Chapter 5

The Power Supply

No amplifier can work unless the power supply is providing the correct voltages and currents. Be sure that it is all right—check it first in every service job. It is the part of the circuit that works the hardest, so it will have the most troubles.

Some typical circuits were discussed in Chapter 3. Almost all of the amplifiers now use the power transformer circuit. However, you will find the transformerless type occasionally, and it is simpler, so it is listed first.

THE TRANSFORMERLESS CIRCUIT

Fig. 5-1 shows the circuit of a typical transformerless power supply with the parts named. It is simple but effective. The rectifier converts ac into a pulsating dc by allowing only one-half of the voltage to get through—those half-cycles which make the anode (plate) of the rectifier positive. These half-cycles of voltage charge the input filter capacitor up to the peak value of the ac line voltage, which will be about 150 volts with a 117-volt line. This drops slightly because of the load current drawn by the amplifier, and the usual dc output voltage, under load, will be about +135 volts as shown.

What kind of troubles can develop in this circuit? One is capacitor failure. Electrolytic capacitors can dry out and become open. If the input capacitor opens, the voltage will drop very badly—to between 40 and 50 volts in most cases. The input filter capacitor acts as a reservoir; it holds a charge as the half-cycles of voltage are fed to it from the rectifier. If it will not hold a charge (if it is open), then the voltage has no place to be stored, and the output falls very badly. This filter is sometimes called a reservoir capacitor for this reason.

A quick test for an open input electrolytic is as follows. If you find a circuit with very low voltage at the rectifier, simply bridge another capacitor across the filter input to take the place of the one you suspect to be open. Hook a dc voltmeter across the output. If the voltage jumps back up to normal when the new capacitor is shunted across the old, the original one is definitely bad; replace it.

If the output filter capacitor opens, you will notice very little difference in the output voltage, but there will be a noticeable increase in the hum. The main job of this capacitor is to take out the last of the ac ripple and leave the B+ as fairly smooth dc. If it fails you will hear a loud hum. The same test as before is used—bridge another capacitor across it. Listen to the hum. If the old one is bad, you will hear the hum drop to an almost imperceptible level. Again, replace it.

Most power supplies have dual filter capacitors that is, both capacitors are in one can. If one fails always replace both of them. The condition inside the can that caused one to fail will quickly cause the re maining one to go, too. Don't take chances—alway replace the complete unit if any section of a multiple unit capacitor fails. You will find as many as four in a single can in the larger amplifiers; change them all for safety.

The rectifiers can fail, also. If selenium rectifiers– the ones with the large cooling fins—are used, the can get weak and develop too much voltage dro across the rectifier itself. This, of course, drops the B+ output voltage. You will naturally suspect the inpu

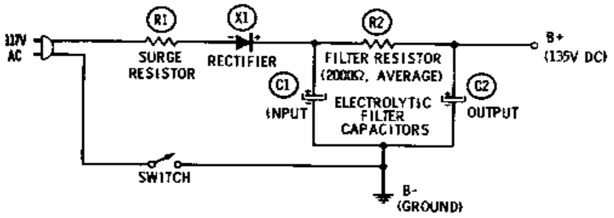

Fig. 5-1. Transformerless power supply.

filter capacitor, for this is a more common trouble; when bridging the old filter does not bring the voltage back up, check the rectifier.

You can bridge a selenium rectifier just as you did a filter capacitor: connect a new rectifier, being very careful to get the right polarity (+ to +, − to −), directly across the suspected one, checking the output voltage at the same time. If the new rectifier brings the voltage back up to normal, replace the old one.

If the much smaller silicon rectifiers are used, you will not find this kind of trouble. Silicons are made in various shapes, but have no cooling fins. You can always identify them by their very small size. They will never get weak and show low output voltage because of their construction. When they fail, they are like the little dog—they die all over. In other words, they short out completely.

A shorted rectifier lets the ac line flow to the input electrolytic capacitor. Since an electrolytic is a very effective short circuit to ac, a large current will flow, and the surge resistor will blow. As a matter of fact, that is part of its job. These are specially built wire-wound resistors or chemical resistors, and they are designed to blow out just like fuses if there is a current overload. They are called fusible resistors. If a surge resistor does burn out, be sure to replace it with a resistor of the same value and type, for it is designed to give the power supply circuit exactly the right amount of protection against overloads.

You will find short circuits in the loads too. If a bypass capacitor or one of the power tubes shorts out, you may find a blown surge resistor. Always check carefully before replacing rectifiers and/or fusible resistors to find out what caused the fuse to blow. Make ohmmeter tests from the B+ point to B−, directly across the filter capacitors. If you get less than about 12,000 to 15,000 ohms, disconnect the B+ circuit from all loads and recheck. This amount of resistance is normal across one of these power-supply circuits; it is the leakage resistance of the very large electrolytic capacitors used. By reversing the ohmmeter prods, you will find that one way there is a much higher resistance; this is because you have hooked up the ohmmeter (with its built-in battery) with the right polarity, and the electrolytics will not show as much leakage current. The 12,000-ohm reading is a minimum; if you get less than this, disconnect parts, one at a time, until you find which one is causing the trouble.

If you get an amplifier where you cannot locate the trouble from the ohmmeter reading, disconnect the load, leaving the B+ supply all by itself, and turn on the amplifier. If you get the normal voltage reading, or quite a bit more (due to the lack of loading), the power supply is all right. The short is in some of the load circuits, and you have eliminated the power supply as a suspect. Use the process of elimination again to find the defective component.

Electrolytic filter capacitors used in transformerless power supplies are very large. You will find values like 80 to 100 μF in the input, and 60 to 80 μF or more in the output. These will have working voltages of 150 volts dc, and they will usually be in the same can. When you replace a filter, be sure to get as close to the original values as possible. However, filter capacitors are not too critical; you can change from the original values as long as you use larger ones. For example, 100 μF is a good replacement for 80 μF, but 60 μF might allow some hum to creep in.

Watch out for output filter capacitors with a high power factor. This happens when the capacitor gets a little too old and starts to dry up, losing some of its capacitance. Since the filter capacitor also acts as a bypass capacitor for all other circuits in the amplifier, this can cause an increased hum level, and can even allow the amplifier to go into oscillation or motorboat (a slow "put-put-put" oscillation, sounding very much like an old motorboat).

In a few cases, to get a positive check on filters with a high power factor, you will have to disconnect the old capacitor entirely and substitute a new one across the terminals of the circuit. Sometimes the old capacitor develops a fairly low series resistance, and this can upset the tests. To make sure the old filter is bad, substitute a new one.

TRANSFORMER-POWERED CIRCUITS

Most of the larger electric guitar amplifiers use power transformers; this is done because much higher voltages can be obtained, and the always-present shock hazard in the line-connected circuits is eliminated. Fig. 5-2 shows a typical power-transformer B+ supply with parts named.

Notice that the filter system is like the one used on the transformerless type, except a filter choke is used in place of the resistor. The choke gives much better filtering action, and has far less voltage drop. The

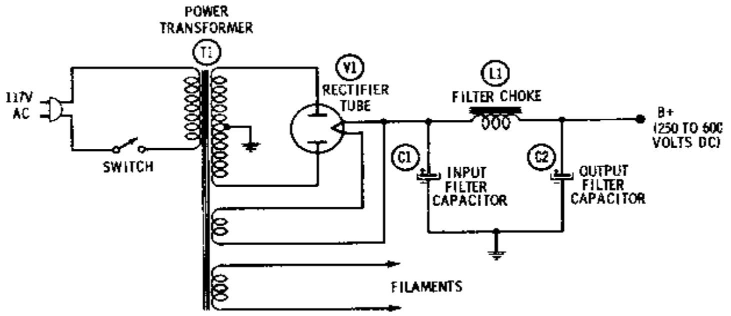

Fig. 5-2. Full-wave power supply using a power transformer.

average dc resistance of a filter choke is about 40 to 50 ohms instead of the 2000 ohms of a filter resistor.

When a choke is a part of the filter, smaller filter capacitors can be used without reducing the filtering action. You will find sizes like 20 to 30 microfarads in the input and 40 to 60 microfarads in the output. The schematic (Fig. 5-2) is for a full-wave rectifier; both halves of the incoming ac voltage are used. There is no 60-Hz hum in this power supply. By folding up the other half of the ac cycle, there results a basic 120-Hz hum or ripple component. Remember this: it is used in further troubleshooting tests. After a little practice you will be able to tell the difference between 120-Hz hum and 60-Hz since the latter is definitely lower pitched and smoother. Fig. 5-3 shows the folding up of the ac voltage in the full-wave rectifier and the 120-Hz hum component (ripple) at the output.

B+ output voltages are much higher in transformer power supplies. You will find from 250 volts to 450 volts in common use, and in some of the very high powered amplifiers there is up to 600 volts dc output at the filter. So, filter capacitors must have a much higher working voltage rating; in such circuits never use units with less than 450 working volts. Check the voltage shown on the schematic or measure it in the actual amplifier circuit, and use a capacitor that will stand it. A good rule is to use a capacitor with a working voltage at least 100 volts above the normal voltage.

Capacitor troubles are the same in transformer as in transformerless power supplies. An open input filter capacitor causes the B+ voltage to fall off considerably; in a full-wave circuit the drop is to about half the normal voltage. Test for it in the same way: Bridge a capacitor known to be good across the suspected unit, and see if the voltage comes back up to normal. Always replace the whole thing when one section of a multiple unit is bad.

Bad output filter capacitors will cause hum, oscillation, or both in the amplifier. Use the same check as before. Bridge with a good one and listen to the hum. Open input filters ordinarily do not cause as much increase in the hum level as open output filters. However, this is not always true, so check both input and output capacitors if you have too much hum.

REPLACING ELECTROLYTIC CAPACITORS

If you do find an open electrolytic capacitor, you will have to replace it. Many amplifiers use multiple units, having as many as four sections in a single can. There is a trick you can use on this to save time. Get a replacement capacitor as near to the same value as possible and with the same type of mounting. Leave the old unit in the circuit until you have done the following.

Check the position and especially the working voltage of each section of the new units. Many will have three high-voltage capacitors and one low-voltage unit

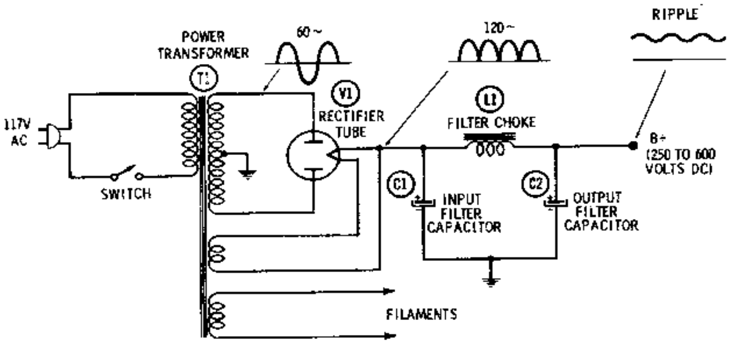

Fig. 5-3. Power-supply waveforms.

(for cathode bypassing) in the same can. You do not want to hook up the 50-volt cathode bypass to a 400-volt circuit—the capacitor has a tendency to explode! Check to make sure just which ones are high-voltage types. All sections are coded by small punchouts in the fiber insulator on the lug end: triangle, square, half-moon, and plain. The values corresponding to each mark are stamped on the side of the can—the capacitor size and rated voltage.

Make a little chart of the wire colors fastened to each lug. Somebody may come in and interrupt you, and you may not get back to this amplifier for hours. This keeps you from losing track. The cathode bypass often has only one wire on its lug, and it is yellow if the manufacturer has followed the standard color code for such wires. This is handy as a locator.

Now you are ready to change capacitors. Instead of unsoldering all the wires (and there may be as many as 4 or 5 on each lug) simply clip lug and all off with diagonal cutters and bend them up slightly. Take the old capacitor out, and mount the new one, trying to get it placed so that each lug comes out as close to the one it is replacing as you can.

Finally, bend the old lugs with their group of wires down and lap them alongside the lugs on the new one. Solder each one firmly in place, and there you are.

SHORT CIRCUITS

Short circuits in the B+ supply network are a common trouble. Looking back at Fig. 4-3 you can see how the B+ voltage is fed to all tube plates and to screen grids (if they are used). There will be numerous bypass capacitors throughout the network; they are not shown in Fig. 4-3 to simplify the drawing. However, they are a source of a lot of the shorts, so they must be checked. Fig. 5-4 shows one bypass capacitor circuit. This may be the screen-grid bypass of a pentode driver tube, for instance.

What happens if the bypass capacitor suddenly develops a very low leakage resistance? Current flows through the capacitor where none should flow at all, adding to the normal current through the dropping resistor. The resistor promptly gets very hot, giving a good clue to the nature of the trouble. Look for hot resistors—not just warm or even uncomfortably hot to the touch (some resistors normally run that hot). Look for the ones that are smoking. Resistors on which the color-coding paint is burning off are definitely overloaded. There are several tests that point directly to the trouble if you find a "hot one." First, turn the amplifier off, and check the resistance readings on both sides of the resistor. Normally, you will get a fairly low resistance on the B+ side of the resistor since you are reading through the leakage resistance of the electrolytic capacitors in the filter. However, going to the load side of the resistor (the screen grid), you ought to find the normal value of the screen dropping resistor, plus the first reading.

If you get approximately 25,000 ohms on the B+ side and about 5000 ohms on the load side, look out. Disconnect the capacitor, and take the second reading. Also check the resistance from ground to the open end of the capacitor itself; in fact, this is usually the first test made. If you get any resistance reading at all across the capacitor, it is bad. Replace it.

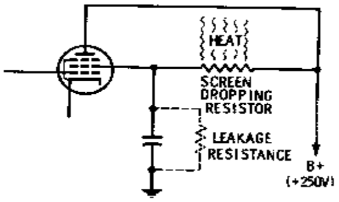

Fig. 5-4. Capacitor leakage overheats dropping resistor.

The axiom for troubleshooting in the RC circuit is: Always check for a short on the load side (not the B+ side) of a hot resistor. This is a simple and obvious test, but it is surprising how many men will not make it correctly. You will find RC networks used all over the amplifiers, expecially in B+ circuitry. Take the time to learn how to check them out correctly, and you will find many of the troubles very rapidly.

LOW B+ VOLTAGES

Sometimes you will find an amplifier that is very weak—not enough volume. This is a common trouble, so it deserves close study. The first thing to be suspected, as always, is the tubes. Replace the rectifier tube and the power output tubes, because these are the hardest working tubes and the most likely to be weak. If this does not help enough, replace the other tubes, one at a time. This will cure most weak amplifiers, since weakness is caused by tubes more often than by anything else.

Tubes are not the only cause, however. If tube replacement fails, check the B+ voltage; this is the next most common cause. Measure the B+ to see whether it is up to normal. If you do not have a schematic, check the ac voltage on the rectifier tube plates (one plate to ground, not plate-to-plate) and add a correction factor of about 10 to 15%, which is the normal amount the rectified output voltage is above the rms ac input. A plate-to-ground measurement of 320 volts ac should result in a rectifier cathode output of 350 volts to 370 volts dc with load connected. The most likely power-supply troubles have been discussed previously.

If the B+ is up to normal (and it must be before you go any farther with this testing), start looking for something off in the rest of the circuits. Most likely suspects are plate load resistors that have increased in size in any of the voltage-amplifier circuits. If a 100,000-ohm plate resistor rises to about 750,000 ohms, it cuts down on the plate voltage of that tube and the amplification. Check them against the color-coded value printed on each one.

A good quick check for off-value load resistors is the plate voltage. Make a fast run through the whole amplifier, looking to see if all plate voltages are about normal. After a little practice you will be able to do this very quickly since these are not critical (within about 10 to 15%). For instance, if you see a stage with a 100,000-ohm plate resistor and you know that the supply voltage is about 175 to 200 volts, then you should expect to find about 100 to 200 volts on the plate. So, if your voltmeter swings up to about 100 volts, don't even wait for it to stop; keep going. This isn't the one you're looking for! What you want to find is the stage with the right dc voltage on the supply end of the load or dropping resistor, but no voltage at all on the load end, or only a small fraction of the supply.

Watch out for filter resistors, especially those secondary filters used to isolate preamplifier stages from the rest of the amplifier. Resistor R1 in the schematic of Fig. 4-2 is an example. If this increases in value, all plate voltages fed from the load end of this resistor will be low, and so will the gain and volume. Leakage in the electrolytic capacitors used to filter the load end of these resistors also causes low supply voltage. In this case the resistor will be very hot, giving a good clue to the source of trouble.

If the low volume complaint is also accompanied by some bad audio distortion and the tone is very mushy, look for a leaky coupling capacitor between two stages. In fact, most really good technicians make it a practice to check the grid voltages on all voltage-amplifier tubes. If you find even the slightest trace of positive voltage (even half of a volt), check that coupling capacitor; it is probably getting ready to break down. Always use replacement capacitors with ample voltage ratings. No coupling capacitor should ever have less than a 600 working-volt rating to get a low leakage characteristic. Some of the cheaper amplifiers will have 400-volt capacitors installed as they come from the factory; these ought to be replaced by the sturdier 600-volt types whenever possible for longer service life.

TESTING POWER TRANSFORMERS

Now and then you get an amplifier with the power transformer smoking or bleeding wax from the bottom. This means one thing definitely: The power transformer has been very badly overheated. However, it does not necessarily mean that it is burnt out.

There are two things that happen to power transformers that cause overheating: (1) an internal short in the windings, which is hopeless since it can't be repaired, and (2) an external short such as a shorted filter capacitor or rectifier tube that has overloaded the transformer and made it overheat. In the latter situation, it is still good unless it has gotten so hot that the insulation inside has broken down.

Here is how to find out. Take off all loads from the transformer: take out all of the tubes, and if the amplifier uses silicon or selenium rectifiers, disconnect these. With all external loads removed, a good transformer will draw practically no current at all. When disconnecting leads for testing, don't unsolder them; clip them off near the terminals, leaving a short piece of the original wire on the terminal so that you can tell the color code. If a new transformer is necessary, you can disconnect the rest of the lead and follow the color coding when installing the new unit. This makes the job faster.

If you have a wattmeter, plug the transformer into it, and apply power. If the transformer is all right, it will not draw enough current to give a reading. The only input current that flows in this condition is the iron loss; this is never more than about one or two watts in a well-designed transformer. However, if you see as much as 25 to 50 watts indicated and you are sure that all external loads have been removed, the transformer is internally shorted and must be replaced.

You can make up an emergency wattmeter that will give you the same answer; Fig. 5-5 shows how. It is not precise, but it will tell you what you need to

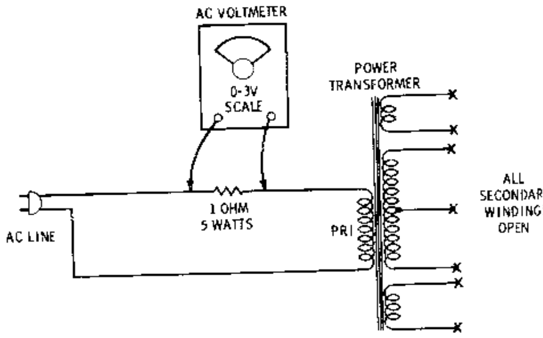

Fig. 5-5. Emergency wattmeter circuit.

know. Hook a noninductive 1-ohm resistor of about 5 watts in series with one side of the input ac line to the primary. Put an ac voltmeter across the resistor, and you can read the voltage drop, which is directly proportional to the ac current through the resistor. Any appreciable current being drawn by the transformer will give you a reading. A 1-volt drop across a 1-ohm resistor means that 1 ampere of current is flowing; 1 ampere of current at roughly 100 volts (approximate line voltage) equals 100 watts of power being used by the transformer. Power is figured by multiplying current times voltage.

There is still a third way. Take off all loads and turn the amplifier on; let it sit on the bench for about 10 minutes. If the transformer gets hot, it is shorted internally. If it is badly shorted, you will know it right away; you will hear it hum inside, and smoke will start to come out very shortly.

Replacing Power Transformers

To make replacements faster after the old transformer has been definitely proven bad, leave it on the chassis until the new transformer is at hand, ready to install. If the old transformer uses nonstandard color coding, trace the circuits (filament, plate, etc.) and make up a scratch-paper list of the colors and where each one goes. This is a great time saver.

If you cannot get a replacement transformer from the manufacturer that is an exact duplicate or if you do not have the time to wait, you can figure out what size is needed. This requires that three things be determined: the electrical ratings of the transformer, the physical size, and the shape and kind of mounting used. This information is not hard to find. The schematic designates what ac plate voltage is used. If you know approximately what the B+ voltage is, you can take 0.9 or 0.95 times it and use the closest available replacement. For example, a 350-volt B+ probably has a 320-volt ac input to the rectifier. The current rating is determined chiefly by the number and type of output tubes used. Take, for example, an amplifier with two 6V6 tubes, in a push-pull output stage. Referring to a tube handbook, two 6V6s draw 70 mA of plate current and 5 mA of screen current with no signal input, for a total of 75 mA. When you add about 50% to allow for maximum signal input, current through other tubes, and a safety factor, a current capability of about 120 mA is indicated. The high-voltage secondary will be rated to show this: for example, "320 Vac, ct (center-tapped), at 120 mA" or "200 mA," or whatever is necessary. You can always use a higher current rating, since this is the maximum current that the transformer can supply. Do not go over the peak ac voltage rating, however. If you do, there can be trouble; a higher than normal B+ voltage for the circuit will blow filter capacitors, bypass capacitors, and so on. Stick within about 10 volts of the original. If you miss it, take one rated 10 volts lower rather than 10 volts higher.

Filaments are easy; just add up the filament currents of the tubes. Most amplifiers use all 6-volt tubes, or 12-volt tubes with the heaters connected for 6 volts. Get a transformer with a 6.3-volt winding at so many amperes. For instance, seven tubes drawing 0.3 ampere each add up to 2.10 amperes, so a transformer with a 6.3-volt winding rated at 3.0 amperes (safety factor) would be needed.

If one 5U4 rectifier tube is used, the transformer must have an additional filament winding "5.0 volts at 2.0 amperes." If two 5U4s are used, the voltage will be the same but the current must be doubled (to 4.0 amperes), and so on. If dry rectifiers are used, there will be no need for this filament winding on the power transformer.

If a bridge rectifier made up of silicon or selenium rectifiers is used, the high-voltage winding will not need the center tap used on full-wave tube rectifier circuits since the B−, or negative return, for the power supply is taken off at one terminal of the bridge. If the transformer you get has a center tap on this winding (probably a red/yellow wire), simply tape it up and forget it.

Get a transformer with the same physical size and mounting if you can; it makes mounting the new transformer a lot easier. However, if you cannot get the right mounting, other types are simple to convert, though it takes time. Get long bolts, brackets, etc., and fasten the new transformer solidly to the chassis; that is all you need to do. Fortunately, in guitar amplifiers there is usually plenty of room above and below the chassis because of the design of the cabinets used.

TRANSISTOR AMPLIFIER POWER TRANSFORMERS

The only difference between power transformers in transistor amplifiers and tube types is the voltage and current ratings. If you have a schematic which shows the highest dc voltage output from the power supply, you can use the formula previously given to find the ac voltage needed. However, you may not find the output current ratings given.

These can be figured, roughly, from the total wattage output of the amplifier, using the "E × I" formula of Ohm's law. If the amplifier has fuses in the dc supply lines (they all should have; some do not), you can use the fuse rating as a rough guide. For example, if an amplifier has a 2-ampere fuse in the dc supply line to the output stages, you can safely assume that the power transformer should be able to supply a maximum current of at least this much. For safety, try to get one with a 2.5-ampere rating on that winding; with this, the fuse will blow, but the power transformer itself shouldn't be damaged.

Watch out for center-taps. In the dual-polarity voltage types, a bridge rectifier will be used with the center-tap of the secondary winding grounded. In the single-polarity types, with bridge rectifiers, a center-tap is not needed. If the transformer has one, you can tape up this lead and ignore it. In the last instance, your ac voltage would be read from end to end of the secondary winding, not from ct to each end, as in the first.

VOLTAGE REGULATORS

In some high-powered tube amplifiers, you may find voltage-regulator circuits. These are used in the plate and screen-grid circuits of the output tubes and sometimes the drivers to keep the B+ voltage the same all the time. If it changes too much under heavy loads or high volume, there will be distortion. Fig. 5-6 shows a typical circuit.

The basic principle of this is simple. The B+ supply is connected directly to the plates of the high-power output stage so that it is not regulated. Another tube (the voltage regulator) is connected in series with the screen grids of the power output tubes and other stages ahead of this point. A tube is chosen for this that is capable of carrying the total currents of all regulated stages. The B+ voltage supply goes to its plate, and the other tubes are all actually connected to its cathode.

This circuit puts the plate resistance of the voltage-regulator tube in series with the stages using the regulated B+ supply. The tube acts as an automatically variable resistor. If the supply voltage goes up, the plate resistance automatically increases to cause a greater voltage drop; the regulated output stays the same. If the voltage goes down, the opposite happens; the regulator tube reduces its plate resistance, taking less of the voltage.

How does this happen? Notice that the control grid of the 6V6 regulator is connected to a voltage divider of a 150,000 and a 100,000-ohm resistor in series; the top of the divided is B+, the bottom is ground. The grid always has two-fifths of the B+ as bias at all times. The bias voltage controls the amount of plate current drawn by the tube, and thus controls the tube plate resistance. If the B+ voltage rises (goes more positive), then the bias rises with it, and the tube draws more current, increasing its plate resistance, and vice versa.

Tube voltage-regulator circuits are not hard to service. Check the voltage input and output of the regulated stages; if it is within limits, the regulator is probably all right. If it is quite high or low, then check the regulator. Replace the tube first, and, if this does not help, turn the amplifier off and measure the resistance of the voltage-divider resistors. These are pretty critical since the ratio between the two determines the amount of bias and the action of the regulator tube. If one is replaced, the other should also be replaced at the same time. Use at least 10% tolerance resistors for this; 5% is even better.

To test these resistors for heat drift, hook an ohmmeter across each one, and heat it up by holding the tip of a hot soldering iron on the body of the resistor until it is good and hot. If the resistance changes more than a very few percentage points, replace it. They must never drift over 5%. Use high-quality resistors, and always use at least the same wattage rating as the original.

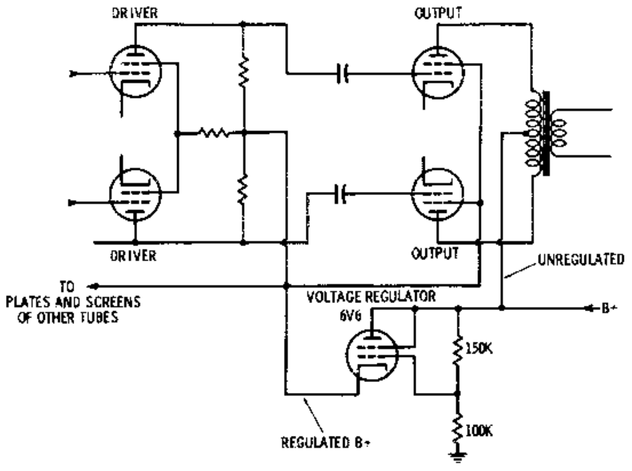

Fig. 5-6. Voltage-regulator circuit.

Voltage-Regulator Tubes

There are several tubes made especially for voltage regulation. Different regulated output voltages (75, 90, 150 volts, etc.) are available. They are gas-filled tubes—basically diodes. The circuit of Fig. 5-7 shows how they work. Until a certain value of positive voltage is applied to the plate, the tube does not conduct current at all. Once this value is exceeded, however, the tube fires and begins to conduct heavily. To use it for voltage regulation, a resistor is placed in series with the tube, connecting the plate to the full B+ voltage.

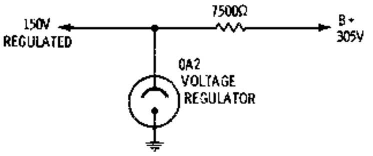

Fig. 5-7. Voltage-regulator tube circuit.

This circuit is used in several commercial amplifiers. When the voltage on the tube plate reaches the ionization value, the tube fires. This acts as a partial short across the circuit, and the tube draws current from B+ through the 7500-ohm resistor. This current is enough to cause a voltage drop across the resistor, so the regulated output drops to the rated value—150 volts with a type OA2 tube.

If the B+ voltage rises above normal, the OA2 conducts more current and a higher voltage drop appears across the 7500-ohm resistor. The output voltage stays at 150 volts. If the B+ voltage falls below normal, the OA2 tube conducts less current, and the voltage stays at 150 volts just as before. Voltage-regulator tubes will hold the voltage constant over a range of 5 to 30 mA of current through the tube itself, taking care of any normal variation in supply voltage.

If the voltage at the output of a VR tube circuit is not correct, replace the tube, and check the dropping resistor.

Voltage Regulators in Transistor Amplifiers

In quite a few of the better amplifiers, you will find voltage-regulator circuits used. There are three major types, but you'll find only two of them in common use. The simplest, and the most popular, is a simple zener-diode regulator. This is normally found in dc supply circuits feeding small-signal stages, special effects, etc., to avoid gain fluctuations, and reduce feedback. Fig. 5-8 shows the schematic of such a regulator.

The action of this circuit is very simple. A zener diode is a special type diode, deliberately designed to go into "avalanche" conduction, sometimes called "reverse breakdown," when the dc voltage across it exceeds a certain value. Each zener diode has a certain "zener voltage" at which it goes into conduction, in the reverse direction. In the circuit of Fig. 5-8, if the zener is a 12-volt type, the unregulated dc supply might be say 14 volts. The resistor is just big enough to cause a small voltage drop under normal current loading.

Now, this will give us a regulated 12-volt supply. As long as the supply voltage is above 12 volts, the zener will be in conduction, and "clamp" the dc output voltage at no more than 12 volts. Of course, this is a sort of one-way action; the zener will keep the output voltage from going *higher* than 12 volts, but if the supply falls below 12 volts, it will stop conducting and have no effect at all.

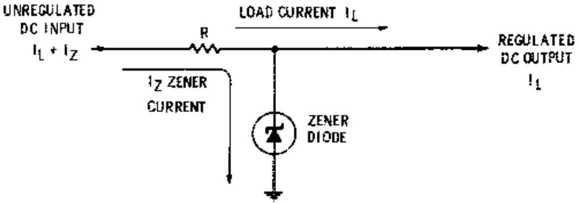

Fig. 5-8. Simple zener-diode voltage regulator.

The wattage rating of the zener is determined by the zener voltage (voltage drop across the zener itself) multiplied by the maximum current which flows *through the diode*, I_z. This is *not* a part of the *load* current, which is determined by the circuits fed from the regulated supply; this is just the shunt current which flows through the diode itself. (As an example, a 12-volt zener which drew 0.5 ampere would be dissipating 6 watts, 12 × 0.5. So, a replacement zener should have at least a 10-watt rating for safety.) Zeners are available in a great many voltage and wattage ratings, from ¼ watt up to several kilowatts (used in very high power work, not in guitar amplifiers).

Testing the Zener Voltage Regulator

Testing of this circuit is simple. If the dc voltage on the output is below the zener voltage, one of two things is happening. The load circuits are drawing more than normal current, or the zener is leaking. Quick-check; just disconnect the zener. If it is really defective, the dc voltage will go back to a value slightly above normal. If it is still quite low, you have an overload from the circuits being fed from the regulator. Leave the zener off, and trace down the cause of the overload by disconnecting each circuit one at a time.

If the regulated voltage is above normal, the zener is probably open. Check the unregulated dc voltage on the input. If this is more than say, 2 volts high, check previous dropping resistors, etc. You can read the zener current of any of them, by simply disconnecting one end, and connecting a dc milliammeter in series with it, and turning the power on. From this reading, the actual zener wattage can be calculated.

Transistorized Voltage Regulators

In the tube-type voltage regulator circuit, you can see how the plate-cathode resistance of a vacuum tube is used as a variable resistor for regulation. The collector-to-emitter resistance of a power transistor can also be used as a voltage regulator; transistors are almost ideal dc amplifiers. Fig. 5-9 shows the basic circuit of this type of regulator; this is called a "series regulator." (The other, seldom-seen type, is a shunt regulator; action is the same, but requires greater power loss.)

As you can see from Fig. 5-9, the unregulated dc supply is connected to the collector of a transistor. The regulated dc voltage is taken off the emitter. So, the load current flows through the collector-emitter junction. Like all transistors, the base can *control* the amount of current flowing in the collector-emitter junction. So, if we hold the base voltage at a fixed level, this will also hold the current at a fixed level.

A large capacitor C is connected from the base to ground. When this capacitor is fully charged, it will tend to clamp the base voltage at this value. The zener diode connected to the same place also helps.

The voltage divider across the output is actually a "sampling" circuit. The base voltage of the regulator transistor is determined by the position of the slider on the "Voltage Adjust" variable resistor. By varying this base voltage, the dc output voltage can be set to any desired level, within the range of the supply. If there is a sudden surge or peak of current in the load, the output voltage will try to drop. When it does, the base voltage of the transistor is changed, and it *reduces* the resistance of the collector-emitter junction to let a greater current flow; this holds the output voltage steady. The reverse is also true, of course. If the output voltage tries to increase, due to a drop in load current, the base voltage of the regulator will be changed in a direction which increases the series resistance of the collector-emitter junction, and the voltage on the output is held down.

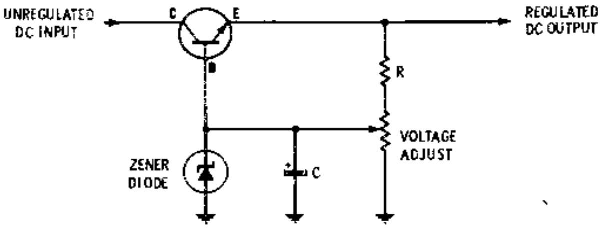

Fig. 5-9. Basic circuit of a transistor voltage regulator.

The limiting factor on this type of voltage regulator is the maximum unregulated voltage of the supply, for the "up" side, and the maximum current rating of the supply, on the "down" side. Within these limits, this type of regulator will keep the output voltage very close to the desired value.

Capacity Multipliers

The same circuit will sometimes be found with the name "capacitance multiplier." There is no difference at all; just a change of title. However, this is just as appropriate. The action of this circuit is so fast that it helps to smooth out even the normal ripple from the dc power supply, as well as any transients that might occur due to line surges, etc. It works like this.

When a pulse of voltage, from the ripple, appears on the unregulated dc input, it would normally go on through and show up on the output. However, this same pulse also appears on the base of the transistor, from the output sampling circuit; this causes the transistor to vary its conduction so as to smooth out the pulse and hold the output voltage absolutely steady.

The big capacitor on the base acts as a clamp, as we said. In effect, the size of this capacitor is multiplied by the dc current gain or beta of the transistor. If the regulator transistor has a beta of 100, and the base capacitor is a 500-μF unit, the equivalent value of this capacitor would look like 500 × 100, or 50,000 microfarads. The zener, too, aids in this action.

Circuit Variations

You will find some series regulators with resistors shunted across the collector-emitter junction. This is done to carry a part of the load current, so that it doesn't all go through the transistor. This lets them use a slightly lower rated transistor as the regulator. The regulation is slightly poorer, but normally adequate.

You will also run across more elaborate circuits. Some of these will have as many as three transistors. The regulator transistor will be in the same place, but an "error amplifier" transistor will be used between the sampling network and the regulator base. In others, a third transistor will be connected between the error amplifier and the regulator base, to get slightly better control action.

Testing the Series Regulator Circuit

These voltage regulators are easy to test. All you need to do is read the regulated dc voltage output. If this is not at the rated value, and the voltage adjust control will not bring it to the right value, check the unregulated dc input voltage. If this is too low, below the normal value of the regulated output, the regulator can't work.

If the input voltage is normal, but the output voltage is too low, disconnect the loads. If the output voltage goes back up to its rated value, check the action of the voltage-adjust control. If this will vary the output voltage at least 10-15% above and below the rated value, the regulator is probably working, and one of the loads is drawing excessive current. For a definite check on the voltage regulator, disconnect the loads, hook a test load across the output, which will draw something like half the normal output current, and adjust the control to give the rated output voltage. Now, vary the ac line voltage on the input, say from about 100 volts to 130 volts. The regulator should hold the dc output voltage almost exactly "on the nose." If it will not, check all transistors and resistors in the circuit, and see that the filter capacitor is not open, or the zener diode is not open or shorted. Normal input voltage, but zero output dc voltage, could mean that the regulator transistor is open, or that the error-amplifier transistor is bad, causing the regulator to be biased to cutoff. If the regulator transistor has a collector-emitter short, the dc output voltage will rise well above rated value, and there will be no control action at all.

Selecting Replacement Transistors for Regulators

Replacement transistors for defective regulators are not hard to find. The main requirement is the collector-emitter maximum current rating. This, of course, must be well above the normal maximum circuit current that will be drawn in actual service. Use a good-sized safety factor; if this current is, say, 7 amperes, use at least a 10-ampere rated transistor. You will normally find power-transistor types used as series regulators, with driver types used as error amplifiers, etc. Zener ratings will depend on the total power drawn by the circuit, and the desired voltage on the control transistor base. Normally, these will be about 1-watt types; check the specs before making replacements.

PARTS REPLACEMENT IN POWER SUPPLIES

Most of the parts replaced in power supplies will be rectifiers, filter capacitors, and dropping resistors. To get a replacement that will stand up in service, you must duplicate, or exceed, the ratings of the original. (You can always go up, but don't go below!) In ube power supplies, you'll have high voltages. So, you'll have to select rectifiers with an ample PIV (peak inverse voltage) rating. In a circuit with 500 volts dc output, you should use rectifiers with 1000 volts PIV. In transistor power supplies, with their low voltages, this isn't important. All rectifiers have PIV ratings far above what you'll need.

Current Ratings

More important, in both types, are current ratings for rectifiers. Check the maximum current drawn, and always use rectifiers with maximum ratings well above this. One good way of quick-checking this is to note the value of the *fuse*. For example, if the dc line has a 2.5 ampere fuse in it, the rectifier should be able to handle at least 5 amperes. The higher rated types will run cooler, and last much longer.

Small rectifiers do not need heat sinks. However, in some of the very large amplifiers, you will find rectifiers in the "stud-mounted" cases, using the chassis as a heat sink. Fig. 5-10 shows a couple of rectifier cases of this kind. The heavy threaded stud is bolted firmly to the chassis, or to an insulated heat sink if the circuit requires it. You can get these in two types, with either the anode or cathode connected to the stud.

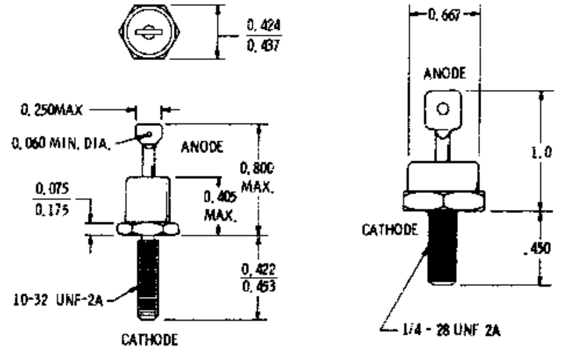

Fig. 5-10. Stud-mount rectifiers used in heavy duty amplifiers.

Filter Capacitors

Bad filter capacitors will make up a lot of your work in these power supplies. When choosing a replacement, you don't have to have an *exact* duplicate, The only thing you need is one at least as big as the original, and with equal or higher working-voltage rating. You can always use a *larger* filter capacitor, but never use a smaller one. If the actual voltage applied to the capacitor is say 50 volts, use at least a 100-working-volt type, and so on. Here, too, the safety factor is important.

In tube amplifiers, a lot of the filter capacitors will be multiple section can types. Transistor amplifiers tend to use more single-unit types. In the multiple-element filters, if one unit goes bad, always replace the entire unit. Do *not* disconnect the bad one and tack a single-unit capacitor across it. (And of course, do not commit the cardinal sin in making capacitor replacements—tacking a new unit across an open section without cutting the old one loose. This is *definitely* out. The old capacitor may short, leak, or develop leakage to the other sections.) Whatever fault conditions developed inside the can of the original will in time affect all of the remaining good sections. So, get it out of there.