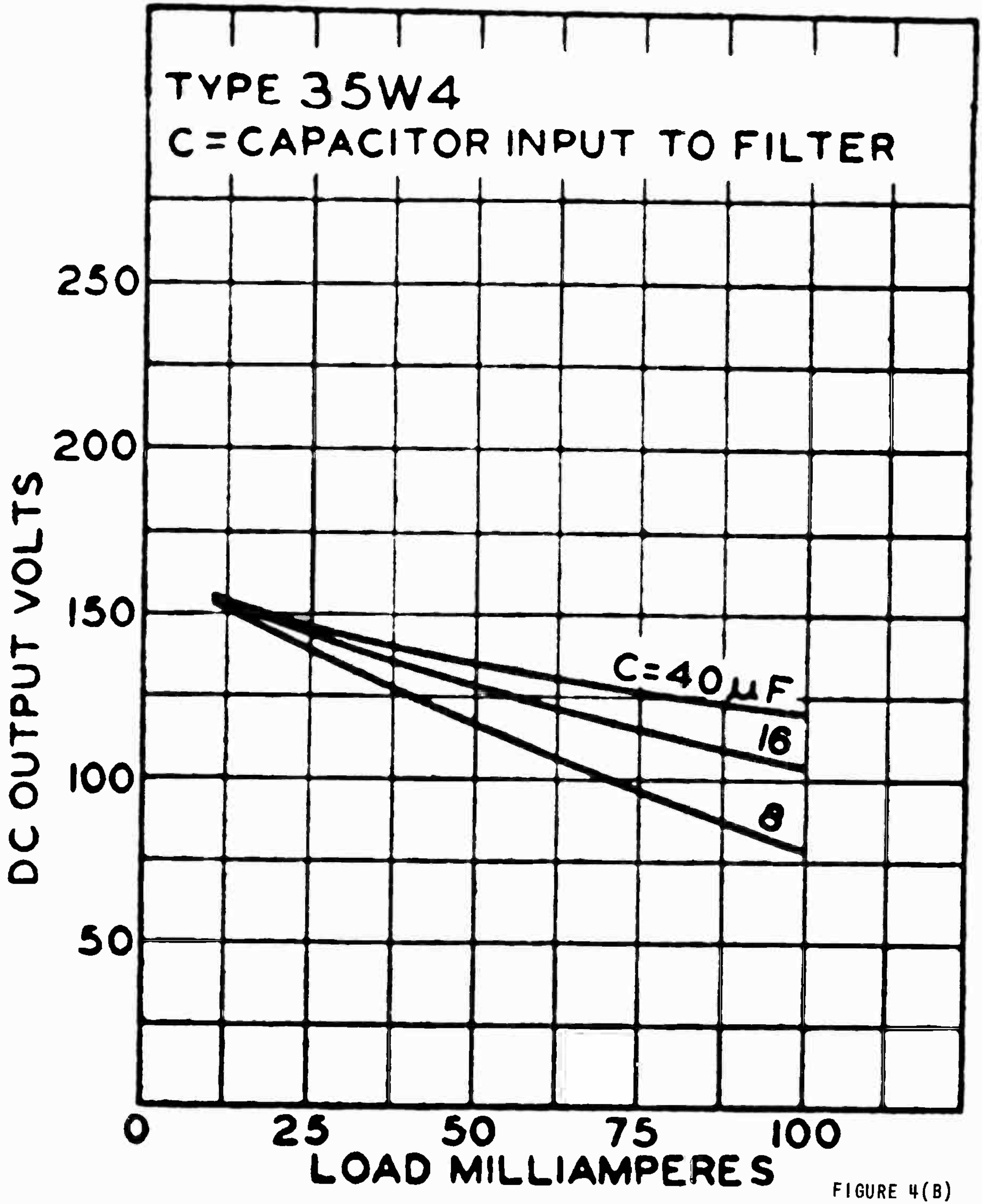

TYPE 35W4
C=CAPACITOR INPUT TO FILTER
DC OUTPUT VOLTS
250
200
150
100
50
0
25
50
75
100
LOAD MILLIAMPERES
C=40 μF
16
8

FIGURE 4(B)

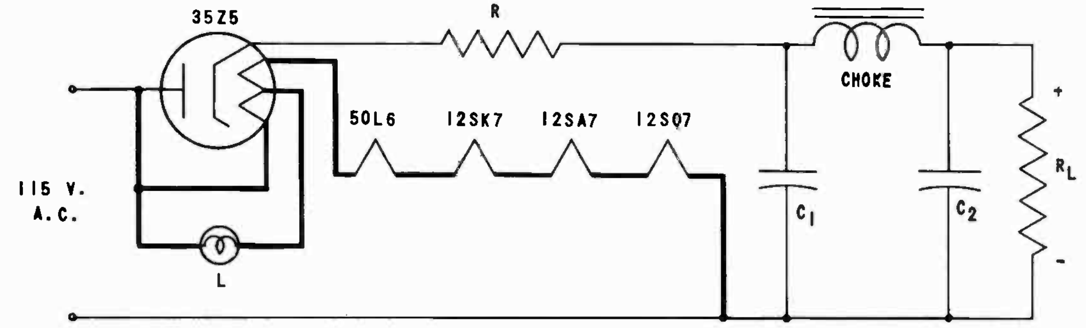


FIGURE 5

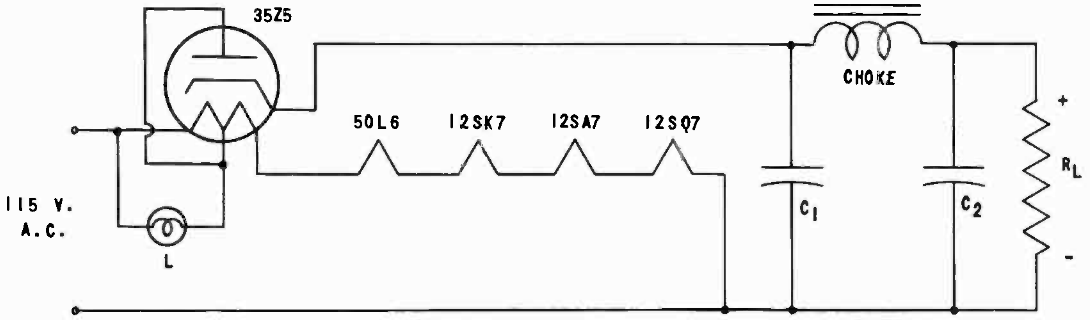


FIGURE 6

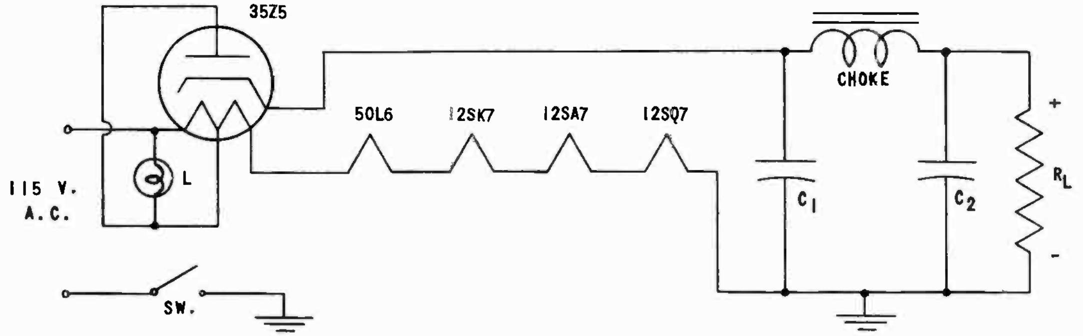


FIGURE 7

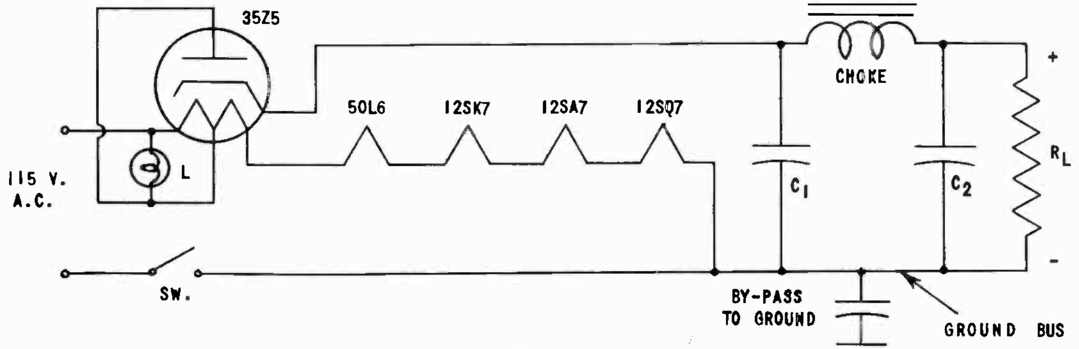
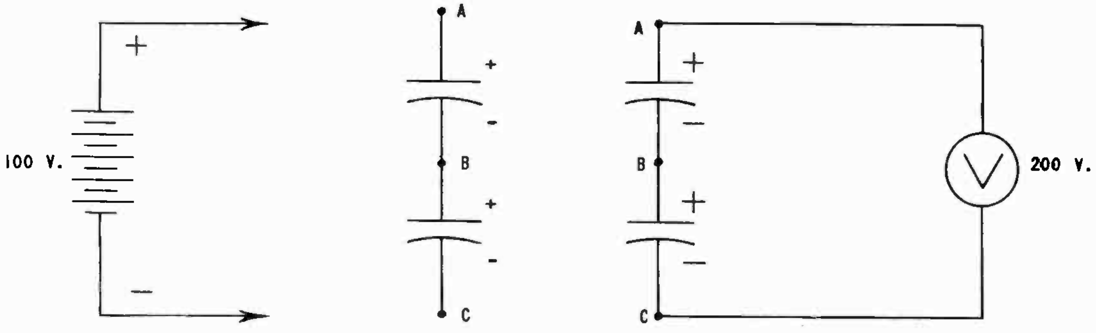


FIGURE 8



(A) FIGURE 9 (B)

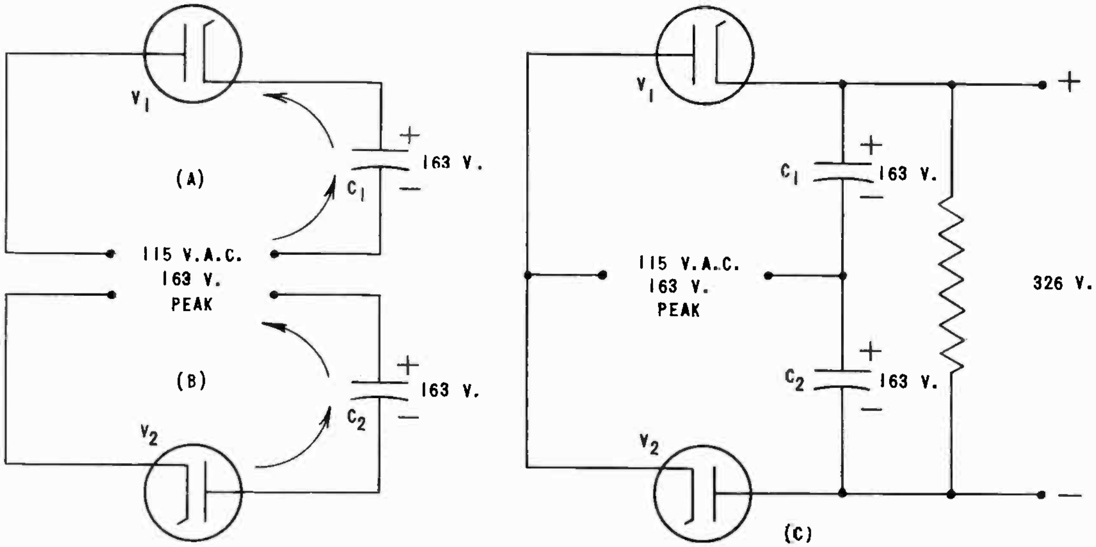


FIGURE 10

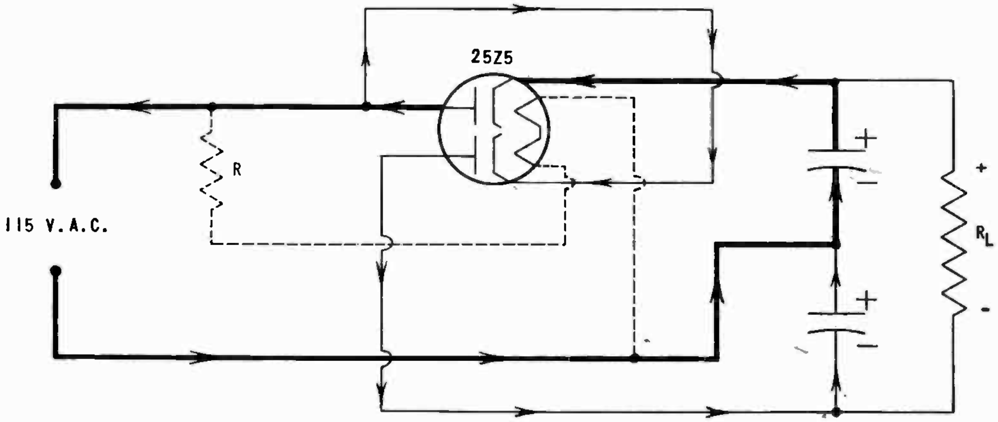


FIGURE 11

24

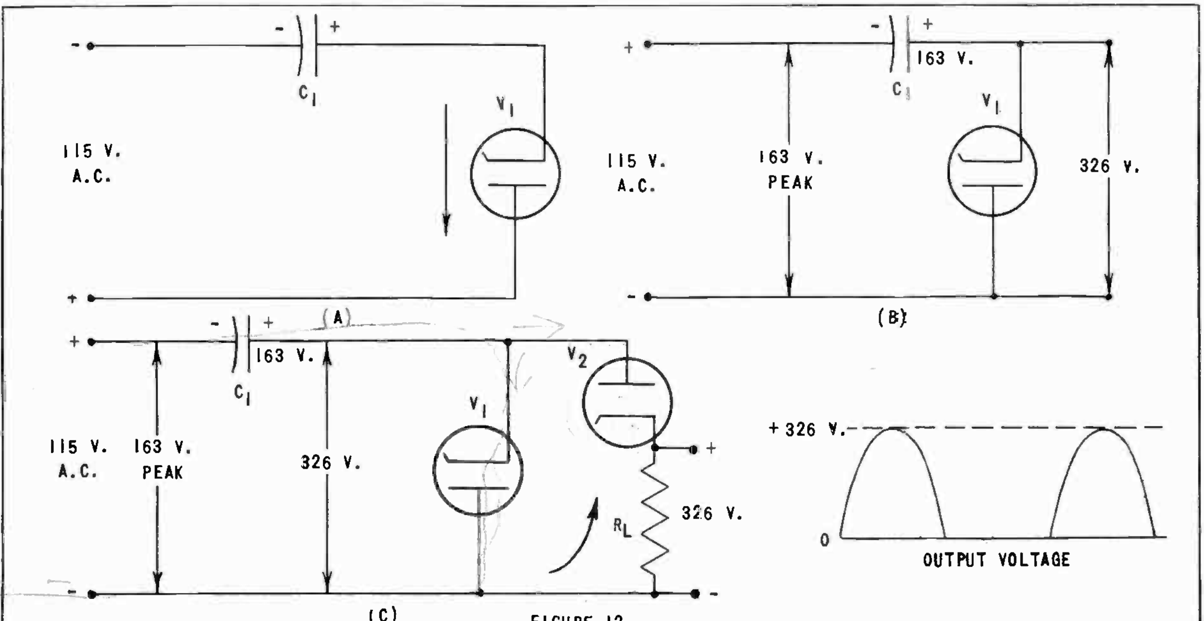


FIGURE 12

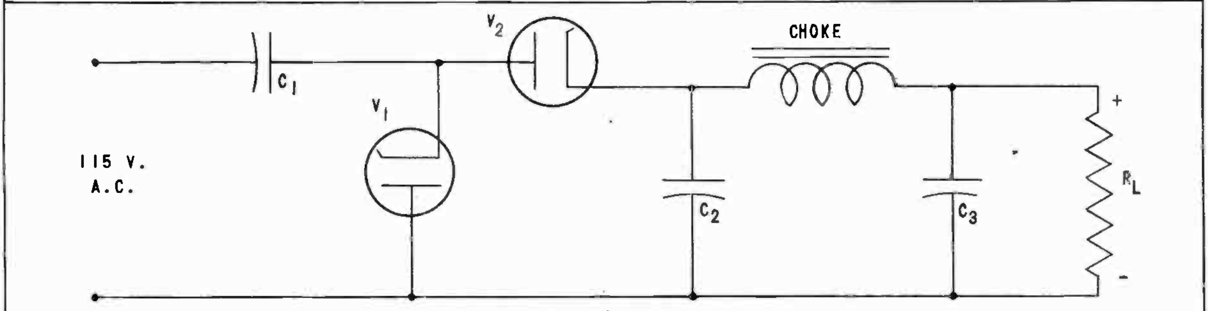


FIGURE 13

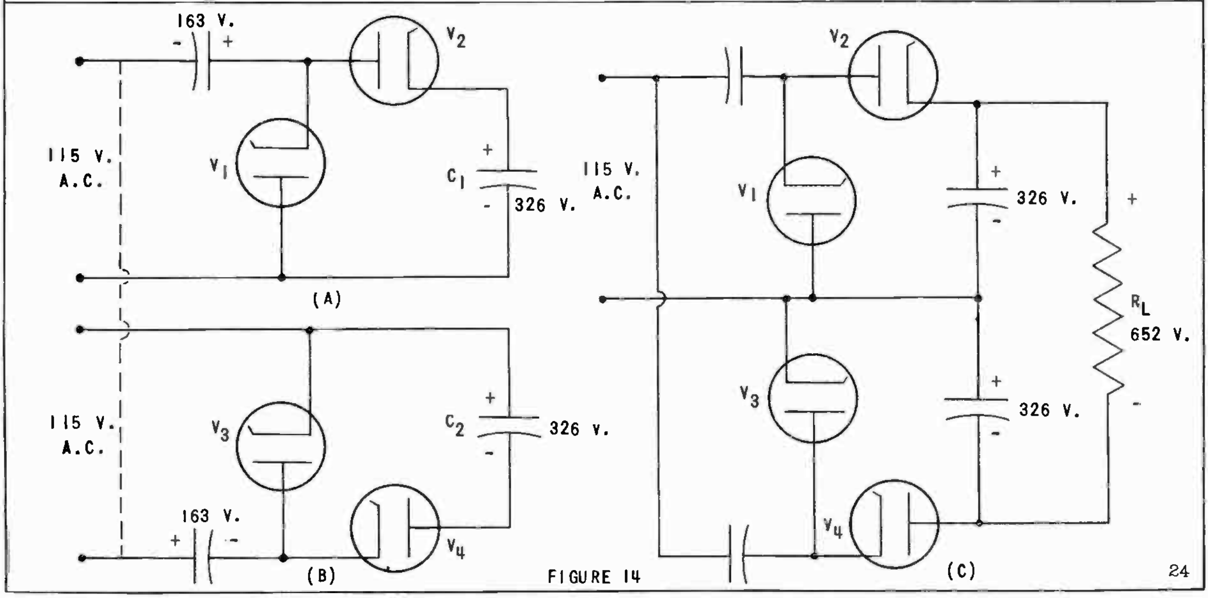


FIGURE 14

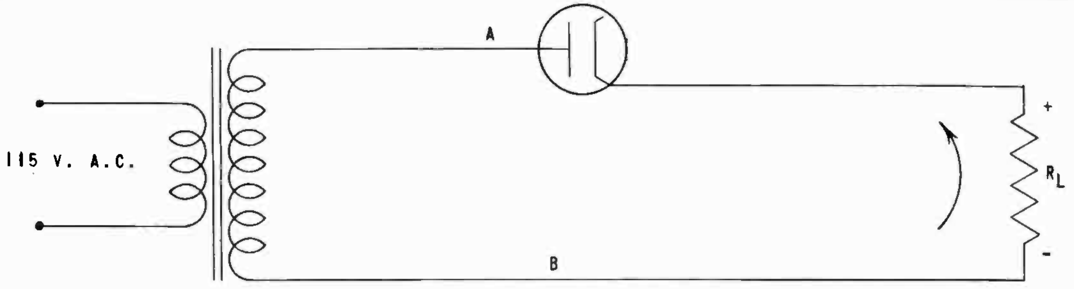


FIGURE 15

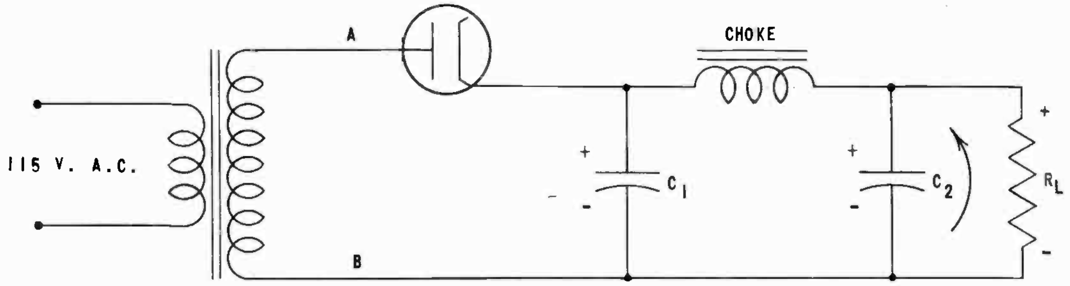


FIGURE 16

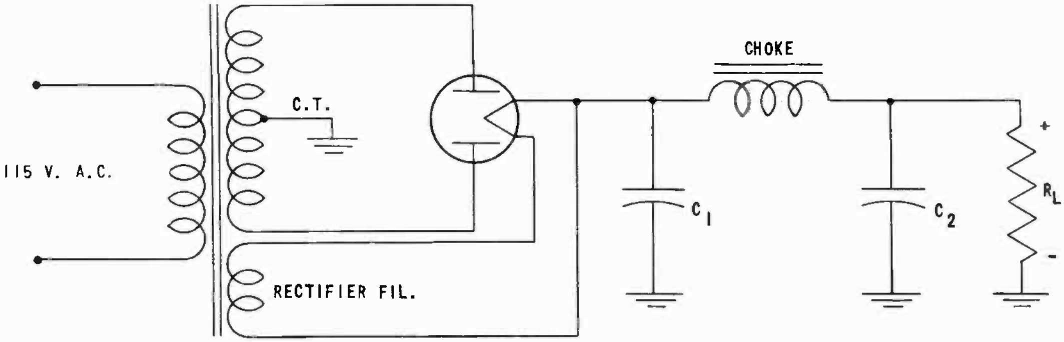


FIGURE 17

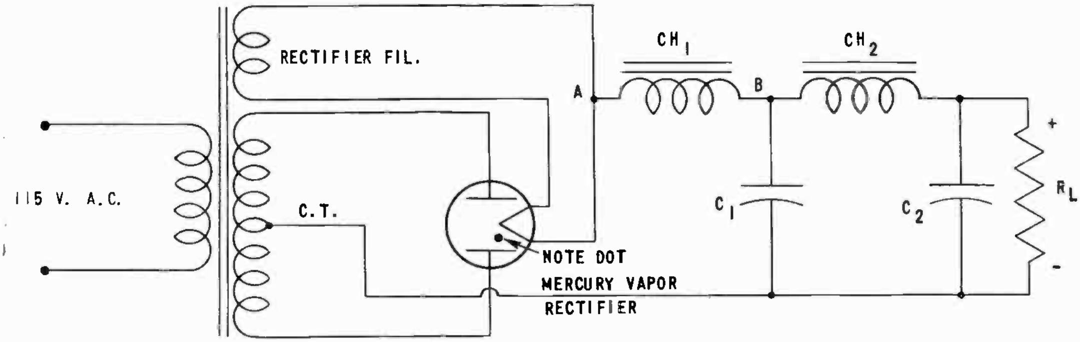


FIGURE 18

24

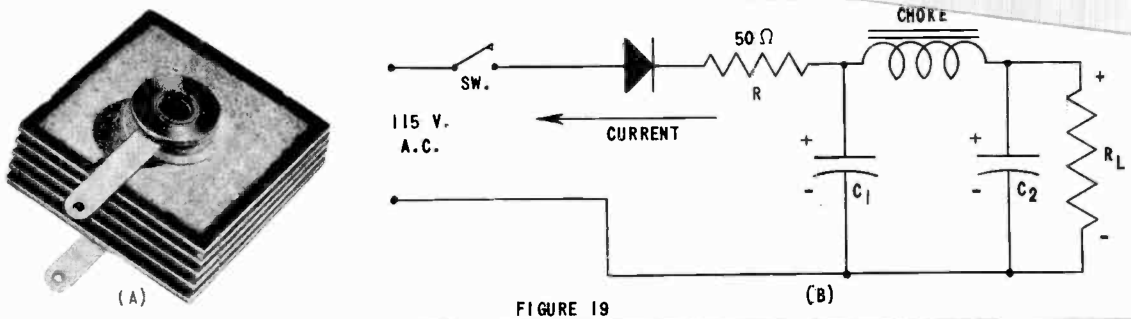


FIGURE 19

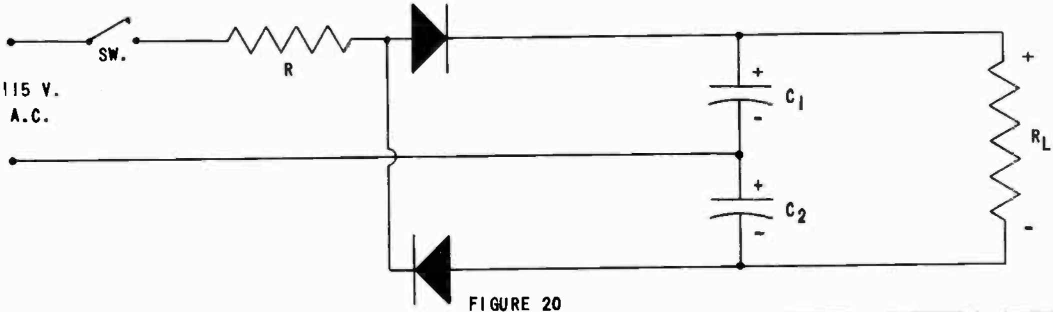


FIGURE 20

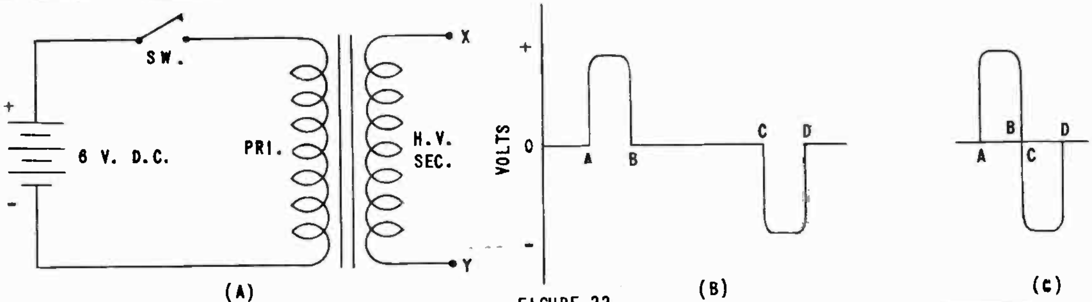


FIGURE 22

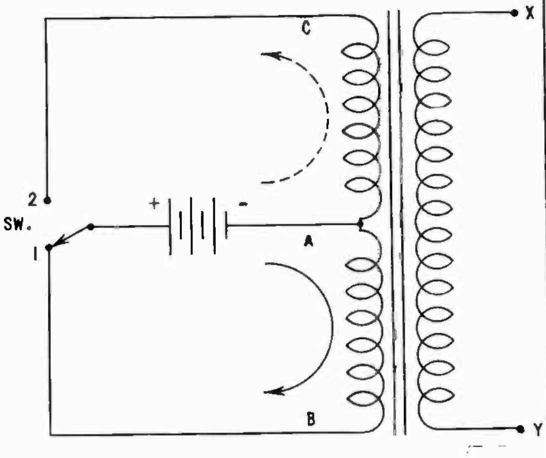


FIGURE 23

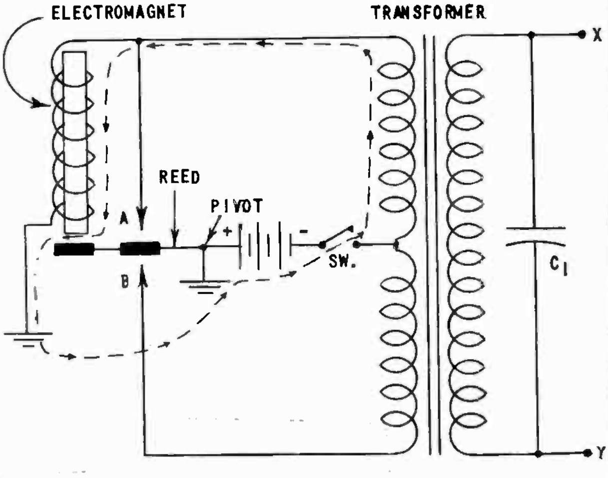
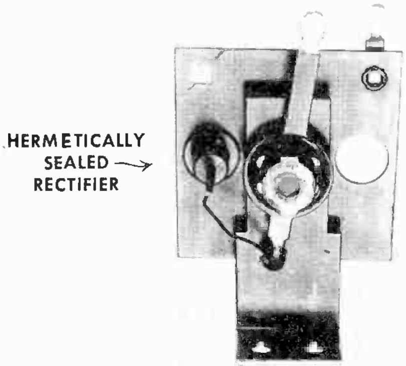


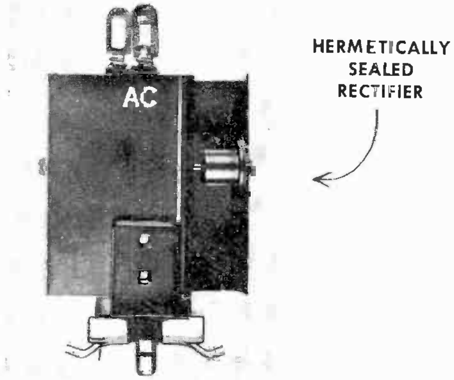
FIGURE 24

24

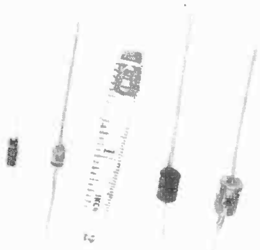
SOLID-STATE RECTIFIERS



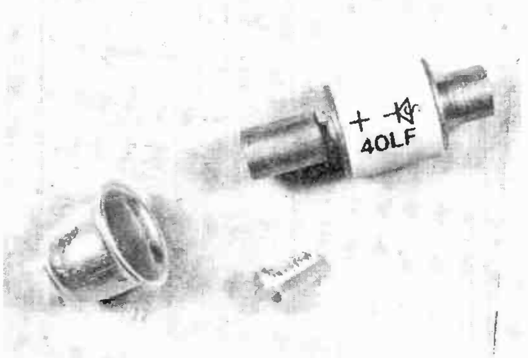
GERMANIUM RECTIFIER
(A)



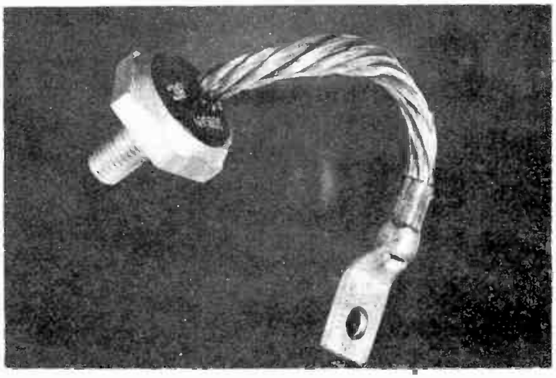
GERMANIUM RECTIFIER
(B)



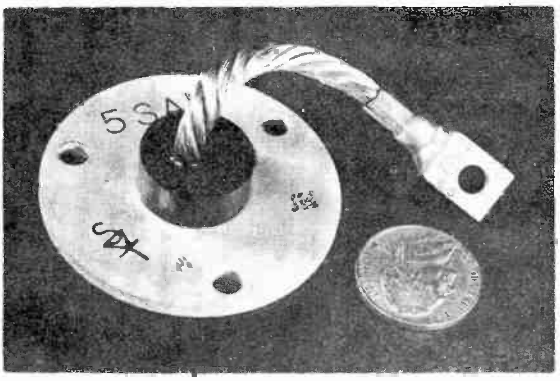
SILICON RECTIFIERS
(C)



SILICON RECTIFIER
(D)



SILICON RECTIFIER
(E)



SILICON RECTIFIER
(F)

FIGURE 21

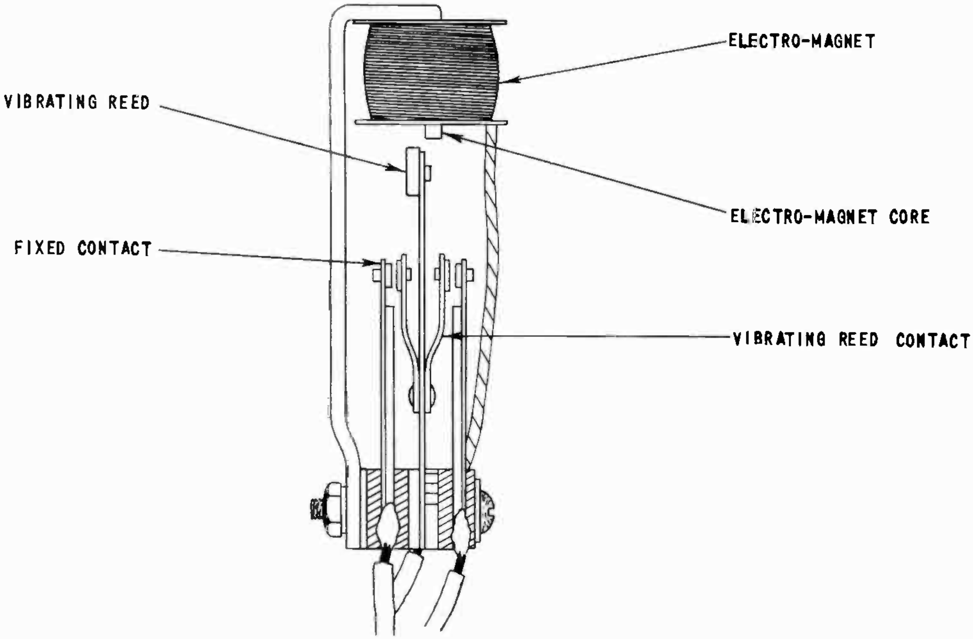


FIGURE 25

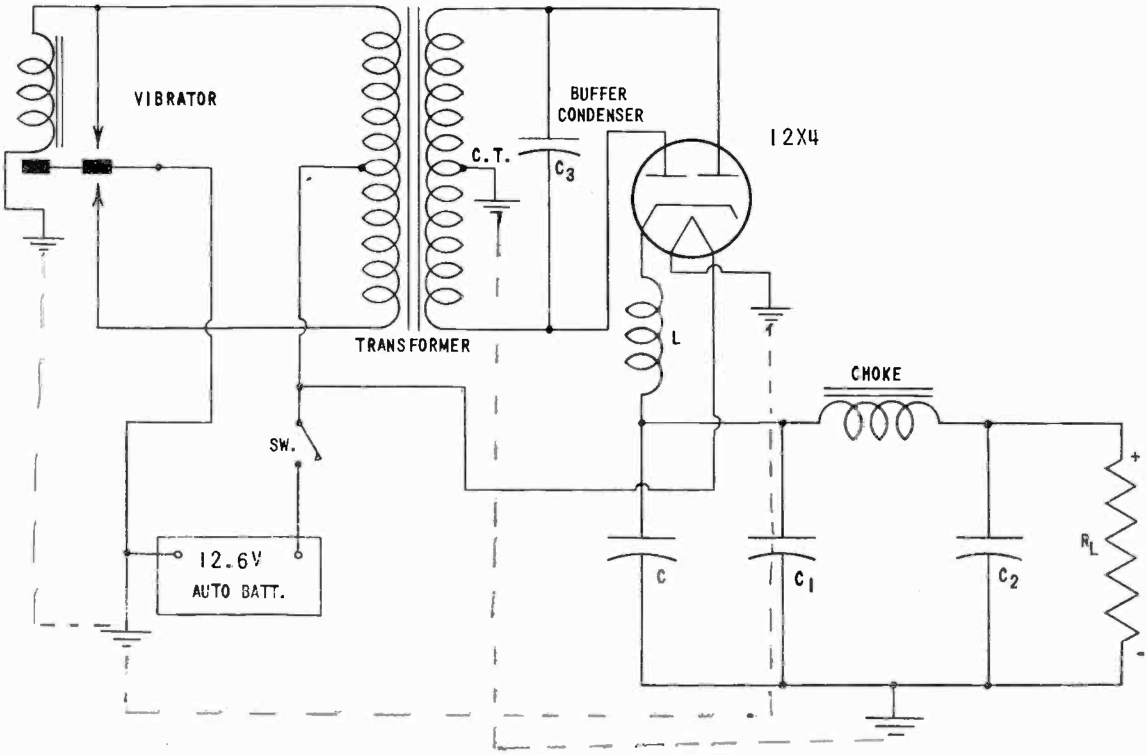


FIGURE 26

24

SYNCHRONOUS VIBRATOR POWER SUPPLY

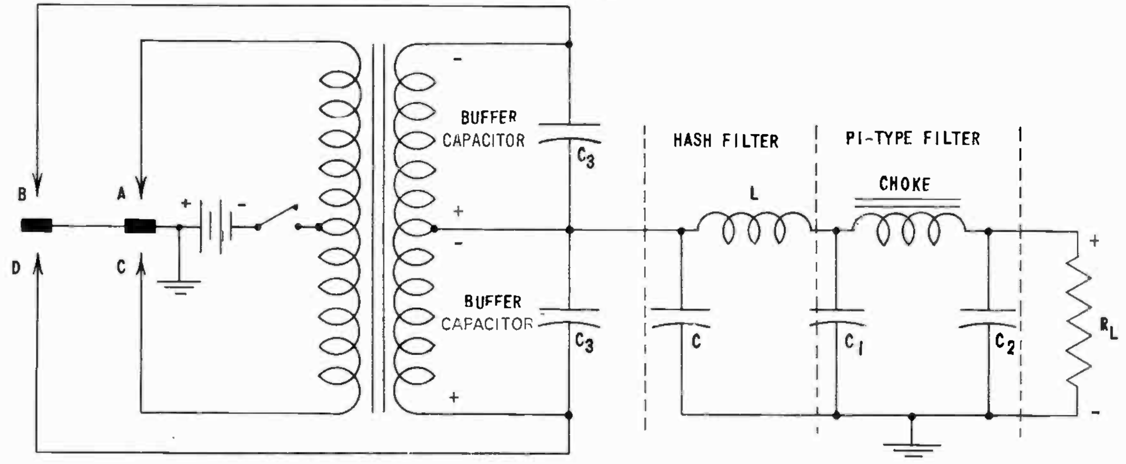


FIGURE 27

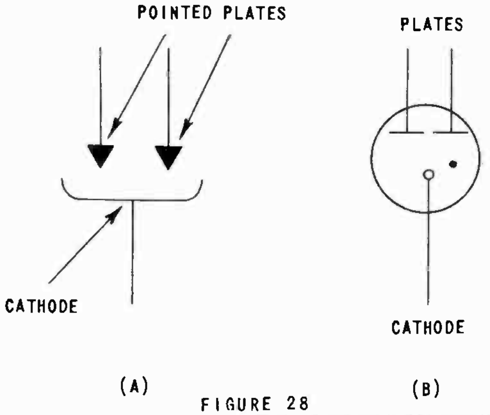


FIGURE 28

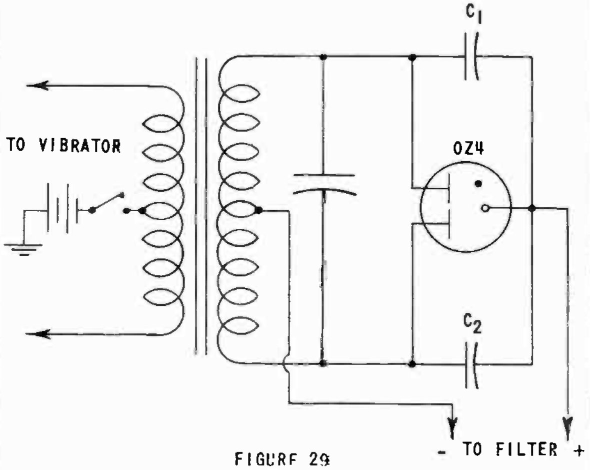


FIGURE 29

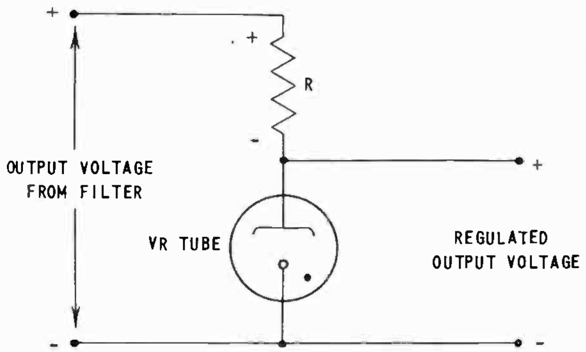


FIGURE 30

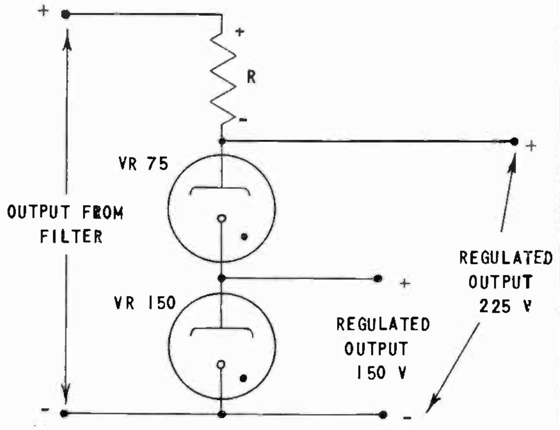


FIGURE 31

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