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The development of AC mains power supplies, Pt.2

Last month, we looked at the development of AC mains power supplies for domestic radios and the all-important power transformer. In Pt.2 this month, we look at some of the other aspects of power supplies that a restorer needs to understand.

UNDERSTANDING THE power supplies in valve receivers is an important aspect of restoration. It's important that you know what you are doing when restoring such equipment, as incorrect servicing can cause a fire or even result in electrocution.

The power supply circuits used in valve radio receivers are usually relatively simple. They typically consist of a transformer, a rectifier like a 5Y3GT, two 16μF electrolytic capacitors and a 12 Henry choke between them. This was almost an industry standard for many years. Later sets used rectifiers such as the 6X4 and a resistor in place of the choke – see Fig.1.

Replacing like for like components with the same ratings is usually quite reasonable when restoring such circuits. However, because the circuits are relatively simple, many people are often lulled into thinking that any odd-value component can be used to replace a faulty part.

A typical power supply

Fig.1 shows the circuit of a typical power supply as used in many late-model valve mantel receivers. Let's take a look at the design requirements necessary to ensure reliability for this type of supply, starting with the power transformer.

Generally, the power transformers used in valve receivers are conservatively rated and it is rare to hear of them burning out. Most (but not all) power transformers have a tapped primary winding that (depending on the connections) can accommodate mains input voltages ranging from around 200V AC up to about 250V AC at 50Hz. However, some transformers were designed to work safely on 40Hz mains, as used in Perth many years ago.

Because they are conservatively rated, most transformers in valve receivers will withstand somewhat higher currents than originally intended. This may be brought about, for example, by substituting a valve that draws greater heater and HT currents than the valve originally specified. However, although they may withstand moderate overloads in the short term without too much fuss (but run warmer in the process), this is not recommended long term.

In any case, the transformer should not run hot in normal use.

Voltage regulation

The voltage drop across a valve rectifier varies significantly between low load and its maximum specified load. The figures provided as examples in the following paragraphs depend on the resistance of the transformer's primary and secondary windings, the type of rectifier used and the value of the first filter capacitor. These values are typically set down in valve data books.

For example, a 6V4 rectifier connected to a 600V centre-tapped transformer secondary winding will have a DC voltage of 424V on its cathode with no current being drawn. This slumps to approximately 300V at its maximum rated current output of 90mA.

A directly-heated GZ32 (with the

same input voltage) will have 424V on its filament at no load and this will drop to 320-360V at its full-load rating of 300mA. By contrast, the output from a 5Y3GT with the same voltages applied will drop to as low as 330V with a 60mA load and to 280V at 125mA.

If a field coil speaker is used in the HT line, then the HT line will typically be reduced a further 100V if a 6V4 or GZ32 rectifier is used. Alternatively, for a 5Y3GT, the voltage drop can be as high as 190V at 60mA.

Often, 5Y3GT valves were used with transformers with a 770V centre-tapped (ie, 385V per side) HT secondary winding. The no current voltage on the output of the 5Y3GT for a few seconds will thus be 385V x 1.414 = 544V DC peak and this voltage is applied to all valves and components connected between the HT line and the chassis. The transformer winding resistances, magnetic losses, field coil resistance and the voltage drop across the rectifier at full load will subsequently reduce this HT voltage to 250-300V DC after filtering.

For this reason, sets using a 5Y3GT or similar directly-heated valve rectifier must use components (particularly electrolytic capacitors) capable of withstanding the high peak voltage. That is why old sets had either 450V working (VW), 525V peak (VP) or 500VW/600VP electrolytic capacitors.

In later receivers, such as the Kriesler 11-99, silicon diodes were used as power rectifiers. In fact, I have a solid-state version of a valve rectifier power supply. It is a 100mA power supply with a 600V (300V per side) centre-tapped secondary transformer winding and the output voltage at no load is 425V DC. This drops to 368V at full load at the cathodes of the diodes and 355V immediately following the filter choke.

In short, silicon diodes are more efficient than valve rectifiers. The peak voltage and the full-load voltage are much closer together when using silicon diodes. This means that the secondary HT winding voltages can be much less than in a valve rectifier circuit for the same output.

In fact, a secondary HT winding of around 225V would be adequate for a HT voltage of 250V DC in a late-model valve receiver.

Rectifier rating limitations

Valve power rectifiers have a number of ratings that need to be observed to ensure a long life. In the preceding section, the 6V4 was described as having a maximum continuous current output of 90mA. However, in practice, the rectifier only supplies current for a fraction of a complete cycle (see Fig3.3-6), during which it charges the filter capacitor at its cathode.

The peak current specified for the 6V4 is 270mA per plate and the size of the filter capacitor is limited to 50µF. To limit the peak current to a safe value, the minimum effective plate supply impedance (ie, per plate) varies from 125-300Ω, depending on the output voltage of the supply. This impedance consists mainly of the primary and secondary winding resistances of the power transformer. However, you will sometimes see a low-value resistor in series with each plate lead to increase this resistance to the minimum recommended.

A scope shot of the peak current through the 6V4 rectifier of this power supply shows that the current is supplied to the filter network in pulses. The traces show both the ripple voltage and the peak capacitor charging current, which occur at the same time as each other.

Using a 16µF electrolytic as the first filter capacitor, the peak current through the rectifier is 0.4A (400mA) and the ripple voltage on the capacitor is 50V p-p with a 100mA load. Note that the 0V line is not shown on the power supply ripple trace (the upper trace).

Note also that the voltage across the 16µF capacitor (upper trace) begins to rise as soon as the charging current from the rectifier diodes (lower trace) commences.

The horizontal line on the lower trace is zero current and the rectifier diodes only conduct when their anodes are more positive than their cathodes.

In the case of the 5Y3GT, the filter capacitor should not normally exceed 20µF, depending on the output voltage and the transformer winding resistances. The 5Y3GT is intended for vertical mounting but it can be laid on its side if pins 2 and 8 are in the horizontal plane. The filament sags as it heats up and under some circumstances the valve could flash over if this precaution is not observed.

Peak inverse voltage

Another rating rarely thought about is the peak inverse voltage (PIV) rating of each diode section when it is not conducting. If you measure the voltage across each half of the HT secondary transformer winding and it is around 285V (a common value), the output voltage following the rectifier will be around 400V with no load.

A common mistake made by radio restorers is to fit 1N4004 diodes (400V PIV rating) in place of a 5Y3GT rectifier valve or similar. Unfortunately, a 400V PIV diode is not adequate in a power supply that's delivering 400V and as some have found out to their sorrow, the power transformer can quickly become a charred, smelly mess.

To understand how this happens, assume initially that the no-load output voltage is +400V on the diode's cathode. What happens then is that the voltage on the winding reverses and this then results in -400V (peak) on the diode's anode. That means that the total voltage across the diode is 800V when it is not conducting, a figure which greatly exceeds its PIV rating.

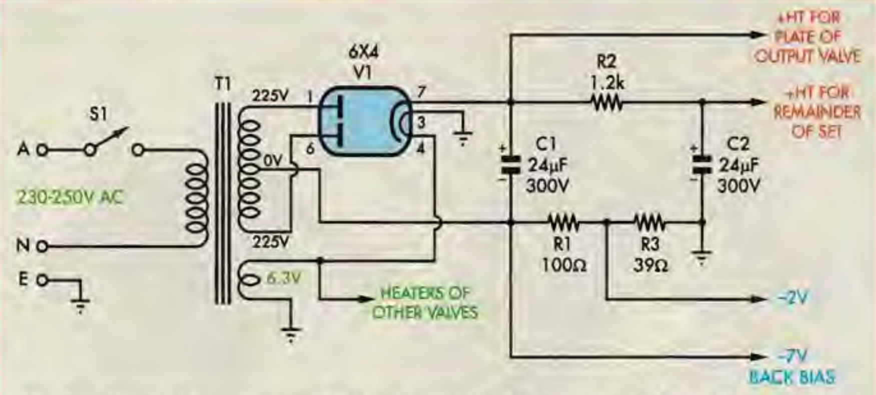
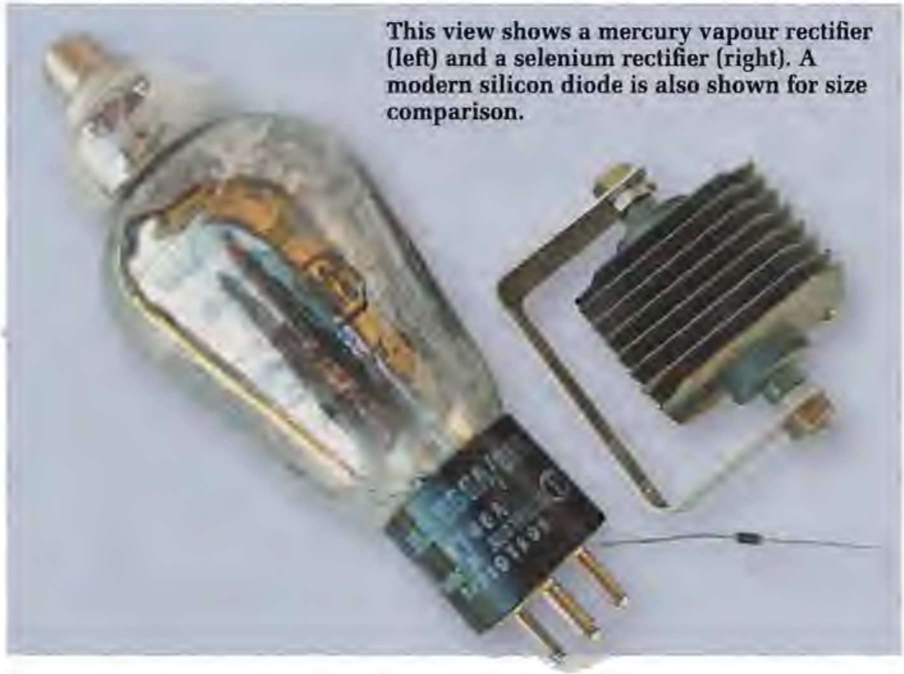


Fig.1: a typical power supply for a receiver that uses a 6M5 as its audio output valve. Note the method used to derive the two back bias voltages.



This view shows a mercury vapour rectifier (left) and a selenium rectifier (right). A modern silicon diode is also shown for size comparison.

Rather than go into great detail, as a rough rule of thumb it's a good idea to allow three times the winding voltage as the PIV required for a rectifier. This is necessary to also allow for mains surges and spikes.

In greater detail, in the example above, the PIV rating of the diode should be at least 2.828 (2 x peak winding voltage) x 285 = 806V (NOT 400V). This means that a 1N4007 1000V PIV diode (or similar 1000V diode) would be necessary in this particular circuit.

If the calculated PIV is greater than 1000V, then two or more diodes can be connected in series to give the required PIV. However, it is necessary to put a resistor and a capacitor across each diode to compensate for unequal leakage currents and capacitances at the diode junctions. The ballpark requirements for a 1000V PIV diode are two 1W 150kΩ resistors in series across the diode and a parallel 1nF 1kV or higher-rated ceramic capacitor.

Solid-state diodes are relatively cheap and may be the only alternative in some restoration projects where the original rectifier type is no longer available. However, when substituting solid-state diodes for a valve rectifier, it is also necessary to install a resistor in series with their cathodes, before the first electrolytic filter capacitor.

This is necessary to reduce the output voltage to the normal value when the power supply is on load.

The value of this resistor is likely to be around 300Ω but the wattage rating needs to be around double the calculated value for pure DC, as the peak current through the resistor will be quite high.

Of course, the thermionic diodes in rectifier valves also have PIV ratings. The venerable 5Y3GT has a PIV of 1400V, the 6V4 1000V and the 6X4 1250V. You exceed these ratings at your peril.

In addition, indirectly-heated valve rectifiers have another rating that many are not aware of – the heater-to-cathode insulation rating. To explain, the heater and cathode are insulated from each other in indirectly-heated valves and for most power valves, the insulation rating is 100-200V. For rectifiers, however, it has to be much higher and in the case of the 6V4, it is 500V and for the 6X4 450V in a conventional power supply.

One rectifier that is prone to breaking down between the heater and cathode if it is overloaded is the 6X5GT.

Back bias & hum reduction

Fig.1 shows a typical power supply for a receiver that has a 6M5 as its audio output valve. Note that instead of the centre tap of the HT secondary winding going to chassis, it is wired to a common point along with the negative side of capacitor C1, one side of resistor R1 and a lead for the -7V bias line.

This arrangement is necessary to minimise hum loops.

Earlier power supplies earthed both the centre tap and the negative of the first capacitor to the chassis at the same spot if possible. If they are not connected to the chassis at the same spot, the peak currents flowing through the chassis due to rectifier action will develop an alternating voltage between the two earth points and this can cause hum in the output of the receiver.

As shown in Fig.1, the bias for the 6M5 and the earlier valves can be taken from particular points across resistors R2 and R3. The bias to the 6M5 in particular has ripple impressed on it due to the operation of the rectifier and filtering components. This ripple can be used to "buck" (or nullify) the effect of the ripple on the plate circuit of the output valve.

When the rectifier is conducting,

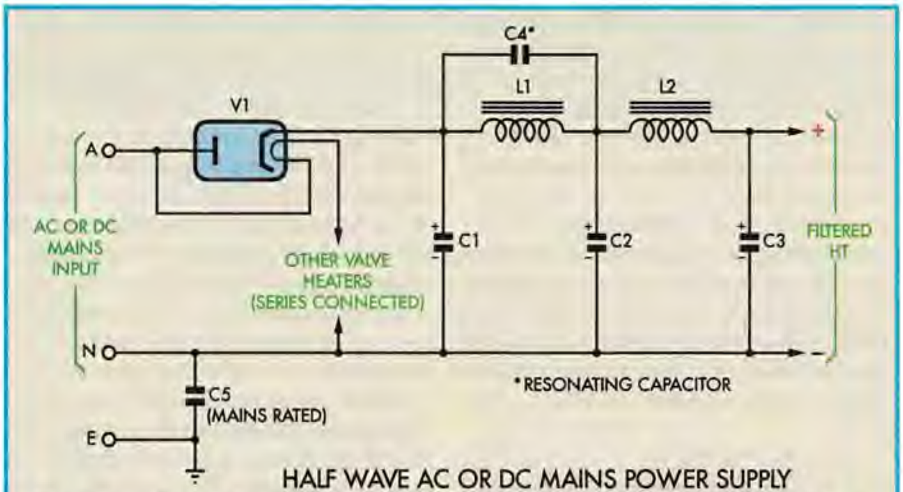


Fig.2: transformerless AC/DC sets had one side of the mains connected to the plate of the rectifier, while all the valve heaters were in series with the mains. Such sets are extremely dangerous to work on – see text.

the positive voltage at pin 7 rises and so the output valve will tend to draw slightly more current, as mentioned earlier. At the same time, the -7V bias will also go further negative and this will largely nullify any rise in the plate current, thus reducing the hum.

The -2V line supplies bias for the front-end valves and for delayed AGC (automatic gain control). So this simple supply performs several jobs using relatively few parts. Note that in some sets, the ratio of the bias variation to the plate voltage variation doesn't match and so additional filtering of the back-bias line is required.

Power supplies for AC/DC sets

The transformerless half-wave power supplies used in AC/DC receivers are extremely dangerous, so don't mess with them unless you are an expert, have lots of experience and understand exactly what you are doing. Do the wrong thing with one of these and you could get electrocuted.

In fact, depending on which way around the mains Active and Neutral are connected, the chassis could be at mains potential! In other words, one side of the mains was connected directly to chassis in some sets.

For this reason, it's vital to use an isolation transformer when working on such receivers. But we repeat the above warning – DO NOT touch such sets unless you are an expert.

Fig.2 shows a typical power supply as used in many AC/DC receivers. As the rectifier is only conducting for less than half the time, adequate filtering of the pulsating DC is harder to achieve than with full-wave rectification.

The values of the first and second filter capacitors were the largest that could be used with the rectifier (usually 8μF or 16μF each), while an iron-cored choke of around 12 Henry was used to achieve reasonable filtering. Even then, AC/DC receivers always tended to have more hum than those that derived their power via a mains transformer.

The Kriesler 11-90 and 11-99 sets, while they are not AC/DC sets, use a 6V4 and silicon power diode respectively in half-wave rectifying circuits. The first filter capacitor is 40μF to filter the pulsating DC output from the rectifier as much as possible.

Resonant tuning

In some power supplies, particularly in earlier times, the filter choke was tuned to resonance by a capacitor wired across it. A 10H choke resonates with a 1μF capacitor at 50Hz and by resonating the choke, the filtering efficiency was increased. If you have a set that has come from America, the value of this resonating capacitor should be increased by 20%, so that it will work better at the Australian 50Hz mains frequency.

Heater supply in AC/DC sets

By necessity, the heaters in AC/DC sets are wired in series across the mains (we said such sets can be dangerous). In fact, a whole series of valves was developed that had heaters rated at either 0.3A or 0.15A and even as low as 0.05A. The voltage across the individual valves varied according to the purpose they served. For example, a 35L6 output valve has a 35V 0.15A heater, while a 12SK7 RF valve has a 12.6V heater that draws 0.15A.

Because the valves on the set do not heat up at the same rate when power is applied, some valves will have excessive voltage across their heaters for a short time and this can ultimately reduce their working life. Several simple techniques were used to reduce this problem, the easiest being to install a resistor in series with the heaters. This resistor introduced an additional voltage drop to make up the difference between the mains voltage and the correct voltage drop across all the heaters.

Another common method was to wire a "Barretter" in series with the valve series heater string. Barretters are designed to stabilise the current through them to some predetermined value for a range of input voltages. For example, the 1941 barretter is rated to provide 0.3A over a voltage input range of 80-200V, while a 161 is rated for 0.16A over a voltage range of 100-200V.

A third method that I like is to use negative temperature coefficient (NTC) thermistors. When cold, they have relatively high resistance and as they warm up their resistance drops dramatically. By wiring them in series with the heaters, the valves will gradually have the correct current applied to them. However, they do take a while to drop in resistance as they warm up and sets using them take quite some time to start working.

Dial lamps can be a problem if wired

Fig.3: this scope shot shows the ripple (top) and the peak current from a typical full-wave rectifier when using a 16μF first filter capacitor. The ripple voltage is 50V peak-to-peak at 100mA.

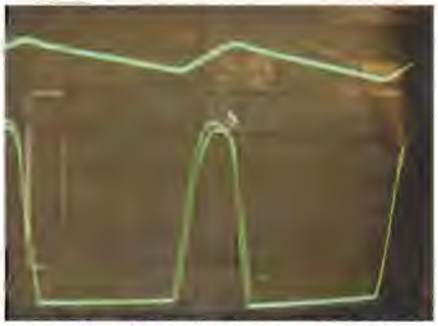


Fig.4: the effect of substituting a 64μF first filter capacitor. The peak current remains nearly the same and the ripple reduces to 15V peak-to-peak.

Fig.5: the waveforms for a half-wave rectifier and 16μF first filter capacitor. The HT voltage reduces from 350V to 305V, the peak current increases to 0.65A and the ripple voltage increases to 120V peak-to-peak.

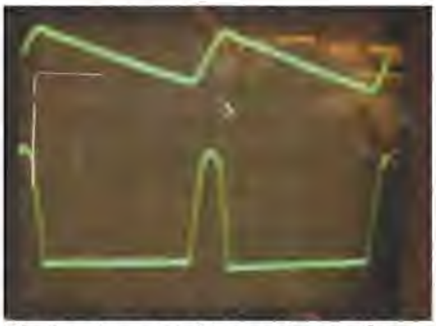


Fig.6: using a 64μF capacitor in the half-wave circuit reduces the ripple from 120V to 30V.

The 6V4, 6X4 and 6CA4 "miniature" rectifiers were commonly used in radio sets towards the end of the valve era. Be careful when changing from one rectifier type to another, to ensure maximum ratings are not exceeded.

in series with the valve heater string. That's because if they blow, the set will be inoperative. However, it is common for the dial lamps in such sets to be run at reduced current so that they are unlikely to fail.

Unavailable valve rectifiers

If a rectifier is no longer available (eg, the 25Z6 which is used in AC/DC receivers), then it is possible to substitute solid-state diodes. For example, if the valve heater is intact but its emission is low, a 1000V 1A diode such as a 1N4007 can be wired directly across the valve's socket.

However, because the voltage drop under load is much lower with a 1N4007, it's advisable to install a resistor in series with one of its leads to drop the on-load voltage to that normally obtained with a good valve rectifier. The value of this resistor will be around 300Ω.

If no rectifier is fitted to the set and none is available, a 10W resistor with the same heater resistance as the original rectifier can be fitted. This is simply wired across the valve socket to the heater pins. For example, the 25Z6 has a 25V heater that draws 0.3A. The formula for calculating the value of the resistance is V/I = R, where V = volts, I = amps and R = resistance. Therefore 25/0.3 = 83Ω. The preferred value of 82Ω will be close enough.

If an indirectly-heated rectifier is replaced with a silicon diode(s), it is necessary to ensure that the electrolytic capacitors (and other components) can withstand the high voltage that appears across the supply line until the valves draw current. A series resistor in the supply line of around 300Ω before the first filter capacitor will usually be necessary.

In some cases, it is possible to substitute another type of indirectly heated rectifier. However, if this has a higher heater current than the original valve, make sure that the power transformer can withstand the increased load. PIV and maximum current ratings need to be observed too.

Electrolytic capacitors

After long periods of time, it's common for electrolytic capacitors to lose their capacitance and become electrically "leaky". For this reason, if a set has not been used or serviced for many years, it's essential to check the electrolytic capacitors to make sure they are still in good working order.

The first thing to do is to check that there are no shorts or near shorts between the HT line and the chassis. If there are, it is necessary to disconnect various components and sections of the receiver to determine where the fault lies. A multimeter can then be used to locate most shorts.

Occasionally an electrolytic capacitor will be found to be defective. What happens is that the dielectric in an electrolytic can lose its insulating properties. As a result, it can become be quite "leaky" electrically and draw many milliamps of current when a voltage is applied.

Any capacitors that are "leaky" either need to be replaced or "reformed". In the latter case, this is achieved by applying a voltage that's close to the working voltage of the capacitor through a current limiting resistor.

A current of 20mA is a reasonable limit when it comes to reforming the electrolytic capacitors found in vintage radios. In practice, it may take several minutes for the dielectric to reform, by which time the leakage current should be just a milliamp or two, depending on the capacitance. If the capacitor is defective, then the voltage across it after a few minutes of "reforming" will still be quite low compared to the voltage source.

If the reforming process appears to have been successful, the next step is to try the set out. However, if the capacitor has lost its capacitance, hum will be quite evident in the output from the speaker. Before condemning the capacitor to the scrap bin though, connect another one across it. If the hum is reduced, replace the faulty unit. If not, there is another fault somewhere in the set.

For more information on electrolytic capacitors and on reforming them, refer to the Vintage Radio column in the October 2006 issue of SILICON CHIP.

Summary

The power supplies used in old valve radios appear to be relatively simple. However, to achieve long-term reliability, particularly when major changes are made to a supply, you have to consider all the points raised in this article and in Pt.1 last month.

From personal experience, many vintage radio restorers are unaware of just how important some power supply design factors really are. Factors such as rectifier peak inverse voltage (PIV) ratings, current ratings, heater cathode insulation ratings and electrolytic capacitor values and voltages must all be considered.

This particularly applies when a switch is made from one type of rectifier to another, regardless as to whether you are simply substituting a different valve or changing from a valve rectifier to a solid state rectifier.

Finally, remember to stay well away from transformerless AC-DC sets. They are a death trap for the uninformed and the unwary. **SC**