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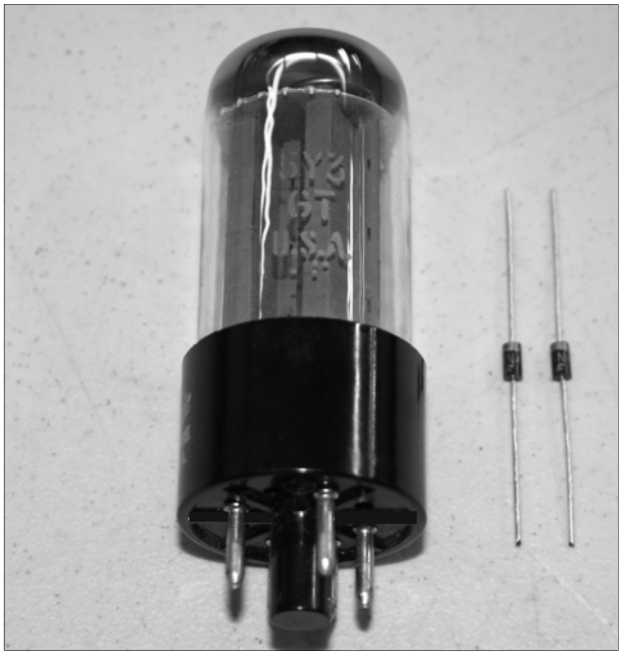
# VR-003A

## Vintage Radio Application Note

# REPLACING THE 5Y3 VACUUM TUBE RECTIFIER WITH MODERN SILICON DIODES



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# ERRATA

1. The 5Y3 pin-out as illustrated in Figure 1 is incorrect. The amended pin-out is as follows: Filaments - Pins 2 and 8. Plates - Pins 4 and 6.

# SECTION I - INTRODUCTION & OVERVIEW

This paper is a vintage radio technical document that discusses in detail replacing the 5Y3 and other vacuum tube rectifiers with modern silicon diodes. The 5Y3 and its variants were widely used in vacuum tube radio receivers and audio equipment for decades until the mid- to late-1960s when vacuum tubes gave way to solid-state circuitry for most new designs.

Although a replacement receiving tube market persisted for some years after this momentous paradigm shift, the most prominent receiving tube manufacturers discontinued production during the 1970s and 1980s. Receiving tubes are still available today (for a price), but most of the supply is either used or “new old stock” (NOS, or unused excess inventory manufactured decades ago). Although there is still some receiving tube manufacturing in Russia, China, and Eastern Europe, this is low-volume limited-selection production oriented to a small niche market of vintage radio and audio amplifier enthusiasts.

Aside from authenticity and nostalgia, there is really no good reason for vintage radio enthusiasts not to replace a 5Y3 with silicon diodes. On the other hand, there are very compelling reasons to make this substitution:

1. Reliability - Being an inefficient rectifier, the 5Y3 dissipates a large amount of power and runs hot. This makes it a high-maintenance component (more so than most other receiving tubes) with a short service life.

2. Filament Power Consumption - The 5Y3 filament draws 2 amperes from the 5 VAC power transformer filament winding. By substituting silicon diodes, this 10 watt load can be eliminated with the benefit of extended power transformer life. This can be important in a vintage radio or audio amplifier since a failed power transformer likely cannot be replaced by any means other than cannibalization.

3. Expense - 5Y3s are among the most expensive receiving tubes on today’s market. (Their short service life as discussed above is no doubt a contributing factor that elevates demand for these tubes which in turn pushes up prices.)

The situation is somewhat more complicated for vintage audio amplifier enthusiasts. Because of the 5Y3's high plate resistance, it exhibits poor voltage regulation (i.e., its output voltage droops with more load current). This has the effect of causing amplifier output compression during loud music peaks.

Although this is actually a form of distortion, it adds a certain quality to the music that appeals to many audio afficionados. Replacing the 5Y3 with silicon diodes alone would improve voltage regulation and thus reduce this desirable compression. This can be mitigated, however, by selecting an appropriate series ballast resistor to replace the 5Y3 plate resistance as discussed in this paper. By carefully selecting an appropriate value of ballast resistance that closely matches the 5Y3 plate resistance, this compression can be restored with sound quality results virtually identical to those obtained with the 5Y3.

Although most readers would suspect (correctly) that changing out a vacuum tube rectifier with a few diodes and a resistor is no major technical feat, there are some subtleties and potential complications that this paper addresses. It is also my hope that the enhanced technical detail provided in this paper will be helpful to other vintage radio and audio amplifier afficionados interested in making this or similar substitutions.

Also, visit my N6DC vintage radio website at www.rdfproducts.com/n6dc.htm for possible revisions to this paper as well as other vintage radio technical articles.

## ** DANGER **

> *Vacuum tube equipment contains dangerous high voltages that can be* ***lethal if contacted****. Those intending to work on such equipment should be well versed in working on equipment with high voltages present and be completely familiar with all necessary safety precautions. Those unfamiliar with these safety precautions or inexperienced in working on equipment containing high voltages should not open the equipment.*

## SECTION II - 5Y3 BASICS & TYPICAL APPLICATION

Referring to the 5Y3 technical data sheet of Figure 2 (taken from the 1968 *RCA Receiving Tube Manual)*, the 5Y3 is a dual-diode with a directly heated common cathode. This tube is designed specifically for use in full-wave center-tap rectifier power supplies. (The full-wave center tap rectifier circuit was the most commonly-used configuration for receiving and audio equipment employing power transformers). Its maximum rated PIV (peak inverse voltage) is 1,400 volts, and it has a rated continuous current output of up to 150 mA.

A typical 5Y3 application circuit is illustrated in Figure 1. This is a simplified representation of the circuit employed by the Lafayette Radio model HE-30 550 kHz - 30 MHz communications receiver (manufactured by Trio of Japan, which later became Kenwood) in the early- to mid-1960s.

As per Figure 1, this circuit is a full-wave center-tap rectifier with a capacitive input filter. The +220 VDC output at the first filter 40 uF filter capacitor is used to power the HE30 6AQ5 audio output amplifier. An additional RC filter (comprising a series 2k/10W resistor and an additional shunt 40 uF filter capacitor) is then employed to produce a low-ripple +125 VDC output for the remaining receiver stages (RF amplifier through audio preamplifier).

Given the high 5Y3 plate resistance, the voltage drop across each diode section is approximately 40 volts. Since this is all dissipated in heat, the 5Y3 runs hot.

This voltage drop gradually increases as the 5Y3 ages with the result that the tube eventually must be replaced. The 5Y3 typically has the shortest service life of all the tubes in the receiver due to its high dissipation.

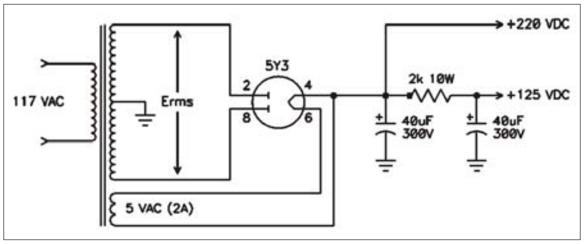
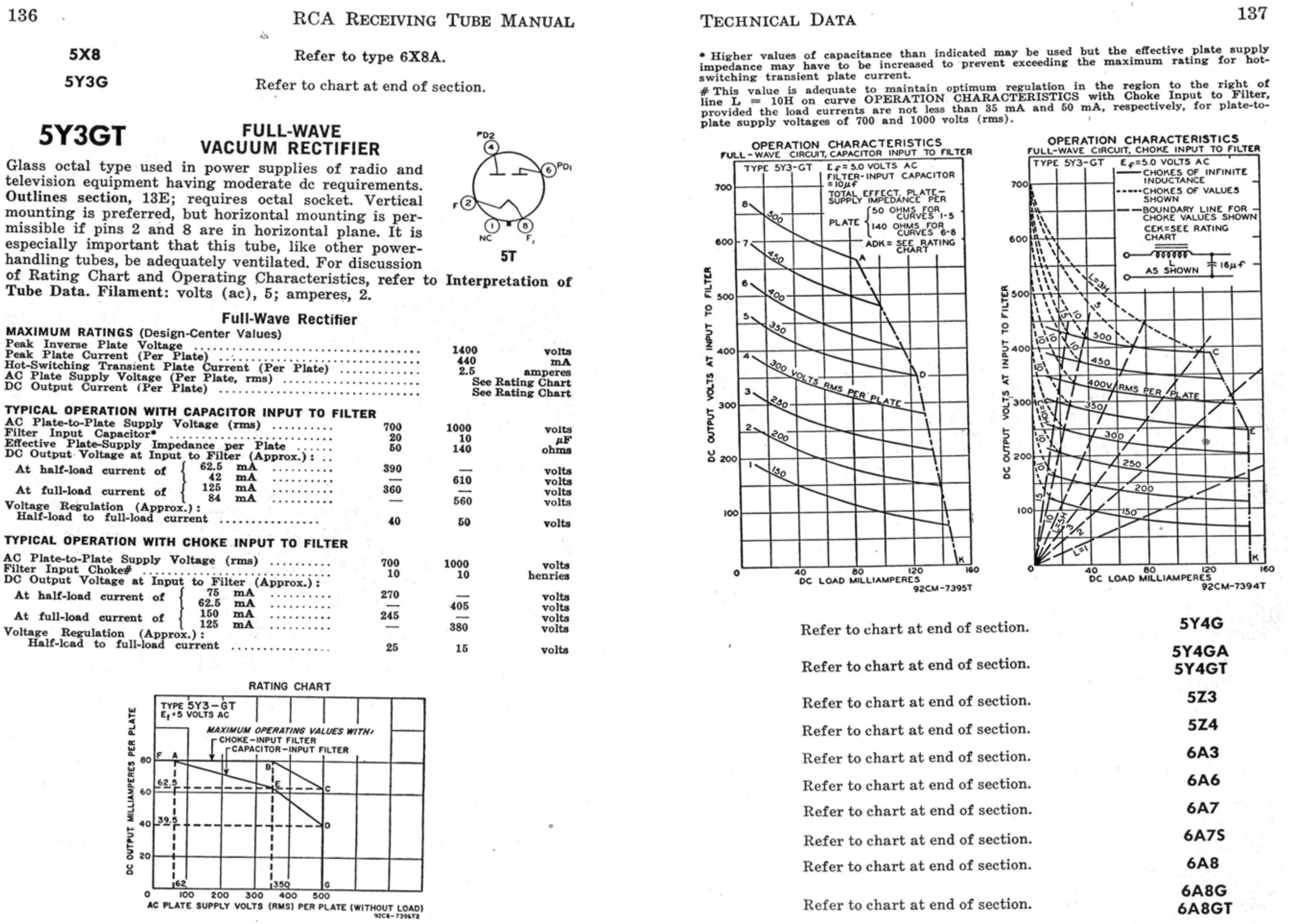


**Figure 1 - Lafayette Radio HE-30 Receiver**
**Simplified Power Supply Circuit**
(see amended 5Y3 pin-out in Errata list on pg. ii)



| | |
|---|---|
| **5X8** | Refer to type 6X8A. |
| **5Y3G** | Refer to chart at end of section. |

## 5Y3GT

### FULL-WAVE VACUUM RECTIFIER

Glass octal type used in power supplies of radio and television equipment having moderate dc requirements. **Outlines** section, 13E; requires octal socket. Vertical mounting is preferred, but horizontal mounting is permissible if pins 2 and 8 are in horizontal plane. It is especially important that this tube, like other power-handling tubes, be adequately ventilated. For discussion of Rating Chart and Operating Characteristics, refer to **Interpretation of Tube Data. Filament:** volts (ac), 5; amperes, 2.

5T

### Full-Wave Rectifier

**MAXIMUM RATINGS** (Design-Center Values)

| | | |
|---|---|---|
| Peak Inverse Plate Voltage | 1400 | volts |
| Peak Plate Current (Per Plate) | 440 | mA |
| Hot-Switching Transient Plate Current (Per Plate) | 2.5 | amperes |
| AC Plate Supply Voltage (Per Plate, rms) | See Rating Chart | |
| DC Output Current (Per Plate) | See Rating Chart | |

**TYPICAL OPERATION WITH CAPACITOR INPUT TO FILTER**

| | | | |
|---|---|---|---|
| AC Plate-to-Plate Supply Voltage (rms) | 700 | 1000 | volts |
| Filter Input Capacitor* | 20 | 10 | µF |
| Effective Plate-Supply Impedance per Plate | 50 | 140 | ohms |
| DC Output Voltage at Input to Filter (Approx.): | | | |
| At half-load current of 62.5 mA | 390 | — | volts |
| At half-load current of 42 mA | — | 610 | volts |
| At full-load current of 125 mA | 360 | — | volts |
| At full-load current of 84 mA | — | 560 | volts |
| Voltage Regulation (Approx.): Half-load to full-load current | 40 | 50 | volts |

**TYPICAL OPERATION WITH CHOKE INPUT TO FILTER**

| | | | |
|---|---|---|---|
| AC Plate-to-Plate Supply Voltage (rms) | 700 | 1000 | volts |
| Filter Input Choke# | 10 | 10 | henries |
| DC Output Voltage at Input to Filter (Approx.): | | | |
| At half-load current of 75 mA | 270 | — | volts |
| At half-load current of 62.5 mA | — | 405 | volts |
| At full-load current of 150 mA | 245 | — | volts |
| At full-load current of 125 mA | — | 380 | volts |
| Voltage Regulation (Approx.): Half-load to full-load current | 25 | 15 | volts |

* Higher values of capacitance than indicated may be used but the effective plate supply impedance may have to be increased to prevent exceeding the maximum rating for hot-switching transient plate current.

# This value is adequate to maintain optimum regulation in the region to the right of line L = 10H on curve OPERATION CHARACTERISTICS with Choke Input to Filter, provided the load currents are not less than 35 mA and 50 mA, respectively, for plate-to-plate supply voltages of 700 and 1000 volts (rms).

| | |
|---|---|
| Refer to chart at end of section. | **5Y4G** |
| Refer to chart at end of section. | **5Y4GA**<br>**5Y4GT** |
| Refer to chart at end of section. | **5Z3** |
| Refer to chart at end of section. | **5Z4** |
| Refer to chart at end of section. | **6A3** |
| Refer to chart at end of section. | **6A6** |
| Refer to chart at end of section. | **6A7** |
| Refer to chart at end of section. | **6A7S** |
| Refer to chart at end of section. | **6A8** |
| Refer to chart at end of section. | **6A8G**<br>**6A8GT** |

**Figure 2** - 5Y3GT Technical Data Sheet (from 1968 *RCA Receiving Tube Manual)*

## SECTION III - REPLACING THE 5Y3 WITH 1N4007 SILICON DIODES

Figure 3 is a modified version of the Lafayette HE-30 receiver power supply circuit of Figure 1 where the 5Y3 is eliminated in favor of two 1N4007 silicon rectifier diodes and a 330 ohm 10W ballast resistor. (This modification was actually successfully implemented on a vintage HE-30 as part of restoration and reconditioning project.)

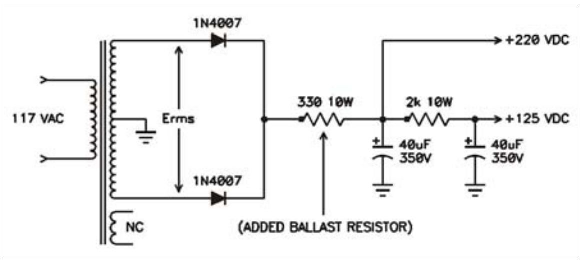


**Figure 3 - Lafayette Radio HE-30 Receiver Power Supply Modified to Replace the 5Y3 Rectifier w/ Silicon Diodes & Ballast Resistor**

The 1N4007 is rated at 1,000 PIV (peak inverse volts) with a maximum forward current of 1.0 ampere. Its forward voltage drop is well under 1.0 volt at moderate current loads, which is negligible in a high voltage rectifier circuit. At its full 1.0 ampere current rating, power dissipation is under a watt. For all practical purposes then, the 1N4007 is an ideal rectifier with an efficiency approaching 100% in a high-voltage application (versus about 60% for the 5Y3). When installed in the HE-30, the two diodes were barely warm to the touch.

The 330 ohm ballast resistor in effect replaces the combined plate resistances of the 5Y3. Although some may question the wisdom of reintroducing the very resistance that makes the 5Y3 hot and unreliable, the rationales for doing so are compelling:

1. If the ballast resistor is not employed, the power supply output voltage will soar to 40-50 volts over its nominal value. This could adversely affect equipment performance and will result in shorter tube life.

2. The 5Y3 plate resistance contributes to power supply ripple filtering. Referring to Figure 1, the 5Y3 plate resistance effectively works in conjunction with the first 40 uF filter capacitor to form an RC lowpass filter that makes a significant contribution to ripple reduction. Incorporation of the 330 ohm ballast resistor in Figure 3 preserves this RC filter. In contrast, eliminating the ballast resistor would likely cause more audible hum.

3. Although incorporating the ballast resistor throws away the benefit of the improved efficiency gained by using the silicon diodes, the dissipation is transferred away from a high-cost high-maintenance 5Y3 vacuum tube to a low-cost long-life power resistor.

In most applications where the 5Y3 is employed the 1N4007 1,000 volt PIV rating is more than adequate. However, since the 5Y3 is rated up to 1,400 PIV, there may be applications where the required diode PIV rating must be higher than 1,000 volts. For the full-wave center-tap rectifier circuits illustrated above, the required PIV rating for each diode is given by the following equation:

$$\text{PIV} = 1.41 \times \text{Erms} \qquad (1)$$

where PIV is the maximum peak inverse voltage and Erms is the power transformer RMS secondary voltage (across the *entire winding* as indicated in Figures 1 & 3). Of course, a generous safety margin should always be added.

If the 1N4007 1,000 volt PIV rating is inadequate, two diodes can be placed in series for a 2,000 volt total PIV. In such cases, good design practice requires that these series diodes be appropriately shunted with equalizing resistors to prevent “voltage hogging” (unequal reverse voltage drops across the series diodes). This issue is discussed in depth in Section VI for the benefit of those readers who need to use series diodes.

## SECTION IV - DETERMINING THE BALLAST RESISTOR VALUE

In principle, the required ballast resistor value can be ascertained from the slope of the 5Y3 load curves presented in the RCA 5Y3GT technical data sheet (reproduced in Figure 2). The difficulty with this approach is that this resistance depends on many variables with the result that only a rough estimate can be made.

Another complication is that eliminating the 2 ampere load from the 5 VAC transformer filament winding (which now no longer powers the 5Y3 filament) will likely result in a higher than normal voltage appearing across the transformer secondary winding.

Given these uncertainties, a more practical method is to determine the correct DC output voltage, temporarily install a trial ballast resistor (e.g., a 330 ohm 10 watt resistor as per Figure 3) and then measure the resulting output voltage. The ballast resistor can then be changed in value as required until the desired DC output voltage is obtained.

All that is necessary to implement this technique is to know the correct DC output voltage (i.e., +220 VDC as per Figure 1). If you have an equipment operator's manual or other suitable documentation, this voltage might be labeled on the schematic or listed in a voltage chart. If so, this is the best answer.

If not, the next best method is to plug in a brand new 5Y3 (or at least one known to be in good condition) and then measure the DC output voltage. If more than one 5Y3 is available, try them all and use the highest measured DC output voltage. Fortunately, vacuum tube equipment was mostly designed for unregulated supply voltages so it should not matter much if the voltage is off by a few volts one way or the other. When the modification is completed, it might be necessary to touch-up some of the internal adjustments to better accommodate the new DC output voltage.

Since most vacuum tube equipment employs point-to-point wiring, there should be plenty of room to install the 1N4007 diodes and the ballast resistor. In fact, you can use the unused 5Y3 octal tube socket pins as convenient tie points. If you avoid using pins 2, 4, 6, & 8, you don't even have to remove the 5Y3 if you would prefer to leave it in its socket as a non-functional tube for the sake of appearance.

On a different, but related note, it is a good idea to replace all electrolytic capacitors in vintage radios and audio amplifiers since these capacitors age, change in value, and become unreliable. Since modern electrolytic capacitors are much smaller (and less expensive) than the ones manufactured decades ago, most vintage radio enthusiasts use larger value replacements for the power supply filters to improve ripple filtering and voltage regulation. (I ultimately replaced the Lafayette HE-30 receiver original 40 uF/300 V filter capacitors with 82 uF/350 V units for these reasons.)

This might not be a good move for vintage audio amplifiers, however. Since using larger filter capacitors improves voltage regulation, this reduces the audio compression during loud music peaks discussed in Section I that many audio afficionados find appealing. Although these filter capacitors should be replaced, these replacements should have the same capacitance values as the originals.

## SECTION V - REPLACING OTHER RECTIFIERS

### A. OTHER HIGH-VACUUM RECTIFIERS

The principles discussed in the above Sections for the 5Y3 are equally applicable to other high-vacuum rectifier tubes as well, both for full-wave (e.g., the 5U4) and half-wave (e.g., the 35W4) devices. Note that these rectifier tubes in general have different plate resistances than the 5Y3, thus requiring an appropriately matched ballast resistor. Note also that peak inverse voltage requirements vary for different rectifier configurations.

For the full-wave center-tap and bridge rectifier circuits, the required PIV rating for each diode leg is given by the following equation:

$$\text{PIV} = 1.41 \times \text{Erms} \qquad (2)$$

For half-wave rectifiers, half-wave voltage doublers, and full-wave voltage doublers, the required PIV rating for each diode leg is as follows:

$$\text{PIV} = 2.82 \times \text{Erms} \qquad (3)$$

For both of these equations, PIV is the maximum peak inverse voltage and Erms is the power transformer RMS secondary voltage (across the *entire winding)*. Of course, a generous safety margin should be added.

### B. MERCURY VAPOR RECTIFIERS

Mercury vapor rectifier tubes (e.g., the 866A) were widely used in transmitter (and even some audio amplifier) power supplies requiring very high voltages prior to the availability of reliable silicon diodes. The advantage of mercury vapor rectifier tubes (in addition to their high voltage and power handling capabilities) was that they were much more efficient than conventional high-vacuum rectifiers such as the 5Y3 and 5U4. In fact, the voltage drop across mercury vapor rectifiers was a relatively low 15 volts and was nearly constant regardless of load current (in contrast to the variable 40-50 volt drop with high-vacuum rectifiers).

The principles discussed in the above Sections for the 5Y3 can be applied to mercury vapor rectifiers as well. Since mercury vapor rectifiers were mostly used for very high voltages, it is necessary to use a series string of silicon diodes in each rectifier leg to achieve the necessary PIV rating. In such cases, good design practice requires that these series diodes be appropriately shunted with equalizing resistors to prevent “voltage hogging” (unequal reverse voltage drops across the series diodes). This issue is discussed in depth in Section VI.

An inelegance with this approach is that the ballast resistor degrades the power supply load regulation somewhat. To explain, the nearly constant 15 volt drop across the mercury vapor rectifiers implies a very low dynamic resistance. If this 15 volt drop is reintroduced using a ballast resistor, the ballast resistor dynamic resistance will be more significant and will thus degrade load regulation.

The loss of some voltage regulation in a +1500 volt supply, for example, would not be a serious issue for many applications. Also, it is likely that a string of silicon diodes will be necessary in each rectifier leg to achieve the necessary PIV rating. Since each diode drops approximately 0.8 volts, the ballast resistor voltage drop can be reduced by 0.8 volts multiplied by the number of series diodes in each leg. (The 0.8 volt diode drop is relatively constant over a wide current range.)

If an elegant solution to this imperfection is desired, however, this can be easily accomplished by eliminating the ballast resistor replacing it with a suitable power Zener diode in series *cathode to cathode* with the silicon diode (or with any silicon diode in the series string). As a case in point, suppose that the mercury vapor rectifier in question exhibits a constant 15 volt drop (as was typical with these tubes) and we want a true solid-state replacement.

To replace this with silicon diodes plus a power Zener diode, a series string of four suitable silicon rectifier diodes would be placed in series with a 12 volt power Zener diode. The net forward voltage drop would then be 12 volts (the Zener diode voltage drop) plus 4 x 0.8 volts (the total voltage drop of the four series silicon diodes). The total voltage drop would be 12 + 3.2 = 15.2 volts (virtually independent of load). No ballast resistor would be included, so voltage regulation would not be impaired. In effect, the circuit would appear as a 15.2 volt rectifying Zener diode.

The Zener diode (and, of course, the silicon rectifier diodes) would have to have a current rating equal to or greater than that of the mercury vapor rectifier tube being replaced. This would require a suitable power Zener. Continuing with the above example as a case in point, if the 12 volt Zener had a 5 watt power rating, it would be able to handle up to 400 mA of load current. To obtain a higher current rating, two series 6 volt Zeners with a 5 watt power rating would handle up to 800 mA of load current.

If a series string of silicon rectifiers is employed, equalizing resistors would be necessary as discussed in Section VI. No equalizing resistor would be required for the Zener diode.

## C. SELENIUM RECTIFIERS

Selenium rectifier series stacks were employed in some vacuum tube equipment up until the early- to mid-1960s when more efficient and reliable silicon diodes became available. Selenium rectifiers were more efficient and ran much cooler than vacuum tube rectifiers. A typical selenium rectifier stack is illustrated in Figure 4.

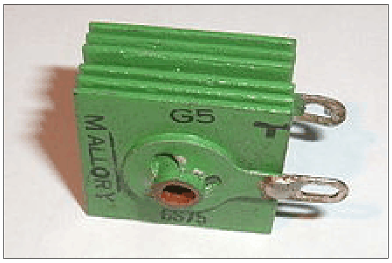


**Figure 4 - Selenium Rectifier Stack**

Each selenium rectifier in the stack has a PIV rating of about 25 volts and a forward voltage drop of about one volt. Selenium rectifiers should be replaced since they are inherently unreliable.  The selenium stack can be replaced using a single 1N4007 silicon diode and an appropriate ballast resistor in the same fashion as discussed for the 5Y3.  To determine the total voltage drop, just count the number of plates in the stack.  As a case in point, since the selenium rectifier illustrated in Figure 4 has 6 plates, its total voltage drop is about 6 volts.

# SECTION VI - PLACING SILICON DIODES IN SERIES

## A. SERIES RECTIFIER DIODE REVERSE VOLTAGE ISSUES

If silicon diodes are placed in series to increase the total peak inverse voltage rating, steps must be taken to ensure that the reverse voltage divides equally across all the series diodes. As a case in point, if we place two 1,000 PIV diodes in series to effectively increase the total PIV rating to 2,000 volts, our implicit assumption is that both diodes have nearly the same back resistance. If this is not the case, there will be “voltage hogging”. To explain, if one of the diodes has (for example) twice the back resistance of the other, then that diode with the higher back resistance will drop 2/3 (rather than ½) of the total reverse voltage. With simple arithmetic, we can see that the total effective PIV rating of these two series diodes would then be only 1,500 rather than 2,000 volts.

To resolve this matter, we need a better understanding of the characteristics of diode back resistance. Unfortunately, diode back resistance is not directly specified in the 1N4007 diode data sheet. The diode specification most closely related to back resistance is the reverse (leakage) current. The “typical” reverse current for a 1N4007 at its maximum 1,000 volts reverse voltage at 25°C is given as 0.05 microamperes (which corresponds to a 20,000 megohm back resistance).

However, this same data sheet lists the “maximum” reverse current for this same diode as 10 microamperes (which corresponds to a far lower 100 megohm back resistance). This in itself is a huge variation, but it even gets worse. At 100°C, the “typical” and “maximum” numbers are given as 1.0 and 50 microamperes, respectively, corresponding to back resistances of 1,000 megohms and 20 megohms, respectively.

Clearly, diode back resistance is an uncontrolled parameter that is all over the place, varying both from unit to unit and over temperature. This being the case, it is clearly poor design practice to place silicon diodes in series without taking the necessary steps to equalize the reverse voltage drops.

## B. EQUALIZING SERIES RECTIFIER DIODE REVERSE VOLTAGE

The issues associated with the highly variable back resistances of series diodes have been well-known for many years along with a mature and time-proven solution. Essentially, the remedy is to place shunt “swamping” resistors of the same value across each diode in the series string. If this resistor value is much lower than the diode back resistance, then the effective back resistance is essentially the value of this swamping resistor and the voltage will divide nearly equally across each diode/resistor shunt pair.

Although there is likely no truly “optimum” value for this shunt resistor, the 1974 ARRL Radio Amateur’s Handbook in its chapter on AC operated power supplies provides the following rule-of-thumb:

$$Rs = PIV \times 500 \tag{4}$$

where Rs is the required value of shunt resistance and PIV is the diode rated peak inverse voltage. Essentially then, the author recommends using 500 ohms of resistance per diode PIV rating. For a 1N4007 diode rated at 1,000 PIV, the required resistor value using Equation 4 would be 500,000 ohms. A 470,000 ohm resistor is thus selected as a good-match standard value.

If 470,000 ohm ½ watt 5% carbon film resistors are used as is the case for the full-wave voltage doubler of Figure 5, the maximum supply output voltage would be limited by the 350 VDC resistor voltage rating. In this case, this circuit would have a maximum safe output voltage capacity of 4 x 350 = 1,400 volts. The power dissipation of each resistor at this maximum voltage would be computed by Ohm's Law as E x E/R = 350 x 350/470,000 = 0.26 watts, which is safely within the ½ watt resistor power rating.

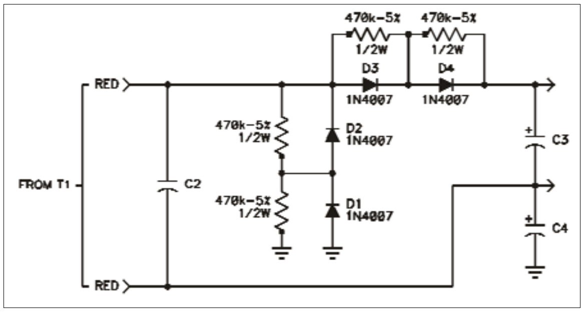


**Figure 5 - Full-Wave Voltage Doubler Using Series 1N4007 Silicon Diodes and Shunt Voltage Equalizing Resistors**

## C. OTHER PRECAUTIONS FOR SILICON DIODE RECTIFIERS

In early silicon rectifier designs, a small series surge resistor was often placed in series with the diode (not to be confused with the ballast resistor discussed above to limit power supply output voltage when replacing vacuum tube rectifiers with silicon diodes). The purpose of this series resistor is to limit the current surge at power-up due to the initial charge-up of the filter capacitor.

In more recent designs, this surge resistor is less common. In most cases it is unnecessary due to the large non-repetitive surge current capacity of modern silicon diodes. (As a case in point, the 1N4007 8.3 millisecond non-repetitive surge current rating is 30 amperes.) Also, the power transformer secondary resistance and filter capacitor equivalent series resistance both contribute to a margin of safety.

On the other hand, modern electrolytic capacitors are much smaller than their earlier counterparts employed in vintage radio and audio equipment, thus making it practical to use much higher value filter capacitors. Since this can result in higher start-up surge currents, designers should not completely rule out the use of a series surge resistor. However, a better alternative for most applications would be to substitute a 1N5408 silicon rectifier diode. The 1N5408 is larger than the 1N4007 with a higher forward current rating (3.0 vs. 1.0 amperes). More importantly, it has a much higher 8.3 millisecond non-repetitive surge current rating (200 vs. 30 amperes). Although the 1N5408 is more expensive than the 1N4007, it is still very modestly priced. Both diodes are rated at 1,000 PIV.

Another practice employed in early silicon rectifier designs using series diodes was to include diode shunt capacitors (typically 0.01 uF) in addition to the diode shunt voltage equalizing resistors discussed above. These capacitors have two rationales. First, they provide some protection against AC power line voltage “spikes” that might damage one or more diodes (if the spike is sufficiently short in duration, the 0.01 uF capacitor shunts the transient around the diode).

Second, these capacitor address the issue associated with the fact that the shift from diode forward conduction to high back resistance does not occur instantaneously (i.e., the reverse bias capacitance is different from one diode to the next). These capacitors protect the “fast” diodes in a series string until all the diodes are fully cut off. Unfortunately, the “cure” can be worse than the disease if this technique is not implemented carefully. The problem is that variations in capacitance values among the shunt capacitors can exacerbate the problem, so it is best to use 5% tolerance capacitors for this purpose.

Although the above technical rationales for using series diode shunt capacitors seem valid, most modern designs do not use them. If I had to make a guess, it would be that modern silicon diodes likely exhibit much more uniform turn-on/off times than their 1960s-era predecessors. If this is the case, it would be prudent to ensure that diodes used in a series string all be from the same manufacturer, and even the same batch if possible.

Another technique sometimes used to protect silicon diodes in very high voltage transmitter power supplies is to employ “soft-start” circuits. This typically comprises a low-value power resistor in series with the power transformer primary that limits the high start-up current spike at power-up (and thus protects the rectifier diodes). A relay coil is then wired in parallel with this resistor so that the relay trips shortly after this start-up. The relay contacts are then wired so as to simultaneously latch the relay a second or so after AC power is applied and short-out the resistor so that the full AC line voltage is then applied to the power transformer primary.

In equipment where such soft-start techniques are employed, it is best to use the heavier duty 1N5408 rectifiers rather than 1N4007s so as to benefit from the 1N5408 higher surge current rating. This is especially true if larger filter capacitors have been substituted for the originals.

## SECTION VII - REPLACING SIGNAL RECTIFIERS

Although somewhat tangential to the primary purview of this paper, vacuum tube diodes used for signal detection (e.g., the 6AL5 and 6H6) can also be replaced with semiconductor diodes to good effect. Even though the reasons are somewhat less compelling (vacuum tube signal diodes dissipate far less heat and are less prone to failure than their rectifier diode counterparts), the rationales are still the same:

1. A relatively scarce failure-prone part can be replaced with a readily available maintenance-free substitute.

2. Eliminating a vacuum tube signal diode in favor of a semiconductor replacement extends power transformer life by eliminating the filament current drain for the replaced vacuum tube.

3. A scarce and expensive out-of-production vacuum tube is eliminated in favor of an inexpensive current-production semiconductor diode.

The best semiconductor diode replacement candidates are the 1N4148 silicon diode and the 1N6263 Schottky (hot-carrier) diode. Both of these diodes are inexpensive and readily available.

The 1N4148 is a better choice in applications requiring low reverse leakage current (keeping in mind that vacuum tube reverse leakage current is essentially zero). Since even the very best semiconductor diodes do not have zero reverse leakage current, the circuit should be studied to determine whether or not this is an issue. This is more of a problem in very high impedance circuits.

The 1N6263, however, has a lower forward voltage threshold, thus making it more sensitive for detection of very weak signals. It is therefore a better choice if its higher reverse leakage current is not a problem.

Both of these signal diodes have a much lower PIV rating than vacuum tube signal diodes (75 PIV for the 1N4148, 60 PIV for the 1N6263, versus several hundred PIV for the 6AL5 and 6H6). Although this should not be an issue in most signal detection applications, the circuit should be examined to confirm this.

For most signal detection applications a 1N4148 or 1N6263 will provide superior sensitivity and linearity. In the majority of applications where their leakage and PIV limitations are not an issue, they will yield superior performance and reliability as compared to their vacuum tube counterparts.

## SECTION VIII - PAPER SUMMARY & AUTHENTICITY ISSUES

To summarize this paper (and also address a related topic), vacuum tube rectifiers and signal diodes (e.g., the 5Y3 and 6AL5, respectively) can be replaced with inexpensive modern solid-state components offering superior performance and much better reliability. For high-vacuum rectifier tubes, silicon rectifiers can be substituted, but it is important that an appropriate series ballast resistor also be included for a true functional replacement that will closely match the performance of the replaced rectifier tube.

Silicon rectifiers can likewise be used to replace mercury vapor rectifier tubes. Since these rectifiers typically exhibited a constant (load-independent) voltage drop of 15 volts, an appropriate series power Zener diode should also be included for a true functional replacement that will closely match the performance of the replaced rectifier tube.

Although not addressed in this paper, power Zener diodes can also be substituted for voltage regulator tubes. This will usually require a series string to handle the higher voltages.

Silicon diodes can be placed in series to handle higher peak inverse voltages. When this is done, however, appropriate equalization resistors must be place in parallel with each diode to avoid voltage hogging.

Although some vintage radio enthusiasts may object to such substitutions based on "authenticity", this must be weighed against the many advantages of solid-state diode substitution. This is especially the case where the substitution is carefully implemented so that performance is unchanged (i.e., including an appropriate series ballast resistor or Zener diode as discussed above.)

My philosophy is that the authenticity issue is greatly outweighed by the significant benefits which include component availability, cost, reliability, and the reduced load burden placed on irreplaceable radio power transformers as discussed above. On the other hand, my colleague Steve Mazur of Mazur Sound points out that the people he deals with (mostly people using vintage vacuum tube sound equipment) tend to be very particular about authenticity issues and are resistant to solid-state substitutions in their vintage equipment.

Steve also tells me that in his business he has learned not to question why people like what they like, and instead (wisely) gives them what they ask for. (This is analogous to my own business philosophy: "Never argue with customers - if you do, you will win the argument and lose the sale.")

My suggestion to Steve was to leave the rectifier tube in the socket, and even connect the filament so that the tube appears functional. Of course, he would do this with the knowledge and consent of his customers.

At the end of the day, each vintage radio enthusiast must decide for himself where he wants to draw the line on this authenticity issue. I've drawn my line to allow substitution of any passive component (e.g., resistors, capacitors, diodes, etc). I would not attempt to replace amplifier tubes, however, with transistors or ICs unless there was no other way to complete the reconditioning project.