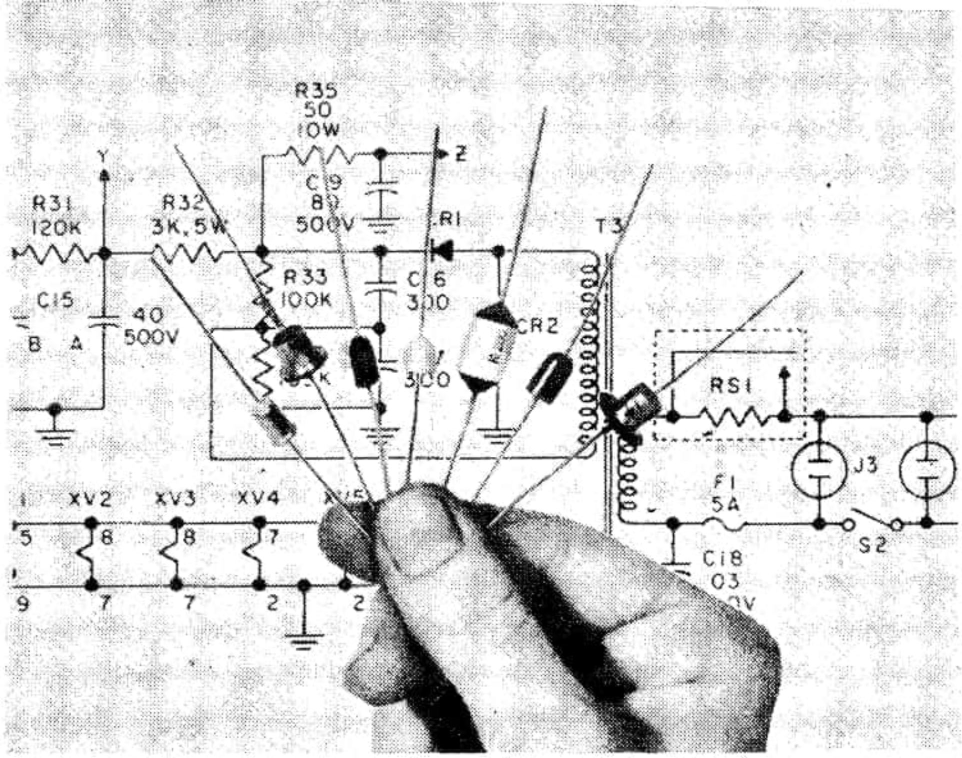


HOW TO USE SILICON RECTIFIERS

Some dos and don'ts on handling the common SR.

By Bert Mann

EVER SINCE it appeared a half-dozen years ago, the silicon rectifier has excited the interest of the electronic hobbyist. And little wonder, for the SR can handle relatively high current, has extreme efficiency, produces virtually no heat and occupies a fraction of the space required by a tube.

Let's compare the SR to an equivalent tube rectifier. The tube may require up to 15 watts to light its filament; the SR has no filament. The tube may have an internal voltage drop as high as 50 volts; the SR's drop is nominally 1.2 volts. The tube is large; the SR is the size of a pencil eraser.

But if silicon rectifiers are so good, why not use them to replace all rectifier tubes in hi-fi rigs, transmitters, test instruments, etc.? When available ratings and cost permit, SR's *are* being used in new equipment. However, when you try to use them to soup up older equipment, you run into snags.

For us, the important SR characteristics are its PIV (peak inverse voltage) also called the PRV (peak reverse voltage) and the maximum surge current rating. PIV is the total voltage applied to a rectifier in a non-conducting direction. For a tube, a PIV of 1,500 volts is not uncommon. However, the PIV ratings of low-cost SR's usually are no higher than 750 volts. This is the SR's first problem.

This PIV rating sounds more complicated than it actually is. A half-wave rectifier circuit allows one-half the 60-cps AC alternation to pass through and blocks the other half. A perfect rectifier would be a dead short for current flowing in one direction (the forward direction) and an open circuit for current flowing in the opposite direction (reverse). The PIV rating is concerned with the peak voltage across a rectifier in the non-conducting direction.

Note that the term *peak* is used. When we speak of the AC line as 117 volts, we actually are referring to the *effective* voltage, or rms. Figure 1 shows the relationship among the rms, peak and peak-to-peak voltages of the sine-wave AC line.

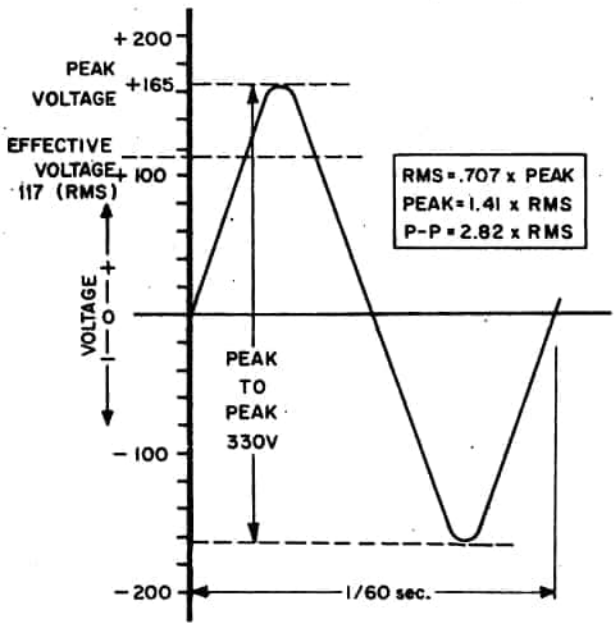


Fig. 1. A 60-cps sine wave from AC line can be analyzed into RMS, peak, and P-to-P voltages.

Practical PIV

Let's take a look at the PIV problems encountered when building new equipment. Figure 2 shows a common half-wave power supply (ignore Rs for the present). For half-wave and full-wave circuits, the PIV across the diode(s) is equal to 2.8 × the applied AC voltage (rms). We get the 2.8 factor as follows. When SR1 conducts on alternate half cycles, filter capacitor C1 charges essentially to the *full peak*. If T1 has a 125-volt secondary, C1 will charge to 175 volts DC. In the part of the AC cycle when SR1 is not conducting, C1's charge of 175 is a positive reverse voltage on the cathode of SR1; at the same time, the negative part of the AC cycle is a negative reverse voltage at the SR's anode. Actually there are two separate voltages "pressing" in opposite directions across the SR. As far as the SR is concerned, the total PIV across it is 2.8 × 125 or 350 V. Even though you are working with only 125 volts AC, you can see how the SR has to withstand 350 volts. Actually you should allow for manufacturing and power line variations by increasing the required PIV rating by another 10%. Therefore, the PIV factor actually is 3.1. With a 125-volt secondary voltage, we would use an SR

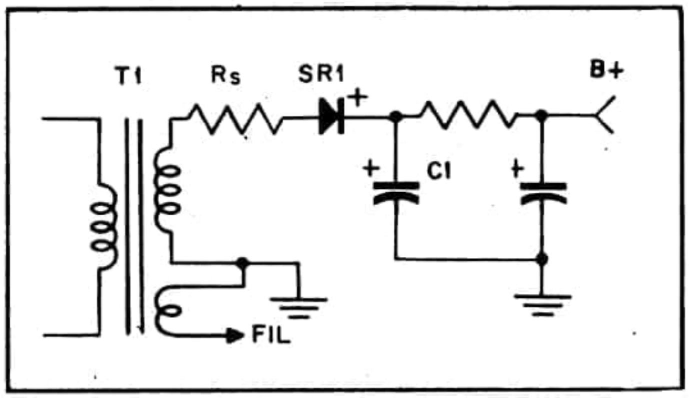
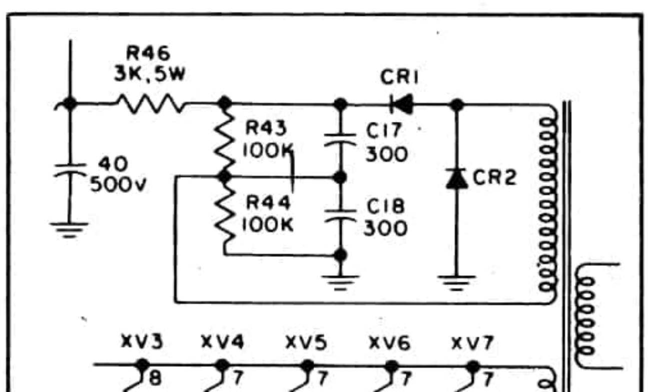
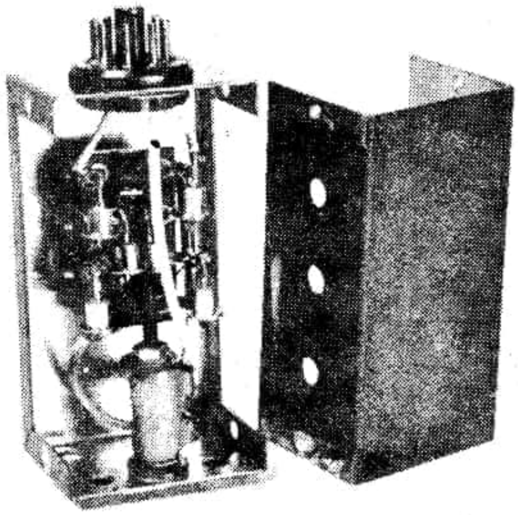


Fig. 2. A common half-wave rectifier circuit.

Fig. 3. Voltage doubler circuit used in hi-fi power amplifiers has excellent voltage regulation.





Rectifier tube replacement sold by TAB includes equalizing resistors and series surge protector.

with a rating of *at least* 390 PIV. You'll find that a PIV rating of 400 is standard value for operation at or around line voltages.

Doubler at Work

Another common SR circuit is the full-wave voltage doubler. Using a doubler straight off the AC line or through a 125-volt secondary power transformer will provide (under a moderate load current) slightly over 260 volts DC. Some TV and hi-fi power supplies use transformer secondaries as high as 180 volts in this type of circuit. The schematic in Fig. 3 is from the EICO HF89 100-watt stereo amplifier power supply which develops a B+ of 500 volts.

Assuming CR1 conducts first (on the first half-cycle) electron flow is from the bottom of the secondary winding up through C17 and CR1 to the top end of the secondary winding. On the second half-cycle, CR2 conducts. Now the electron flow is from the top end of the secondary through CR2 and C18

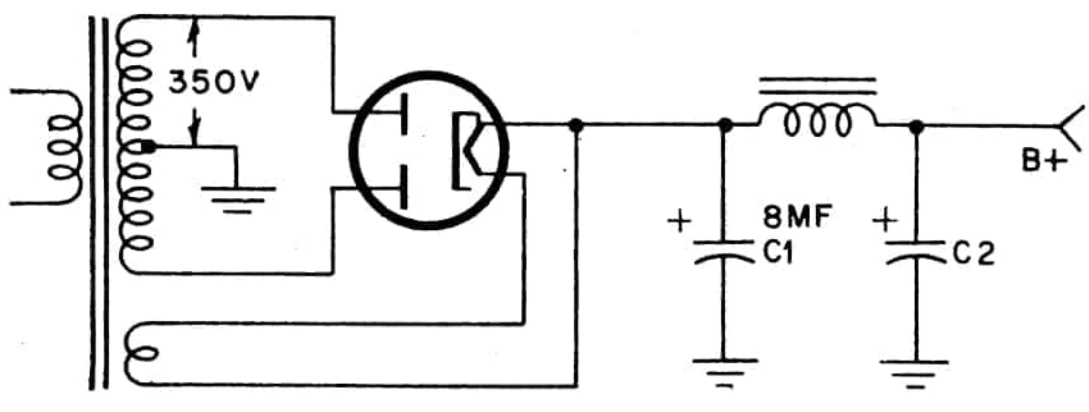


Fig. 4. Standard full-wave rectifier found in numerous amplifiers.

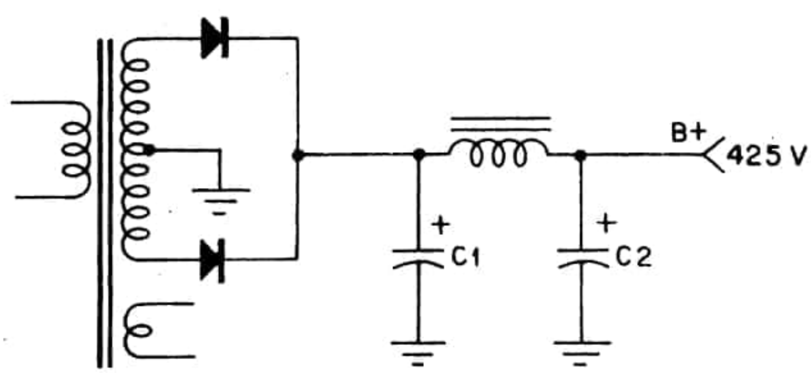
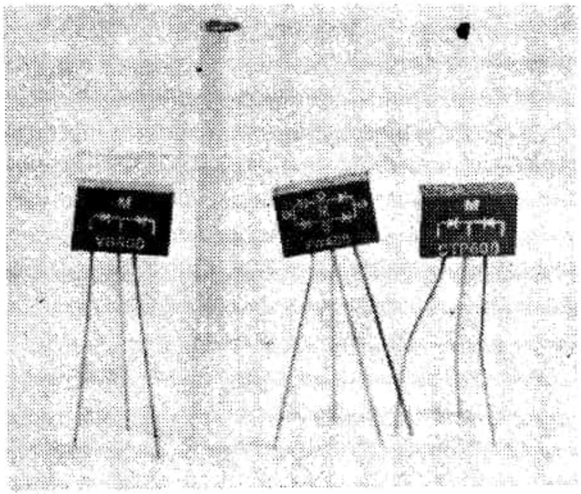


Fig. 5. Replacement of rectifier tube with silicon diodes results in a higher B+ voltage.



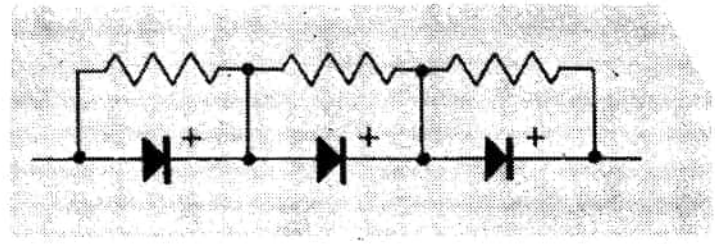


Fig. 6. Circuit above is used when diodes are series-connected for operation at high voltage.

The new Mallory prepackage silicon rectifier circuits include several configurations. The four-lead unit (center) incorporates a full-wave bridge.

to the bottom end of the secondary winding. Both C17 and C18 get charged close to the peak voltage of the secondary. Since C17 and C18 are connected in series under no-load conditions the *total* voltage across them (as read from the positive end of C17 to ground) is *double* the peak AC voltage applied. However, as current drain increases, the voltage output of a doubler tends to fall. Since the doubler is actually two half-wave circuits in series, the minimum PIV rating of each diode still must be 3.1 times the applied voltage.

The Surge Story

Now let's get back to Rs in Fig. 2. Usually not used in rectifier tube circuits, Rs is a protective device which limits the surge current through the diode. At the instant SR1 first conducts, uncharged C1 is practicaly a short circuit. This causes a high current through SR1, limited only by the resistance of the transformer secondary and the negligible resistance of the diode. Note that when working directly from the AC line there is nothing to limit the current through SR1 except its internal resistance. Even though the current surge lasts only a fraction of a second (until C1 charges) it may destroy the semiconductor.

Low-cost SR's have a safe surge current rating of only 15 to 30 amperes. Since the rating seldom is given, assume a rating of 15 a. Rs, which in this case represents a fixed resistor *plus* the DC resistance of the secondary, is calculated to limit the surge current to 15 a. (When working from the AC line, Rs represents *only* a fixed resistor.) The value of Rs is determined from Ohm's Law: $R=E/I$. I equals the maximum surge current of 15 amperes and E equals the *peak* applied voltage, which is 1.4×125 or 175 V. Therefore in Fig. 2, $Rs = 175/15 = 11.7$ ohms. If the transformer secondary's DC resistance is more than 11.7 ohms, no additional resistor is needed. Low-current 125-volt power transformers usually measure more than 25 ohms and semiconductor safety is assured. However, with high-current, high-voltage transformers the secondary resistance may not be sufficient for surge protection and an additional fixed resistor will have to be used. In our illustration, the AC source is the line. The 11.7-ohm resistor (rounded off to 12 ohms), therefore, must be used since the line has no internal resistance.

The *fixed* Rs must have the proper wattage rating, which is twice the dissipated power. The dissipated power is equal to the continuous current multiplied by the fixed Rs ($W = I^2Rs$). The wattage rating of twice the dissipated power gives a good safety factor.

Knowing how PIV and surge current ratings are used, we can progress to the replacement of rectifier tubes with semiconductors. Figure 4 is the reference, a power supply used in an audio amplifier. Each rectifier plate has 350 volts AC applied. As shown, the supply delivers 385 volts at 90 ma current. When the tube is replaced with silicon diodes, the B+

..ises to 425. This extra 40 volts (usually lost in the rectifier tube) is responsible for most problems arising in modernizing older equipment. While C1 in Fig. 4 is rated for 450-volts DC, it normally operates with about 400 volts on it. The new higher B+ reduces C1's safety margin drastically. If the manufacturer's safety margin hadn't been as good as it was, the increased voltage might have exceeded the normal capacitor voltage ratings—and pow!

Safety in Series

Now to the second problem. The 350-voltage AC secondary of the transformer in Fig. 4 means the SR must withstand 1,100 PIV (3.1 × 350). SR's with 1,100 PIV ratings are quite expensive, but by wiring two or more diodes in series as shown in Fig. 6, you can inexpensively obtain the required rating. Three 500 PIV SR's in series result in a total rating of 1,500 PIV—a more-than-adequate safety margin.

Whenever SR's are to be wired in series, use individual ratings which approach the required PIV. This way you can be sure the total PIV rating is more than adequate. Do not series-connect two diodes whose total PIV rating just equals the required value. Should the reverse resistance of one diode vary, or not be up to spec, the diodes will blow and probably take several components with them. Even if you're not using close-rated diodes it's a good idea to wire equalizing resistors across each diode as shown in Fig. 6. The equalizing resistors (500,000 ohms or 1 megohm) have no adverse effect and compensate for variation in the reverse resistance of the diodes.

Protective Capacitors

You may come across circuits which have a capacitor or capacitors connected across the silicon rectifier instead of resistors. The capacitor also serves as a protection device by taking up the shock of spikey transients generated either in the power transformer or line.

Let's take a look at the occasions when it is advantageous to convert from a tube to silicon rectifiers. Such would be the case when equipment, because of inadequate ventilation, runs hot. Substantial heat reduction can be accomplished if silicon diodes are used to replace the rectifier tube. However, as we've discussed, silicons have practically no internal voltage drop and precautions must be taken to insure that the B+ voltage doesn't go sky high. A resistor in series with the B+ *would* drop the voltage back to the original value, but the resistor itself probably would generate almost as much heat as the rectifier tube. A better voltage-dropping technique would be to shift the location of the input filter capacitor. In Fig. 5 this would mean moving C1 over to parallel C2, thus changing the filter from capacitor-input to choke-input type. If you're lucky, the reduction in B+ will be about equal to the increase caused by the use of SR's. However, if you end up with a voltage drop greater than required retain the capacitor input filter but lower the value of C1. If C1 is 8 mf, try a 4, 2 or 1 mf electrolytic, paper or coil capacitor. The peak voltage charge across C1 under load will decrease as the capacitance is reduced and, therefore, the output voltage will drop.

Better Audio Response

Another instance when it probably would be beneficial to replace a tube rectifier with SR's is in the case of 30-W (or higher) hi-fi or PA amplifiers. The superior voltage regulation of diodes (due to low internal resistance) usually can coax from 5 to 10 watts more out of an amplifier and improve its bass power rating. In fact, silicon diodes will raise the rms (sine wave) power rating close to the same level as the "music power" rating.

The physical installation of SR's is quite an easy job (even when the chassis is crowded) because the units are small and have only two pigtail leads. These two leads are soldered directly to the terminal lugs in exactly the same manner as resistors and small capacitors.

In most applications the silicon rectifiers will carry an appreciable current. Therefore, they should be positioned above the chassis plane so as to receive a little ventilation.