EXPERIMENTING **WITH ELECTRONICS**

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In this last installment of Experimenting with Electronics, Darren Yates delves into the world of thermionic valves, how they work and how to make them work.

Valve Audio: An introduction

IN THE FIRST decade of the 20th century, man learned to do three things — he learned how to fly a 'heavier-than-air' aircraft, how to drive a car and how to amplify an alternating signal.

Now you could easily debate which of the three things was the most significant, however I don't think there's a shadow of doubt that the last one is the winner.

Thermionic valves, or just plain 'valves' or 'tubes' as they came to be known, really brought us out of the 'electrics' era and into the modern world of electronics.

Thomas Edison, of electric light fame, once noted a current flow between two electrodes inside one of his globes when one electrode was at a higher voltage than another.

In 1904, British Professor Sir John Fleming took this one step further and discovered the thermionic diode, the first valve that was able to rectify an alternating signal.

In 1906, American inventor Lee DeForest figured out that he could control the flow of electrons by inserting a third electrode into an evacuated glass envelope diode and throwing some negative volts on it. Whether or not DeForest actually knew how his 'Audion' worked has been debated by many, however one thing is clear — the early Audion, or 'Triode' as it became known, revolutionized the world of electrics and electronics was born.

Australia's own EA - or more correctly, its forerunner *Wireless Weekly* - was at the forefront of this new field of electronics starting from 1922, regularly giving updates on the world of radio as well as describing an ever increasing array of build-it-yourself radios and gramophone record players. I'm sure there are more than a few readers of this column who have built at least one *Radio & Hobbies* project over the years.

The Second World War saw valve development hit its peak but the beginning of the end dawned one day in 1948 inside Bell Laboratories when the transistor was invented.

From that day on, it was inevitably only a matter of time that names such as RCA, Telefunken, GEC, Mullard and Australia's own AWV (Amalgamated Wireless Valve) faded into the sunset as names from another time.

These five brands were arguably the most trusted and reliable of all valve vendors and even today audio valves from these companies fetch a handsome sum.

Mullard was the last of the big name valve vendors to shut its doors, doing so in 1988.

The Amalgamated Wireless Valve Company was one of the world's leading think-tanks as well as being a maker of fine valves, producing its world-renown monthly *Radiotronics* publication as well as the famed *Radiotron Designer's Handbook* by F. Langford-Smith.

This 1500-page tome became the industry bible covering all aspects of valve receiver and amplifiers from preamps through to transformers and loudspeaker design. In the last couple of years, this book has been reprinted by Butterworth-Heinemann and really is a must-read for anyone seriously thinking about understanding valve theory.

While many may regard valves as a study of history only, valves are still being produced around the world. A number of manufacturers in Russia, Asia and Eastern Europe continue to produce both transmitting and receiving valves and at quite reasonable prices too.

Triodes

Although arguably he didn't know it, Lee DeForest discovered the very first amplifying device, which he named the 'Audion'. However, for reasons of uniformity, the name 'triode' soon stuck.

A triode valve consists of three basic elements — an anode, nicknamed the 'plate', which is really what it is; a cathode, which is heated to produce a cloud of electrons, and finally a wire mesh wrapped around — but not touching — the cathode, called the 'grid' (See Fig.1). The triode was the forerunner to today's field-effect transistor and works in a similar way.

In all valves, the cathode is heated to a very high temperature — around 800°C. This high temperature allows some of the electrons on the cathode surface to break free and form a cloud around the cathode.

With the plate at a voltage more positive to the cathode, electrons flow from the cathode to the plate — which is basically what Sir John Fleming found, and was later called the diode.

However, if a voltage is applied to the grid that is negative with respect to the cathode, then the flow of electrons can be controlled. Varying this voltage

Fig.1

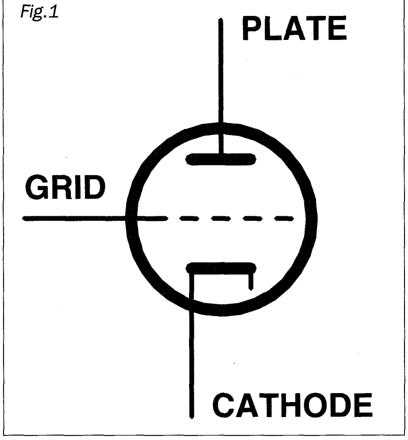
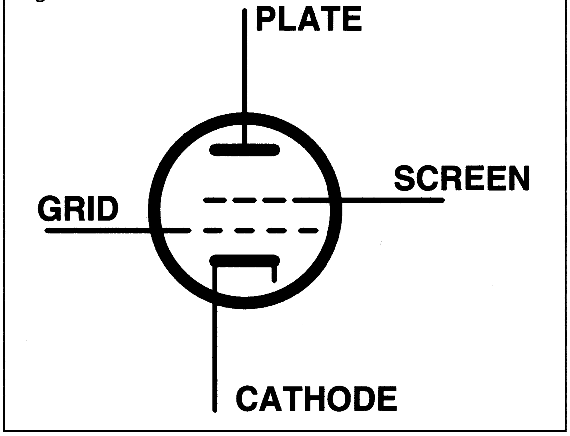


Fig.2



varies the cathode current flow. This was what DeForest found.

Triode valves were built in all shapes and sizes but by far the most famous (and now among the most valuable) is the 300B, first built by Western Electric, in 1935.

These valves were first used as the power output stage in audio amplifiers in movie theatres across the US and were made, as far as my research tells me, right through to the early-80s.

Western Electric was also the name behind many of Hollywood's movie sound recordings from the early 30s through to the 50s.

It's a sign of the rejuvenation of valve technology that Western Electric has begun making these famed valves again for a cool $US900 a pair. You can find out more about Western Electric at their Internet site **www.westernelectric.com**.

The 300B has a plate power dissipation of some 40 watts and is capable of producing 8 watts of Class-A audio — that might not sound like much but when connected up to quality hifi speakers, I'm told there's no sweeter sounding amplifier.

Transistors or Valves?

And that's part of the reason audio valves are coming back into vogue — more and more people are agreeing that valves sound better than transistors.

Now at this point, the transistor brigade will trudge out their superior signal-to-noise and total harmonic distortion figures as evidence of transistor's superiority over valves.

And if that's all there was to it, they'd be right — but I've read enough from more knowledgeable men than I over the last fifteen years to know that "one sunny day does not a summer make".

While much of the debate between 'hollow' and 'solid-state' comes down to a personal preference, there is some evidence to suggest why people's ears are saying valves are better. Valves are inherently far more linear than transistors in their operation and at low levels (more likely the levels you would listen to music in your lounge room), produce less distortion than transistors. This is something that famed engineer John Linsley Hood alludes to in his book *The Art of Linear Electronics*.

Another argument is that valves produce more second-harmonic distortion than transistors and less third-harmonic distortion — and it's It's this third-harmonic distortion that causes the problem.

But at the end of the day, while we can make measurements of speakers, amplifiers and signal sources, we don't know how to model the human ear.

Our ears also change over time — for example, the older we get, the less high frequencies we can hear. So if transistors sound better to you, great. If valves sound better, that's fine too.

It seems to me that we will learn far more about what really makes great audio by considering all the options.

And while it is clear many believe valves have a place in the story of audio, it makes sense to ensure that our knowledge of them, how they work and why should not be allowed to disappear.

Tetrodes

While triodes were great at audio, they did have limitations.

Firstly, the efficiency wasn't great — 40 watts in for 8 watts out isn't too efficient.

Secondly, triodes had limitations at higher frequencies because of the internal capacitance between the grid and plate. Triodes were also known to be unstable when used as RF amplifiers and transmitters and it was clear that something else was needed.

That 'something else' turned out to be a second grid called a 'screen' inserted between the grid and plate to reduce the grid-plate capacitance.

The screen is almost always connected to a voltage more positive than the cathode but less than or equal to the plate. Fig.2 shows the schematic symbol for a tetrode.

This screen grid also had a new effect on the operation of the valve — it was now the screen voltage, much more than the plate voltage, that controlled the amount of plate current.

However this screen grid caused a problem: if a tetrode was used to amplify a large signal, it was possible for the instantaneous plate voltage to drop below the screen grid.

This caused what was known as 'secondary emission' when electrons slamming into the plate would ricochet into the screen. This had the effect of reducing the plate current at higher loads and reduced the overall efficiency.

Pentode

The solution was the addition of a third grid between the screen and the plate. The schematic symbol and construction of this new device called a 'pentode' is shown in Fig.3.

This third grid, called a 'suppressor grid', was connected to the cathode and stopped this secondary emission.

Pentodes became the most efficient valves at turning electricity into audio power but it turned out that the downside to this increased efficiency was an increase in third harmonic distortion.

Despite that, there have been many notable audio pentodes produced and with good design, that harmonic content can be minimised.

These days, most audio purists turn their nose up at pure pentode power amplifiers but one area where pentodes have made their presence felt is in guitar amplifiers.

The English amplifier company Vox used four 6BQ5 pentode valves in its 30-watt AC-30 guitar amplifier, which may not mean much except that the AC-30 was the amplifier used by the Beatles during their early years.

The most famous pentode is arguably the EL34, used in hundreds of hi-fi and guitar amplifiers and introduced by Mullard in 1953 as a low-cost way of achieving 40 to 50 Watts. Again, EL34s are still being made today by a number of manufacturers.

Beam-power Tetrode

In an attempt to combine the lower distortion of triodes with the higher output power of pentodes, the suppressor grid was replaced with two electron-beam confining electrodes between the screen and the plate. This helped to further linearise the current flow, reducing distortion.

The beam plates (plus the distance between the internal electrodes) stopped secondary emission problems that plagued normal tetrode valves, giving designers high output power, high sensitivity (gain) and efficiency.

The first major beam-power tetrode was the 6L6 built by RCA in 1935, but there were two other famous beam-power tetrodes: the KT66 and KT88s produced by GEC in England.

In a recent article in an English electronics magazine, John Linsley-Hood recalled working as a student assistant for GEC in England during 1942 and seeing many KT66s glowing away in the test laboratory.

Both of these valves were used in many legendary audio amplifiers during the 1940s, 50s and 60s, appearing in everything from hi-fi to public address to guitar amps with 'attitood'.

While KT88 and 6L6 valves are still being manufactured in Russia and Eastern Europe, the original GEC-made versions of both the KT66 and KT88 fetch big money. Mullard continued to make KT66 and KT88 valves right up until it closed its doors in 1988.

Multi-valves

During WWII, the bulk of valves produced required what was known as an 'Octal' socket.

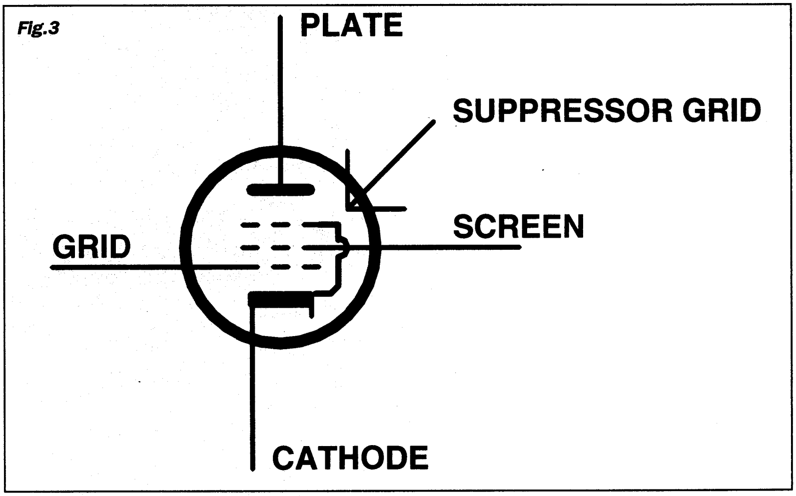
The internal structure of a valve comes out to a series of pins at one end, which fit into a socket. The back of the socket has solder lugs that allow you to wire up the other components. You can still buy octal sockets from both Dick Smith Electronics and Jaycar Electronics for around $5 each.

The main problem with the octal socket was that it was big and as the war required electronics to become miniaturised, the smaller 9-pin 'Noval' socket was created.

Having this many pins enabled designers to come out with 'multi-valves' or valves with more than one active unit inside. There were some notable octal 'multi-unit' valves including the 6SN7.

The most common noval multi-valves were dual triodes and the most famous of these are the 12AX7 and 12AU7 audio preamplifier valves. These tiny valves contain two separate triode units inside and helped reduce the number of sockets and valves required in a circuit design.

Fig.3



Another common multi-valve was the triode-power pentode and the triode-power triode.

These units contained a small-signal triode with either a power-output pentode or triode.

Funnily enough, most of the triode-power triode valves were used as frame output stages in TV sets rather than audio amplifiers, mainly because the power triode was generally only rated to no more than 10 watts, which meant little more than three watts of audio.

The triode-power pentode was used in many TV sets and small hi-fi power amplifiers - the two most common are 6BM8 and 6GW8 valves.

6BM8 valves could do double work as either frame output stages in TV sets or as audio amplifiers while 6GW8s were audio amplifier valves only. While 6GW8s are no longer made, 6BM8s are still being made in Russia today.

Both of these types were used in many EA 'Playmaster' amplifier kits during the 1960s, producing between 8 and 13 watts RMS per channel.

Name that valve

Valves grew up in an era where the term 'global communications' had yet to be invented and in the end, there were several naming conventions worldwide. The two that have stood the test of time are the US JEDEC and the Mullard systems.

There were many valves that in the end were known under two different names: the Mullard-built EL34 pentode was known as a 6CA7 in the US, the 12AX7 dual-triode preamp valve was known as an ECC83 is Europe, and so on.

While it might seem there is little rhyme or reason in valve nomenclature, there actually was.

US naming convention

The JEDEC format was generally a number, followed by two letters and then a second number. The first number referred approximately to the heater or filament voltage.

'1' — 0 to 1.6 volts
'3' — 2.6 to 3.6 volts

'5' — 4.6 to 5.6 volts
'6' — 5.6 to 6.6 volts
'12' — 11.6 to 12.6 volts, etc.

The number '7' was given exclusively to special 'Locktal' valves.

These valves were used during WWII in aircraft receivers and transmitters and were built with a locking pin in the centre, the locking pin preventing the valves from vibrating out of their sockets, which B17s and Lancaster bombers were quite capable of doing.

Next, the two letters usually referred to the family from which the valves belong.

Rectifier diodes using started from 'Z' while triodes, pentodes etc started from 'A'.

F. Langford-Smith in his 'Radiotron Designer's Handbook' states that when all the single letters of a group were used, they proceeded with two letter domains e.g. 'AB'.

The only difference to this was that the letters 'I' and 'O' were not used to ensure they weren't confused with '1' and '0'. The letter 'S' was used in a special way.

Initially, a number of popular early valves had what was known as a 'top cap'. Instead of all the pins of the valve coming out of the bottom, the plate would come out to the top of the valve via a metal knob, to which a special cap was connected not too dissimilarly to a spark-plug lead. Later, some of these valves were redesigned as 'single-ended' valves, i.e., all electrodes came out only at one end. The 6SN7 valve for example was a single-ended version of the 6N7 dual triode.

Finally, the last number was said to be the number of active elements inside the glass envelope. A single triode ended in a '4' as did full-wave rectifiers while a Pentode completed its naming with a '5'. Dual triodes were '7' while triode-pentodes were '8'.

So a 6BM8 was recognised as a triode-pentode with a 6.3V heater voltage requirement.

However, you couldn't just look at the valve name and know exactly what it was, so while the JEDEC naming system worked, it wasn't perfect.

Mullard naming convention

The Mullard system was similar in its approach but more methodical. It began with a series of letters followed by two numbers, as shown in Fig.4.

The first letter referred to the heater voltage requirement. Those with series heaters were designed to be wired in series with other valves in a string. They had specifically-timed turn-on times to ensure none of the valves in the string received more than its required heater voltage.

The second letter referred to what was inside the valve glass while the first of the last two numbers referred to the socket type.The second number was used to differentiate between similar types.

For example, EL84 and EL86 valves were both 6.3V-heater (E) output pentodes (L) Noval-socketed (8) types, the main difference between the two is that the EL86 has a lower plate resistance than the EL84 and is also useable as a frame output valve in TV sets.

An ECC83 valve is a 6.3V-heater (E), double signal triode (CC), noval-socketed (8) type. The difference between the ECC81, ECC82 and ECC83 are that the ECC81 is designed primarily for RF applications, the ECC82 is an audio driver valve and the ECC83 a small-signal light-duty preamp valve.

This didn't stop designers using the ECC81 for audio applications though.

As a further note to the serial heating type valves, one example of these was the European version of the 6BM8 known as the ECL82. There was also a PCL82 and a UCL82. They were identical to each other except for their heating requirements.

Valves do have sentimental value to many readers. They bring back memories for many of elder generations and they are a link to our recent history for a few younger ones (including yours truly) but in their own right, valves have much to offer when it comes to the science of truly 'high-fidelity' amplifier design. ea

Fig.4 *Mullard naming convention*

1ST LETTER: HEATER VOLTAGE	2ND (OR 3RD) LETTER: VALVE TYPE	1ST NUMBER: SOCKET TYPE
A = 4 V	A = single low level diode	0,1 - miscellaneous
B = 180 mA series-heater	B = double low level diode	2 - Loctal
C = 200 mA series-heater	C = small-signal triode	3 - Octal
D = 1.4 V	D = power triode	4 - B8A socket configuration
E = 6.3 V	E = small-signal tetrode	5 - B9G, B9D (Noval socket arrangements)
F = 12.6V	F = small-signal pentode	8 - B9A (Noval socket arrangement)
G = 5 V	H = heptode/hexode	9 - B7G (seven-pin socket)
H = 150 mA series-heater	K = octode	
L = 450 mA series-heater	L = power tetrode or pentode	
P = 300 mA series-heater	M = tuning indicator	
U = 100 mA series-heater	W = gas filled single rectifier diode	
V = 50 mA series-heater	X = gas filled double rectifier diode	
X = 600 mA series-heater	Y = power diode	
Y = 450 mA series-heater	Z = full-wave rectifier	
Z = cold cathode		