# Vintage Radio

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## The development of AC mains power supplies, Pt.1

**The development of AC mains power supplies was an important step in the evolution of domestic radio receivers. Understanding how they work is important for vintage radio restorers, especially if the power supply has to be modified in some way.**

This photo shows two common mains transformer styles from the valve radio era. The one on the left is an above-chassis mounting type while the other is a through-chassis type.

PERHAPS THE MOST common modification to a vintage radio's power supply is the substitution of a different rectifier valve. This may be necessary if the original type is no longer available or is difficult to obtain. Before substituting a rectifier valve though, it's important to first determine if the replacement is indeed suitable.

Considerable care is also necessary if a valve rectifier is to removed and converted to a solid-state circuit using diodes.

### Different voltages

Valve radio receivers invariably require a number of different voltage rails to supply various parts of the circuit. What's more, the current requirements for these voltage rails can vary widely, depending on the circuitry that's being powered.

Originally, the necessary voltages in radio receivers were supplied by primary and secondary batteries. The capacity of the batteries depended on the current drain at the particular voltage required. For example, many old radios typically needed just 10mA at 90V for the high tension (HT) voltage supply, whereas a current of 2-3A may have been required to heat the filaments (usually at voltages of 1-5V).

As a result, the HT battery consisted of many small cells of limited capacity in series, while the filament or low-tension (LT) battery commonly used two or three large wet cells with perhaps 100 amp-hours (Ah) capacity.

In short, batteries were used to power the earliest valve radios and also to power the various valve portable radios that were later developed.

Unfortunately, the high power consumption of battery valve receivers meant that the cost of powering such receivers was quite high (this also applied to the later portable sets with their specially-designed "battery valves"). As a result, set manufacturers and experimenters looked at ways of supplying the necessary power to a radio from the mains. In the end, a fairly standard circuit quickly evolved and this was used in a wide range of receivers during the valve radio era.

Of course, running a set from the mains supply restricts where the set can be used. In most cases though, that didn't matter because the set was installed in a fixed location and the aim was to eliminate the use of batteries which were expensive.

### Early mains supplies

As already mentioned, the early battery receivers used quite a bit of power to heat the valve filaments. However, these valves could not be powered from the AC mains via a transformer for a very simple reason: the cyclic current variations over a full mains cycle meant that the filament emissions and thus the HT current drain varied in sympathy.

Although the mains frequency in Australia, New Zealand and most of Europe is 50Hz, the severe hum heard in the audio output is at 100Hz. This occurs because the mains waveform reaches two peaks per cycle – see Fig.1. Similarly, in North America the mains frequency is 60Hz and so the hum occurs at 120Hz.

Converting the raw AC to DC was initially achieved using selenium or copper oxide rectifiers and devices called Tungar rectifiers. These were used to charge secondary cells/batteries but the hum they produced was intolerable for powering the valve filaments.

Because these problems were not immediately solvable, the filaments were supplied from batteries, usually wet-cell lead-acid types. However, it was possible to power the filaments while the batteries were on charge although some hum was still likely. Another problem was that as the battery neared the end of its charge, its output voltage could exceed the filament voltage rating of particular valves.

In short, this was a messy solution that required careful attention during the charging part of the cycle.

By contrast, deriving HT supplies was not as difficult as the currents were quite modest. In fact, Philips and other manufacturers made battery eliminators that could be used in place of the HT batteries in early receivers. The transformer was wound with either a centre-tapped secondary winding or a single winding. Its output was then rectified and filtered to provide the correct HT voltage for the plate circuits.

The early rectifiers were solid-state types but the 280 (also known as the 80 and the 5Y3GT) eventually made its appearance. This was used as a "bi-phase" (or full wave) rectifier, its two plates (the anodes) being connected to opposite ends of a centre-tapped secondary transformer winding – see Fig.2. The centre tap of the transformer was usually connected to earth.

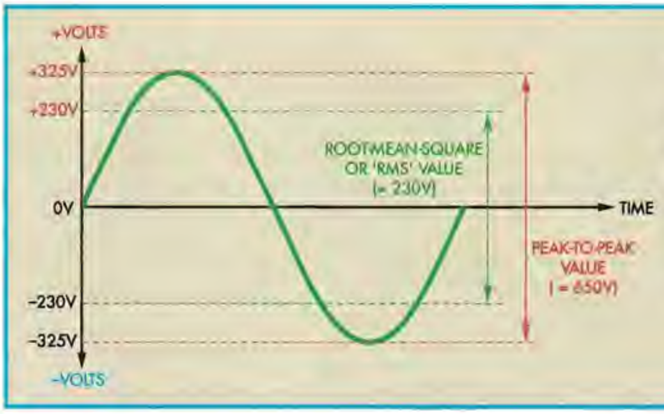


Fig.1: the AC-mains waveform. There are two peaks per cycle and this can give rise to 100Hz hum unless proper design precautions are taken.

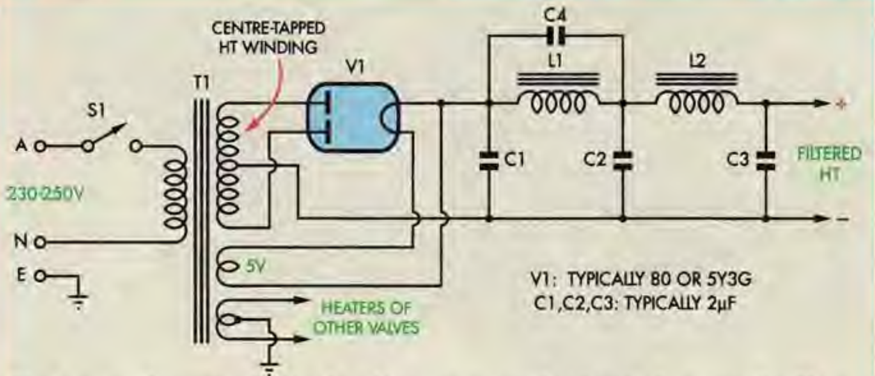


Fig.2: an early mains-derived radio power supply circuit. Because the filter capacitor values were so low, two chokes (L1 & L2) were used in series to achieve adequate filtering.

The 100Hz pulsating DC output from the rectifier cathode/filament was applied to a high-voltage paper capacitor of around 2μF, wired between the cathode and the centre-tap of the transformer winding. This reduced the hum somewhat. Following this capacitor, a choke of 10-30 Henries was placed in series with the HT+ and its output in turn applied to a second 2μF paper capacitor wired between HT+ and HT-.

An additional stage consisting of a further 2μF capacitor and large inductance choke was also often used and with this amount of filtering, the HT voltage was near enough to pure DC. It might be thought that having two chokes and three capacitors was a case of overkill. This was not so, as electrolytic capacitors were not available and manufacturers had to make do with low-value, high-voltage paper capacitors.

## Valves with AC filaments

Having successfully come up with a scheme of deriving filtered HT from the mains, the manufacturers next at-

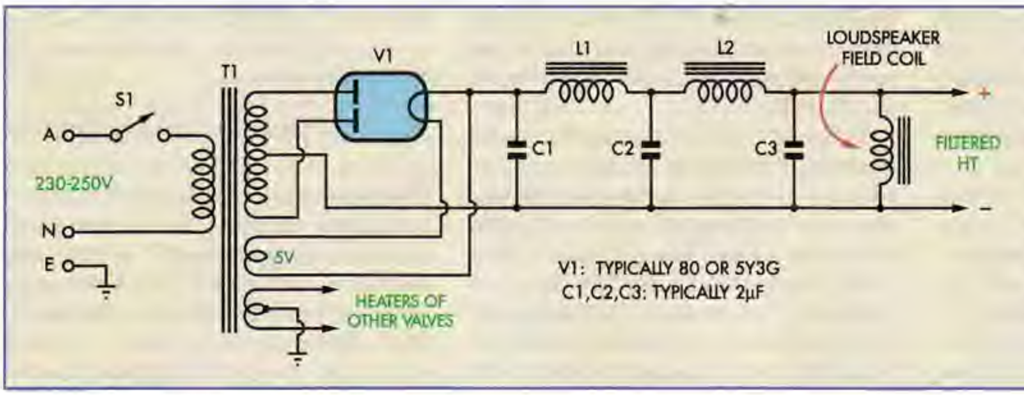


Fig.3: the field coil of early electrodynamic speakers was powered by connecting it across the filtered HT line. In later sets, the field coil performed a dual role and was placed in series with the HT line, taking the place of one of the filter chokes.

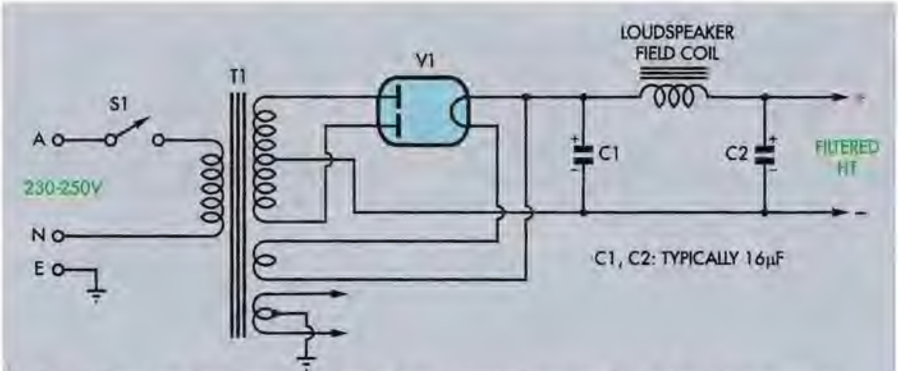


**Fig.4: the development of electrolytic capacitors enabled the designers to use just one HT filter choke. This could be either a separate choke or the field coil of an electrodynamic loudspeaker.**

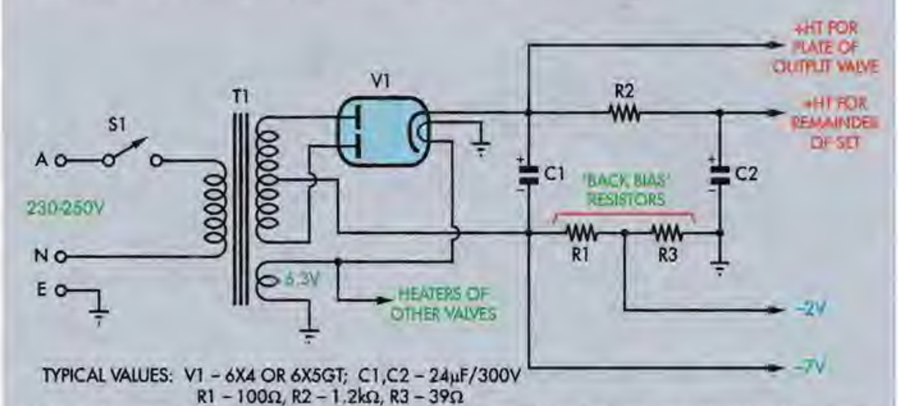


**Fig.5: towards the end of the valve era, the filter choke was eliminated and was replaced by a resistor (R2). The HT for the output valve was derived directly from the first filter capacitor – see text.**

tacked the problem of hum from the valve filaments.

This was done in several in several ways. First, for the power output valves, they reduced the filament voltage (2.5V was common) while increasing the current. This had the effect of increasing the thermal inertia of the filaments so that they didn't cool significantly between each peak of the mains cycle. This in turn meant that there was less variation in the current drawn by the valve over a mains cycle and so hum was reduced.

However, by itself, this was often not enough and so the 2.5V heater lines were often centre-tapped, with the centre tap going to chassis to further reduce the hum. The 2A3 is a typical example of a valve built to minimise the hum problem.

In other cases, where no centre tap was provided on the 2.5V heater line, a device called a "hum-dinger" was fitted. This consisted of a 6-25Ω wirewound potentiometer, which was connected across the 2.5V transformer winding. The pot's moving arm was connected to earth, either directly or via a resistor.

In practice, the potentiometer was adjusted so that hum in the output was minimised. This "hum-dinger" arrangement was also used in later high-performance valve audio amplifiers (also referred to as "hum-bucker" but see reference below) to minimise residual hum, even with indirectly heated, low-noise valves.

However, the same method of reducing hum from the filaments in earlier stages of a receiver or amplifier was impractical. That's because their heaters drew less current than the output valve and so they cooled down too much between each successive peak on the 50Hz mains.

To overcome this, manufacturers eventually developed indirectly heated valve filaments. In this case, the filament (or the "heater" as it is called in indirectly-heated valves) was encased in a sheath that had good emissive properties when heated. The sheath and the filament/heater are insulated from each other and so the sheath has considerable thermal inertia.

This thermal inertia is the reason it takes so long for an indirectly-heated valve to start operating after power is applied. The average time is 10-15 seconds, which is much slower than the fraction of a second it takes for a battery valve to start operating.

As a result, indirectly-heated valves (ie, valves with indirectly-heated cathodes) generate very little hum although it did take the manufacturers some years to achieve consistently low levels. Eventually, some valves were designed to have extremely low heater hum, such as the low-noise EF86 pentode.

Towards the end of the valve era, the designers of low-voltage power supplies were able to provide much better filtering as high-value electrolytic capacitors became available. Some hifi manufacturers even supplied the heaters in the preamplifier valves of audio amplifiers with well-filtered low-voltage DC to largely eliminate residual hum.

## More economical filtering

Indirectly heating the valve cathodes using low-voltage AC largely solved the hum problem, at least as far as the valve heaters were concerned. In fact, during the 1930s, the filament/heater voltage was increased to 6.3V and directly-heated output valves were phased out. A 6.3V heater rating meant that they could be used in car radios, as most cars had 6V batteries at that time (ie, three cells at a nominal 2.1V per cell).

During this time, there were also further developments in filtering the HT voltage. Electrolytic capacitors were becoming quite common so instead of having a filter with three 2µF capacitors and two 10-30H chokes, it was now possible to use two 8µF or 16µF electrolytic capacitors separated by just one filter choke. This provided superior filtering at considerably lower cost, as large-value chokes were not cheap to produce.

## Electrodynamic loudspeakers

There was also a problem with loudspeakers. While early battery sets used speakers with permanent magnets, they were not particularly sensitive and could lose their magnetism if badly treated (eg, dropped). With the advent of mains-operated sets, it became practical to employ so-called electrodynamic loudspeakers. These used an electromagnet instead of a permanent magnet. However, the electromagnet had to be fed with well-filtered DC otherwise hum would once again be prevalent in the audio output.

In the early days, the electromagnet was fed with DC from the output of the power supply filter network. However, it was soon realised that the electromagnet could serve a dual purpose as both the HT filter choke and as the speaker magnet.

Unfortunately, this wasn't without its own problems initially, as the first filter capacitor is unable to remove all the ripple from the HT line before it is fed to the electromagnet's coil (or voice coil).

To overcome this problem, manufacturers developed a simple yet effective fix. A small coil called a "hum-bucking coil" was connected in series with the voice coil. The two were basically wired in anti-phase and this arrangement effectively cancelled out any hum produced by variations in the voice coil's magnetic field due to ripple on the HT line. For this reason, if you ever send away an electrodynamic speaker for repair and remove the output transformer, make sure that the leads to the hum-bucking coil are reconnected correctly when re-installing the unit.

**A typical electrodynamic loudspeaker, this one from a 1920s Lyric 8-valve console. In this case, the iron-cored chokes and the speaker transformer are attached to the unit to form a single assembly.**

## Indirectly heated rectifiers

By now, most of the problems with mains supplies had been solved. However, there was one last problem to be solved – excessive HT voltage immediately after switch on.

To explain, considerable power is used to energise the field coil and so the voltage dropped across it when the set is operating is normally around 100V or more. However, at switch on, a directly-heated rectifier such as an 80 conducts within about a second while all the other (indirectly-heated) valves in the set take at least 10 seconds to start conducting.

During this warm-up period, the electrolytic capacitors will be fully charged and the rectifier will have virtually no load. As a result, the voltage on the HT line feeding the valves (ie, following the HT filter network) may be up to 200V higher than when the set is operating. This in turn meant that the components in such sets had to be rated to withstand this high voltage for a short period.

This problem was eventually overcome by using indirectly-heated rectifiers, larger value electrolytic capacitors and efficient permanent magnet loudspeakers. In addition, several further refinements were made which reduced the need for a filter choke.

First, the plate (anode) of the receiver's audio output stage was connected directly to the junction of the first electrolytic filter capacitor (C1), the cathode of the rectifier and a resistor between that point and the second filter capacitor (C2) – see Fig.5. The HT at the junction of R2 & C2 is then fed to the rest of the set.

Typically, a resistor of 1000-2000Ω separated the two 24μF electrolytic capacitors and this combination provided very effective HT filtering. However, the output valve's plate can be fed directly from the rectifier because the plate circuit has no gain. This means that the ripple with a high-value filter capacitor is reasonably low.

Most sets by now used a tetrode or pentode output valve and the plate current of such valves is controlled mainly by their screen and grid voltages. These voltages are well-filtered and are nearly pure DC. In addition, the low-frequency audio response of mantel sets was deliberately restricted so that hum was rarely a problem.

Finally, another innovation introduced at about the same time involved applying an anti-phase hum signal to the grid of the output valve (more on this later).

## Power transformers

The power transformers used in domestic radio receivers came in many different shapes and sizes. In particular, the transformers used in older, larger receivers were often equipped with a primary winding which had several tappings to accommodate a variety of mains voltages, both locally and overseas. In Australia, most locations had AC mains voltages of between 200V and 250V.

In addition, there could be up to half a dozen secondary windings or more. In fact, four separate heater windings were not uncommon, some of them centre-tapped. In addition, there was usually one high-voltage centre-tapped winding (eg, 285V or more) and sometimes also an addi-


The filter chokes used in valve radios looked very much like small transformers. A typical unit is shown here, together with several electrolytic capacitors.

tional secondary winding to provide bias voltages for the receiver.

Towards the end of the valve era, the primary transformer winding was untapped as the nominal supply voltage at that time was 240V AC (it is now 230V AC). The secondary windings usually consisted of one 6.3V filament winding rated at around 3A plus a single untapped high-tension (HT) winding of 110V (eg, as used in the Kriesler 11-99).

In keeping with the construction techniques then used, the transformers were designed for chassis-mounting, with the laminations either parallel or at right angles to the chassis. Various techniques were used to prevent the transformers from generating circulating currents into the chassis, which reduces their efficiency.

In addition, because there was often quite a bit of electrical interference on the mains in earlier times, an electrostatic shield was commonly fitted between the primary and secondary windings. This greatly reduced the interference that could be inducted from the primary into the secondaries and hence the signal circuits of the receiver.

Electrostatic shields were more prevalent in earlier transformers and were not used towards the end of the valve era.

## Transformer temperature

Power transformers become warm during normal operation and later models often become warmer than earlier ones. There are a couple of reasons for this. First, the insulation on the windings in later models could withstand higher temperatures and this allowed the manufacturers to compromise on the materials used. This meant they could build smaller, lighter transformers which ran warmer for the same power output as earlier designs.

This also allowed manufacturers to save on the cost of materials.

By the way, anyone who has an American receiver will probably find that its transformer gets quite warm if run from 115V 50Hz AC. That's because it was designed for 60Hz mains and the transformer windings have a lower impedance at 50Hz. Because of this, it's prudent to operate such a set from about 105V AC if possible, to minimise transformer heating.

The power that can be drawn from a transformer is measured in volt-amps (VA). For example, the ubiquitous 2155 15V 1A multi-tapped transformer is rated at 15VA. Simply, it is just 15V x 1A = 15VA (or 15 watts for a purely resistive load)!

If the 15V AC output is rectified by a bridge rectifier and filtered, the DC output voltage at low load will be about 21V (less the voltage across the rectifier block). This voltage is simply the peak voltage of the AC sinewave and is 1.414 x the root mean square (RMS) voltage (the AC voltage measured on a typical digital multimeter). Note, however, that the DC voltage reduces as the current drawn increases (ie, as the load increases).

Note also that we cannot draw 1A from this power supply if the transformer is not to be overloaded. Instead, the maximum current drawn needs to be reduced to 1/1.414 x 1 = 0.7A. This ensures that the transformer's rating isn't exceeded since 21V x 0.7A = 15W (approximately).

However, that's really not the end of the matter because quite high peak currents are drawn from the transformer by the rectifier and filter capacitors. This in turn causes increased heating of the transformer. As a result, it's good practice to derate the maximum DC current to around 0.6 of the transformer's current rating.

Many transformers these days come with a built-in thermal fuse. If you do exceed the transformer's current rating, this fuse can blow and the transformer will cease to work.

By contrast, the transformers in valve radios are usually rated somewhat differently to the 2155. The heater windings are usually rated in terms of voltage and current, while the HT secondary winding is rated indirectly. For example, the HT secondary may be rated at (say) 300V at 100mA DC, following the rectifier and choke-capacitor filter network.

However, this is not a purely resistive load due to the charging current involved, as discussed above. In fact, the DC output of the power supply can be as high as 424V DC (at the input to the first choke) and if it can supply 100mA at this voltage, then the VA rating of the winding is around 42.4W. If the winding is only feeding a pure resistive load with no rectifier and filter network, the current that can be drawn will be 141.4mA x 300V = 42.4W.

In short, it's important to keep the VA ratings of a transformer in mind when you have to modify a power supply. This will ensure that the transformer operates within its rating and doesn't fail prematurely.

That's all for this month. Next month in Pt.2, we'll look at how to maintain vintage radio power supplies so that they continue to work well, despite being 70 years old or more. This is particularly important when the original parts are no longer available and substitutes must be used to keep a receiver operational. SC