Chapter 3

# The Power Supply

The power supply has deliberately been left until the last because it is the most important part of any amplifier. It is also the source of about 90% of the troubles you will find. Why is this? It is the part of the circuit that works the hardest—its components work under a greater voltage strain than any others, with the possible exception of the power tubes. (As a sidelight, be sure you are not confused by the following. A power tube in an amplifier is the output tube—part of the power amplifier. The rectifier tube in the power supply is the one that supplies the operating power to all the tubes. So, if power tubes are mentioned, look in the power amplifier; if the power supply is referred to, look for rectifiers.)

Parts will break down under load—resistors will burn up and capacitors dry out or change value. Then you have problems. Hum, noise, oscillation, and many other troubles have their origin in power-supply voltages—from insufficient filtering, incorrect voltage values, and so on. Ways of finding and fixing all of this will be dealt with in detail in the section on servicing. At this point, here are brief descriptions of the different types of power supplies you will find in commercial amplifiers.

## THE AC/DC POWER SUPPLY

The simplest is the ac/dc power supply, found only in very low-powered amplifiers with an output up to about 2 watts (audio). Fig. 3-1 shows a typical ac/dc power supply circuit using a vacuum-tube rectifier. Typical tubes used in this circuit have type numbers beginning with 35 (35W4, 35F5, etc.), indicating their filaments are designed to operate at approximately 35 volts. The ac line (117 volts is standard) is connected directly to the plate of the rectifier tube, where it is rectified to pulsating dc by the tube, then filtered to a fairly smooth dc in the filter circuits. Resistor R2, capacitor C1, and capacitor C2 make up what is called a pi-type filter; its schematic resembles the Greek letter $\pi$. In the better circuits, filter resistor R2 is replaced by a small iron-core choke. The choke gives much better filtering action, but the resistor is cheaper. Most of the actual filtering in this circuit is done by large electrolytic capacitors C1 and C2 that are usually 80 to 100 microfarads at 150 working volts.

In these circuits the tube heaters, or filaments, (either word is correct) are simply connected in series. This is possible because they all will have been designed for the same filament current. The total voltages must add up to the line voltage, 117 volts. In the circuit shown in Fig. 3-1, for example, the tubes could be a 35W4, 50L6, a 12SQ7, and two 12SK7's. This would give a total of 121 volts, but this is common; designers usually leave a small margin of safety in the voltages to take care of line surges, etc. Any combination of tubes that adds up to the right line voltage can be used; if the total comes out short, a series resistor is added to take up the extra voltage. These tubes are usually operated at about 5% below their rated voltage for longer life.

This type of power supply is called ac/dc, because it will work just as well on 117-volt dc as it will on the more common ac. Of course, the applied dc must be of proper polarity so it can flow through the rectifier to supply plate voltages (B+). Due to the fact that one side of the circuit is connected directly to the ac line, there is always a shock hazard present when this circuit is used. If you do have one of these to work on,

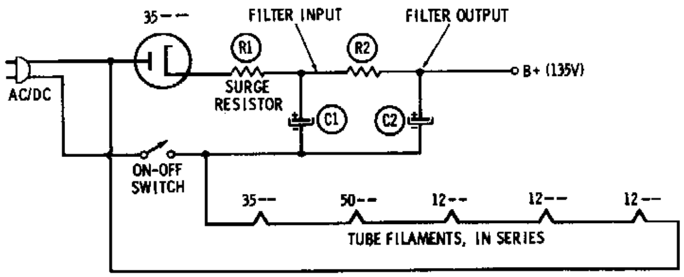


Fig. 3-1. An ac/dc power-supply circuit.

be very careful not to touch the chassis unless you are standing on a dry, well-insulated surface. Incidentally, a concrete floor is not an insulator—it is a well-grounded conductor.

You may have noticed that the output voltage seems to be higher than the input: 135 volts on the simple half-wave rectifier with 117-volt line input. This variation is due to the method of measurement used for the ac voltages. See Fig. 3-2. Dc voltage is straight, but when measuring ac voltages, one normally reads the rms value. In the operation of rectifier circuits, the filter capacitors are actually charged up to the peak value of the voltage. This is 1.414 times the rms voltage. The load on the B+ will pull this down slightly, but the output will still be higher than the numerical value (rms) of the input. This is normal, and it is just a trick of measurement and definitions.

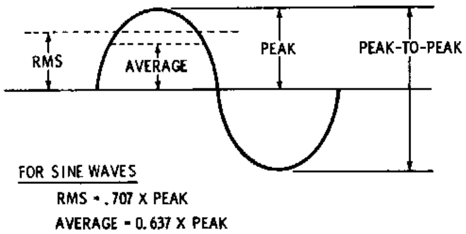


Fig. 3-2. Measuring alternating voltages.

## DRY RECTIFIERS

In many sets today you will find a silicon or a selenium rectifier instead of a vacuum tube. These so-called dry rectifiers (semiconductor diodes) do not require any filament voltage, thus saving that much power. Also, their life is much longer than the vacuum-tube rectifiers that are prone to sudden failure if there is a short in the amplifier itself. Fig. 3-3 shows a typical power-supply circuit using a dry rectifier. Note that the dc output is higher than for the comparable tube circuit since this rectifier is more efficient.

The schematic symbol used is the same for both the older selenium rectifiers and the new silicon types. The triangle is the plate or anode of the rectifier, and the crossbar is the cathode. In this circuit the triangle (anode) is always connected to the source of ac voltage, and the B+ comes from the crossbar (cathode).

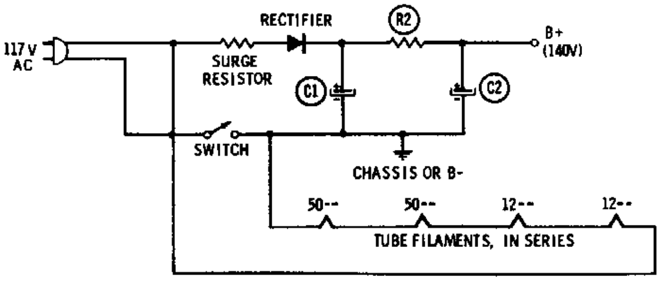
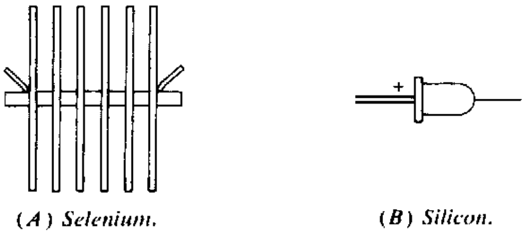


Fig. 3-3. Dry rectifier power supply.

Fig. 3-4 shows the two rectifiers: the selenium types have the large cooling fins, while the silicon are much smaller and more compact. Silicon rectifiers are available in many different sizes and shapes other than the one shown. Voltage drop across the silicon types is much smaller than even the seleniums, and the former have replaced the latter in modern designs. Incidentally, you can use either one interchangeably, providing the current rating of the replacement rectifier is equal to or higher than that of the bad one you are replacing.

The PIV (peak inverse voltage) or breakdown rating of the rectifier must be at least 20% greater than the applied voltage. For safety, the current rating must be at least 25% higher than the peak current to be drawn by the amplifier. The safety factor can be greater than this; these are minimum figures. Rectifiers with a good safety factor will last much longer in service.

Note the little resistor shown in the schematics, between the rectifiers and the ac line. This is small, usually 8 to 15 ohms and is used to hold down the first inrush of current; therefore it is called a surge resistor. Since the dry rectifiers do not have to warm up, they conduct full current as soon as the set is



(*A*) *Selenium.* (*B*) *Silicon.*

Fig. 3-4. Selenium and silicon rectifiers.

turned on. To keep this full current from damaging something, a small limiting resistor is included in the circuit.

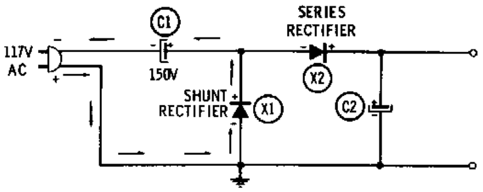
## VOLTAGE DOUBLERS

With semiconductor rectifiers it is possible to build a type of circuit that will give more than double the amount of the standard line voltage. One of the drawbacks of ac/dc or line-rectifier circuits has been the low B+ voltage available—usually about 135 volts dc. With a circuit like that shown in Fig. 3-5, the B+ output can be double the line voltage.

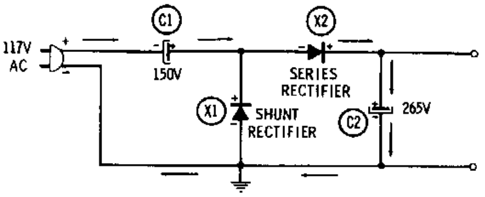
The half-wave doubler power supply works as follows: Capacitor C1 is apparently connected directly to the ac line, despite all you have been told about electrolytics not working on ac. Actually, because of the circuits following it, the capacitor is not on the ac line. On the first half-cycle of the supply voltage, current flows through shunt rectifier X1, because its plate (anode) is positive (Fig. 3-5A); this charges C1 to approximately the peak line voltage minus the drop across the rectifier. On the next half-cycle (Fig. 3-5B) the polarity is reversed, and series rectifier X2 carries the current. The line voltage is now in series with the charge on capacitor C1, so capacitor C2 charges to approximately the sum of these voltages. Allowing for losses in the circuit and the slight discharging of the capacitors, the output is about 265 volts dc. Effectively, the line voltage has been doubled and rectified at the same time.

The two electrolytic capacitors are the key to this doubling action; it is their charging and discharging that make the circuit work. This holds true in all voltage-doubling circuits. All parts must be in good shape, of course, especially the rectifiers, but it is the charge/discharge cycle of these big capacitors that does the trick. C1 will be about 150 to 200 μF at 200 working volts, and C2 will be from 120 to 150 μF and must have at least a 300 working-volt rating.

Incidentally, this is the circuit that stopped the ac/dc designation, although many diehard service technicians still call them that. The ac line is rectified for B+, and the tube filaments are in series, but this is not an ac/dc circuit at all; it won't work on dc. You must have alternating current to make the voltage doubler function. If this half-wave doubler were connected to the wrong polarity of dc voltage, components could be damaged. The correct name for this circuit, and all others like it, is transformerless.



*(A) Current during first half-cycle.*



*(B) Current during second half-cycle.*

**Fig. 3-5. Half-wave voltage-doubler circuit.**

## TRANSFORMER POWER SUPPLIES

The power-supply circuit used in most guitar amplifiers is the full-wave rectifier with power transformer. Fig. 3-6 shows a typical circuit. It works like this: The line voltage is stepped up in the high-voltage secondary winding to any desired value. In the average medium-power amplifier this is about 350 volts ac, so the output is about 300 volts dc after taking off the filter and rectifier-tube voltage drops. The other tube filaments are all connected in parallel and supplied from a filament winding as shown.

The rectifier tube is a full-wave type. Both halves of the ac wave are rectified as first one plate and then the other goes positive. This produces a small 120-Hz ripple in the rectifier output in addition to the dc voltage. This ripple is just a little bit easier to filter out than the 60-Hz ripple that results in half-wave recti-

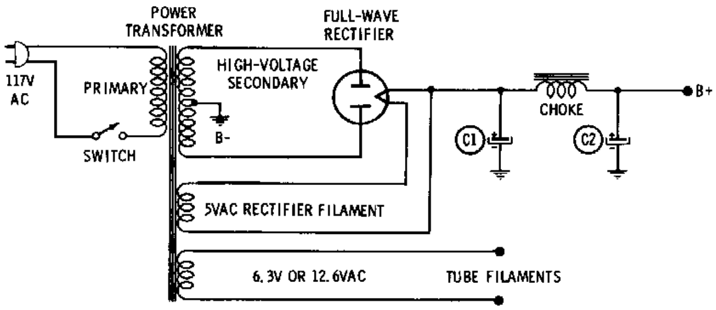


**Fig. 3-6. Transformer power supply with full-wave rectifier.**

fiers, so you will find much smaller filter capacitors in this circuit compared to the transformerless types. Filters will run about 60 to 80 μF instead of 125 to 150 or even 200 μF in the brute-force filters needed for the others.

The center-tap of the high-voltage winding is returned to the chassis, and this is used as B−. Filter chokes are generally used in place of resistors for better efficiency, and the dc output is usually very smooth. Normal ripple at the filter output is less than 2.0 volts pk-pk, which can be considered as almost pure dc.

This type of power supply has several advantages. For one, the power transformer provides complete isolation from the ac line, so there is no shock hazard. For another, the desired B+ voltage can be easily obtained by simply choosing a transformer with the desired step-up voltage ratio. Tube filaments are connected in parallel. If one burns out, it is easy to find since all the others remain lit. In series circuits, if one burns out, it opens the circuit and they all go out.

In some circuits you may find dry rectifiers used in place of the vacuum tube. These will sometimes be in a bridge arrangement as shown in Fig. 3-7. This circuit gives good rectification and simplifies the power transformer; no center tap is needed on the secondary. The output is slightly higher than when a tube is used.

In the larger amplifiers you will find two rectifier tubes. This is done to share the load between them, so the tubes will last longer. In the very high-powered amplifiers, two rectifier tubes will be used on the very high voltage for the plates of the power output tubes (up to 600 volts dc), and another will be used to supply the B+ to all other stages.

Formerly dry rectifiers were sometimes used in series to get a higher voltage breakdown rating. This caused some trouble, due to inequalities between the units. Now, you can get silicon rectifiers rated at 600, 800, and even 1000 volts, so there is no need for the series connection. These new units can be used to replace older series-stack rectifiers, with much reduced chances of failure.

Silicon rectifiers can also be used to replace rectifier tubes directly, to reduce the heat generated inside the amplifier case. Simply connect silicon rectifiers, with ample safety ratings, directly across the tube socket. For a full-wave rectifier tube, such as the 5U4, and others, two rectifiers are needed. Tie the cathodes to the original filament (or cathode, if the tube had a separate cathode), and tie one anode to each of the original plate pins. When making a conversion like this, you may have to add a small series surge resistor. Your dc voltage output will be quite a bit greater. This is due to the lower voltage drop across the silicon rectifier, as compared to that across the tube. Always check the dc voltage to make sure that it does not exceed the original voltage; filter capacitors and other parts may be overloaded and break down.

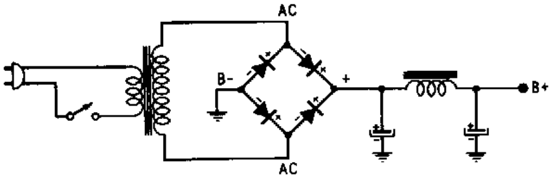


**Fig. 3-7. Four dry rectifiers connected in a full-wave bridge circuit.**

## SPECIAL BIAS SUPPLY

A fixed-bias voltage is used for the power output stage in some of the larger amplifiers (Fig. 3-8). Follow the control grid circuits of the output tubes. They do not return to ground, as in the smaller units, but go through 1500-ohm swamper resistors (to damp out any tendency to ultrasonic oscillation) and 200,000-ohm grid resistors to a special negative voltage supply. This is provided by a 50-volt tap on the high-voltage secondary of the power transformer (T1). The ac is rectified by diode D1 and filtered by the 5600-ohm series resistor, the 100-μF electrolytic capacitor, and the 56,000-ohm loading resistor across the output of the bias rectifier. Notice that the output voltage of this circuit is negative: it comes from the triangle side of the dry rectifier instead of from the bar side as in the normal B+ circuits. Bias voltage varies with the type of tubes used and their bias requirements; it is usually around −50 volts in most of the high power amplifier circuits. This fixed bias is necessary to get 5881s and similar power tubes up to their rated output.

## TRANSISTOR-AMPLIFIER POWER SUPPLIES

The power supplies used on transistor amplifiers will be exactly like the ones already shown. The same kind of transformer, rectifier, and filter circuits will be used. The only difference will be in the dc voltages and currents. Voltages will be much lower, ranging from about 15-20 volts up to perhaps 75-80 volts or more. Currents will be much higher, of course, to get the needed wattage (voltage times current).

The only new circuit you'll find will be in the transistor amplifiers using a dual-polarity dc supply for the output pair. Fig. 3-9 shows how this is done. The center-tap on the power-transformer secondary is grounded. A full-wave bridge rectifier is used, with

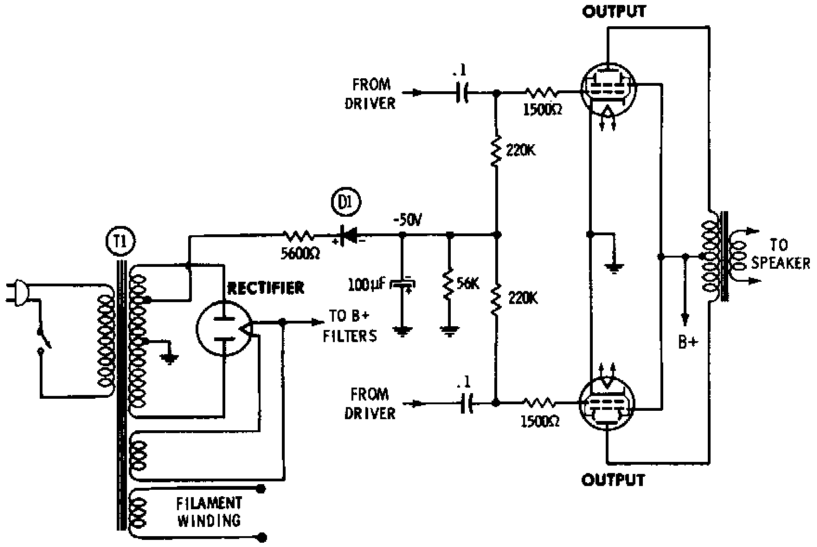


**Fig. 3-8. Negative grid-bias voltage supply.**

the negative voltage output taken from the minus (−) terminal, and the positive voltage from the plus (+) terminal. Duplicate filter circuits are used, with the polarity of the filter capacitors reversed.

The current rating of the transformer secondary winding and the rectifiers must be at least 25% greater than the maximum current to be drawn at full output. Voltage rating of the filter capacitors should be 25% higher than the maximum voltage; here, 50-volt capacitors should be used as a minimum. Filter capacitors will be much larger, often up to 1000 or even 2000 µF, and in some cases, filter capacitors up to 4000 µF have been used. Transistor circuits must have pure dc.

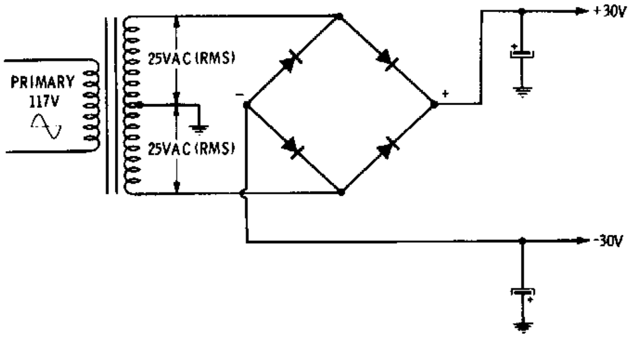


**Fig. 3-9. Dual-polarity power supply.**

## SAFETY PRECAUTIONS—SHOCK HAZARDS

There is one thing which *must* be checked very carefully, whenever any ac-powered guitar amplifier is serviced. This is the *isolation* of the ac power line from the amplifier chassis. The "line-connected" power supplies, like those shown in Figs. 3-1, 3-3 and 3-5, may have one side of the ac line connected to the amplifier chassis. This is *not* a standard circuit, nor is it approved by the Underwriter's Laboratories, who set the standards for shock-safety in electrical equipment. However, by accident or design, it may be found in some of the cheaper models, so be on the lookout for it.

The reason for the danger is simple. One side of every ac power line is grounded; the other side is always "hot," with respect to *any grounded object.* In fact, you can light any incandescent lamp, by connecting one wire to the hot side of the ac line, and the other to a water pipe or other grounded object. In all musical instrument amplifiers, the amplifier chassis is a "common" which is connected to the shields of the cables, as well as the metal control-plates on the guitar itself, to avoid hum pickup. So, if the amplifier chassis is connected to the hot side of the ac line, the "grounded object" may be the *musician* himself, if he happens to be standing on bare earth, a cement floor, or touching water pipes or other grounds.

In this case, a dangerous, even fatal current can flow through his body. There has been one known instance of a musician being killed by a shorted amplifier, and unless we're very careful, there could be more! So, all ac-powered amplifiers should be checked carefully for deliberate or accidental shorts from the ac line to the chassis. Line-connected type amplifiers should *never* be used out-of-doors, or on a bare earth or cement floor, or near water-pipes, etc. However, these amplifiers are in the very low-powered class, and are not normally used for concert or dance work; they are used mostly by students and for indoor practicing. On wooden floors or insulated surfaces, they are safe.

The larger amplifiers are powered by power transformers, as in Fig. 3-6. Note that the primary of the transformer is completely isolated from the secondary and the chassis of the amplifier. So, this type is completely safe, as long as there are no *accidental* short-circuits from the ac line to chassis.

### Checking for Safety

There is a good quick-check for this. Whenever an amplifier has been serviced, and is working normally, connect a 1500-ohm, 10-watt resistor between the amplifier chassis and a ground. Connect an ac voltmeter across this resistor, as shown in Fig. 3-10. Now, plug the amplifier in and turn it on. There should be practically no voltage reading on the meter. If you read more than 2-3 volts ac on the meter, look out. If there is no voltage indicated, pull the amplifier ac line plug, reverse it, and plug it in again. If you get no ac voltage reading with the amplifier plugged in either way, the amplifier is safe to use. If you read even 10 volts ac with the plug in either position, there is too much leakage; reading the full line voltage indicates a dead short between ac line and amplifier chassis, and this is a potential killer!

In some amplifiers, a "line-reversing" switch is used to minimize hum (Fig. 3-11). This switching arrangement has the same effect as reversing the ac plug in the socket. In other circuits, you may find a large resistor, 2.2 megohms or so, bypassed with a small capacitor of about .05 $\mu$F connected from one side of the ac line to the chassis. This, too is for hum-reduction; the reversing switch is flipped so that this side of the ac line is grounded. Now the amplifier chassis is connected to the ground side of the line, and is safe.

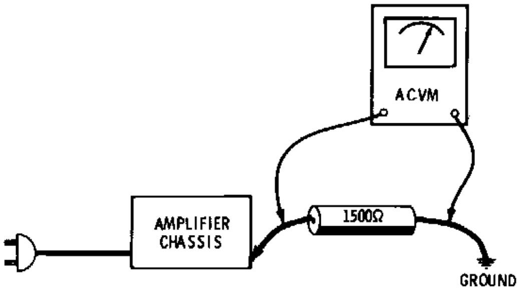


Fig. 3-10. Checking ac powered amplifier for a short to chassis.

If the amplifier has been plugged in at the time a nearby power line was hit by lightning, the "line bypass" capacitor may break down and short. Normally, this capacitor is shunted by the high resistance and only a very small current can flow. With a dead short in the capacitor, a dangerous potential can exist between the amplifier chassis and a ground. The quick-check will catch this hazardous condition. An ohmmeter test of the capacitor will confirm it. If this capacitor is replaced, be sure that the replacement has a rating of at least 1000 volts. This will make it harder to blow if the amplifier is hit again.

In very rare cases, a power transformer primary can short internally to the core. This has the same effect as a shorted line bypass capacitor. This kind of short can have no effect at all on the operation of the power transformer, except for the shock hazard. This, too, will show up on the quick-check test. You'll generally read about half of the full line voltage with the plug one way, and the rest with the plug reversed. For example, 40 volts one way and 70 volts the other; they will add up to the full 110-volt line voltage. Power transformers with this kind of defect MUST be replaced.

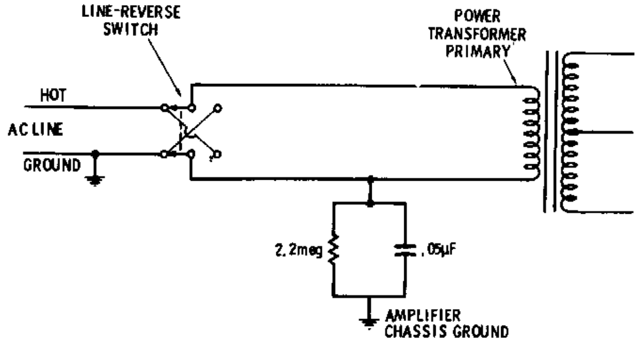


Fig. 3-11. Line-reversing switch and bypass capacitor circuit used to reduce hum.

## SUMMARY

There you have a complete rundown on all of the circuits used in guitar amplifiers. If you know how each one works and what it is supposed to do, then it will be a lot easier to find and fix any trouble that shows up. In the next chapter professional methods of locating and curing trouble will be explained. Diagnosis is half the battle. Anybody can fix an amplifier; it takes only the replacement of a leaky capacitor or a burned resistor and two solder joints. The trouble comes in finding the correct part to replace. This separates the men from the boys, electronically speaking.