A brief history of valves...

Robert Harris shines a light on the dark art of tube amp technology

Since the 1990s there has been a real resurgence in valve amplification. Yet for many that grew up with plain looking transistor devices, tubes are often viewed as an exotic technology. This need not be the case. After all, the very first valve was based on a 'light bulb'.

Invented in 1904 by Fleming, the 'oscillating valve' comprised a diode (two element) rectifier based on the two-element light bulb built by Edison in 1883 to demonstrate thermionic emission (the transfer of electrons from one element to another). A heated cathode emits electrons that are attracted to a positively charged anode.

Two years later American inventor Lee De Forest came up with the triode. In an attempt to circumvent the Fleming patent, De Forest added a third element, called the grid. If a signal is applied to the grid it modulates the electron flow to the anode in accordance with the signal. This makes amplification possible. Although it's true that transformers amplify signals, triode valves can be considered to be the first successful electronic amplifying technology.

ABOVE: A Mazda AC2/Pen indirect-heated power pentode – the improved version of the AC/Pen, an innovative 1930s industry standard that gave enough power at a claimed 4W to be used in radios with better sounding moving-coil speakers

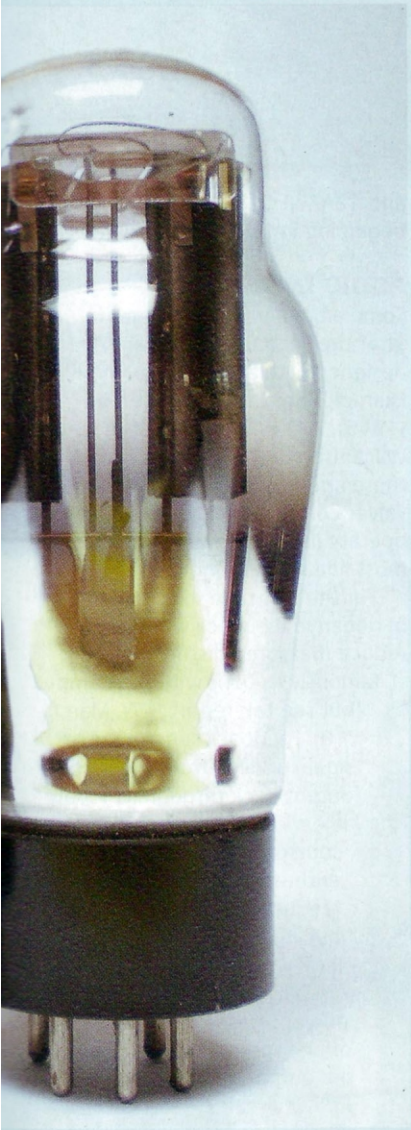
VACUUM PACKED

The earliest valves were not enclosed in a complete vacuum since the role of air particles was not fully understood. These 'soft valves' would thus burn out quickly. It was around 1914 that long-life hard vacuum valves appeared in the US. Huge numbers of hard vacuum French R triodes were used for communication during the First World War. It was at that time that disagreements between the American government and Marconi in the US – which owned many radio patents – led the US authorities to take control of radio technology away from foreign interests. This was believed to be crucial militarily so RCA (Radio Corporation of America) was set up to obtain assets and patents to control radio development and valve production.

Perhaps the valve manufacturer of greatest renown is Mullard, which was founded in the UK in 1920. Commercial interest in radio increased and voice-based radio stations appeared in the early 1920s in many countries. Valves like the RCA 01A and Mullard ORA (both released in 1922) were increasingly used in radio design and played a major role in what can be considered the second revolution in mass communication after print.

Valves continued to improve greatly in the 1920s. More specialised triode valves for commercial use were developed in the later years of that decade. Some offered greater output power while others were more suited to the amplification of small signals (*eg*, the indirect-heated 27 valve).

Direct-heated valves, where the initial cathode element heats itself, were the norm until the start of the 1930s. Indirect-heated valves use a separate heating element to power the cathode. This resulted in lower noise levels, which is advantageous – especially for valves dealing with weak signals. As the decade progressed, new valve types were introduced. The four-element small signal tetrode added a screen



BELOW: 1930s Mullards all round! EF39 Pentone (left) – an RF pentode for RF/IF amplification; PM24A (centre) – direct-heated output Pentode for audio use; AZ31 (right) – a rectifier for power-supplies

grid to limit interaction between the grid and anode while the five-element pentode, which appeared later, added a suppressor grid to better guide electrons to the anode.

The oldest tubes resurrected for use in high quality amplification today are the PX-4 from 1928 and the 45, first released in 1929.

Sound reproduction also improved considerably in the '20s. Pioneering audio engineers Rice and Kellogg set down many principles of audio reproduction in 1925 and greatly enhanced the quality of speakers by improving moving-coil driver technology. Amplifiers were needed for new tasks and firms like Western Electric took important steps in making linear amps a reality.

In 1924 electronic sound recordings began appearing on disc while the arrival of 'Talkies' (films with audible dialogue) meant powerful PA systems were needed to fill cinemas with sound. Even very large amps could only produce a few watts, so power-efficient speakers were essential.

SIMPLY DOES IT

Single-ended circuits are the oldest and simplest amplifier topology. They use just one output valve to power a speaker. Push-pull amplifiers use two valves operating at opposite sides of the signal cycle. They operate in either Class A, Class B or Class AB, depending on how they are configured. Due to their nature, single-ended circuits only operate in Class A. The primary innovations in push-pull design occurred in the 1910s and '20s. Single-ended and Class A push-pull circuits have differing advantages and disadvantages but represent the best modes of operation in terms of sound quality. In Class B and A/B, the output valves switch on and off according to the signal cycle. For a given circuit, output power increases but distortion worsens, and the switching action may cause an unpleasant audible distortion.

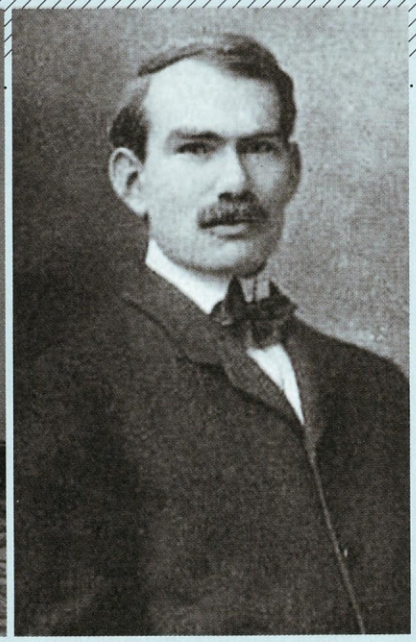
By the 1930s valve design had reached a certain maturity. More powerful direct-heated output triodes were introduced, *eg* the 2A3 (1932) and 300B (1938), which many listeners prefer to later power valves. These became popular for use in high-end amplifiers in the '90s due to the extremely fine sound quality they can achieve.

Newer small signal valves (now indirect-heated as standard) were greatly reduced in size. For example, the 6J5 triode introduced in 1935, ancestor of the popular 6SN7 double triode from 1941 (essentially two 6J5s in the same glass envelope), stood just 2in tall. Meanwhile, power pentodes, such as the AC/Pen from 1930, provided a good deal of volume when used in radios without manufacturers having to incur the extra expense of using triodes.

> 'A grid makes amplification possible'

There were difficulties in using tetrodes as power valves until the invention of the beam tetrode, which improved electron guidance. The earliest beam tetrode power tubes are the indirect-heated 6L6 (KT66) from 1936 and the 6V6 (1937) – a lower power valve often used in radios. Both are still popular.

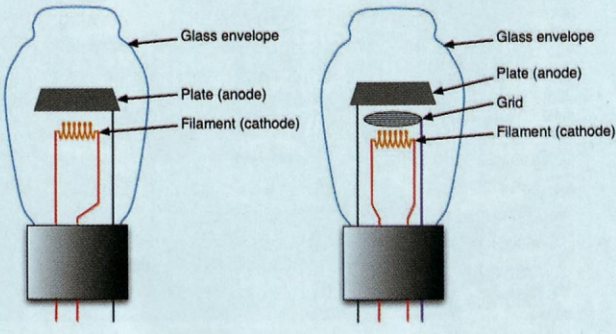
Public interest in high quality sound grew in the 1930s and ⇨



ABOVE LEFT: Thomas Alva Edison, pictured in 1887. It was his two-element light bulb on which the very first valve was based

ABOVE RIGHT: Lee De Forest, whose attempts to circumvent Fleming's patent on the two-element valve saw a third element added in the form of 'the grid'. The triode was born – a valve that could be used for amplification

BELOW: Cross section of two-element (diode) and triode valves showing position of third element (Grid)



designers were aware of this. Radiograms with a hi-fi theme appeared but there wasn't really a hi-fi industry at this time. The triode remained the primary power valve type, although the invention of negative feedback in 1927 by Harold Black would change this as his ideas were explored in the 1940s and '50s.

Pentode and beam tetrode power valves produce higher power levels but have a high output impedance, making them less suitable for direct-coupling to speakers. They also produce several times more distortion. This includes a proportionally higher level of anharmonic or odd-order distortion harmonics, less pleasing to the ear. Triodes, on the other hand, are the most intrinsically linear (least distorting) designs and their primarily even-order distortion patterns are considered to be less subjectively invasive.

'Small signal valves became even smaller'

THE '30S EVOLUTION

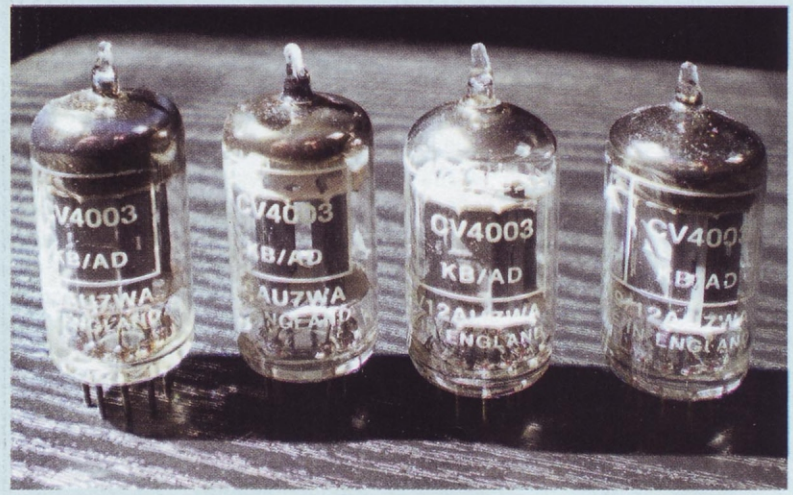
Amplifier design continued to improve in the 1930s. In fact it was thought to have reached a point where sound quality could not improve significantly, a judgement that would be dismissed in the 1950s when higher power pentode-based push-pull amplifiers, tempered with moderate levels of negative feedback, would become a dominant force.

Nevertheless, certain amplifiers built in the 1930s, such as the cinema amplifiers from Western Electric that use 300B triode valves in single-ended output stages, are still very highly regarded in hi-fi circles today. Single-ended output stages fell out of favour after the 1930s because the more popular Class A push-pull circuits had the benefit of cancelling out even-order distortions. Yet the merits of these old amps began to be rediscovered in the 1970s, and since the '90s single-ended output stages have been utilised in many new valve amplifiers.

In the 1940s valves were used for a variety of advanced applications, such as in radar and early digital computers, which reputedly helped enhance the reliability of subsequent valve designs. Direct-heated valves became less common.

The few triode power tubes introduced in the '40s offered low impedances but were designed for voltage regulation rather than as an alternative to tetrodes/pentodes.

Meanwhile, small signal valves became smaller still and required less energy to power. The ubiquitous '12A...7' double triode series (*eg* the 12AT7/ECC81, 12AU7/ECC82 and 12AX7/ECC83) was introduced, beginning in 1946 and onwards.



LEFT: Four Brimar CV4003 valves; CV valves don't often have brand names printed on them as they are military-coded

ABOVE: A rebuilt Williamson amp sporting four 6JS triodes, a 53KU rectifier and a pair of KT66s

BELOW: A QP25 valve by Mazda – a late 1930s quiescent push-pull double pentode designed for efficient use in battery-powered radios

AUDIO IN MIND

Some amplifiers manufactured after the Second World War were designed with audio fidelity in mind. Examples are the Leak Type 15 (1945), TL/12 (1948), and the famed Williamson design (1947). Often these amplifiers use tetrode power valves connected as triodes, and operate in Class A push-pull – the most linear operating mode.

For the first time moderate levels of negative feedback were used to reduce measured distortion levels, famously to 0.1% with Leak amps [but see Lab report *HFN*, March '10]. Feedback sends an error signal derived from the amp's output back through its input, linearising its performance. Of course, since the 1970s many enthusiasts have claimed that feedback degrades sound quality, especially when high levels are used.

When operating normally, power tetrodes and pentodes offer approximately twice the output of triodes in a similar circuit. Yet some inherent qualities make them less suitable for high-fidelity applications unless feedback is applied to reduce output impedance and distortion. In turn, where output coupling transformers are employed feedback is typically moderated to ensure optimum amplifier stability.

CATHODE COUPLING

Further innovations in the application of feedback occurred in the late 1940s. Quad and McIntosh used cathode coupling, where the cathode is connected to an additional winding on the output transformer (distinct to the

anode winding) which introduces feedback. The famous Ultra Linear circuit, where a connection from an output transformer sends feedback at an optimised level to the screen grid in tetrodes/pentodes, reduces distortion. With increasing levels of feedback being applied to amplifier circuits, tetrode and pentode power valves became predominant and during the 1950s, the production of many power triodes ceased.

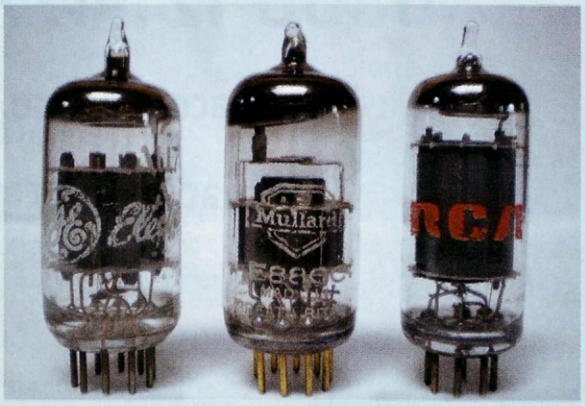
While Class AB circuits offer a higher efficiency and the promise of higher output levels than Class A circuits, they suffer an increase in overall distortion, including a proportional increase in more perceptible odd-order distortions. Firms like McIntosh obtained higher feedback levels by using better transformers, which greatly reduced the distortion of Class AB. With competition for customers, it was inevitable that similarly priced amps with twice the output had a real commercial advantage. Quoted distortion figures could be quite acceptable by using maximal amounts of feedback. Therefore Class AB was utilised increasingly.

TRANSFORMERS

As power valves produce very high output voltages and impedances they require output transformers to match speakers. Yet output transformers degrade sound quality, are costly, difficult to design well and limit the use of feedback. Output-transformer-less (OTL) valve amps usually reverse-connect power valves in a 'cathode follower' configuration. This is very inefficient but yields a much lower output impedance, which is suitable for direct coupling to loudspeakers.

Single-ended push-pull (SEPP) OTL circuits can achieve good power but suffer from an asymmetry which limits their linearity. American electronics engineer Julius Futterman published a solution in 1954, but it could only partially balance SEPP circuits. OTLs were re-introduced in the 1980s. Designers often used low impedance pentodes rather than triodes to produce more power, but this made already poor linearity worse.

The general low impedance Circlotron circuit from 1955 has been adapted for OTLs, and it is claimed that modified Futterman OTLs reduce circuit asymmetry. However, it is still often thought that OTLs can be problematic and don't function at their best with most speaker designs.



ABOVE: 12AU7 (ECC82) double triode from General Electric's 12A...7 series (left); Mullard E88CC double triode from 1958 (middle); RCA 6BJ6 pentode (right)

BELOW: Little and large – two popular 1950s power valves in the form of a GEC KT88 beam tetrode with box (left) and an EL84 output pentode

THE CLASSICS

The majority of widely known power valves come from the latter days of valve development. The EL34 (6CA7) and EL84 (6BQ5) pentodes, introduced in 1953, are used in many hi-fi amps and the very popular Mullard designs. Two EL34s usually produce 25W (push-pull Class A), while the smaller highly popular EL84 offers around half that power. The KT88 beam tetrode, introduced in 1957, was one of the last successful power tubes. Used together, two typically produce 40W (push-pull Class A).

In the 1950s transistors were employed with great success in early computers and portable radios. Transistors would inevitably replace valves. Tiny, low-signal Nuvistor valves appeared in the early 1960s but by the mid '60s development of most valve types had ceased under the solid-state revolution.

Valves continued to be developed for specialist applications, such as high frequency transmitters where they have advantages over transistor technology and, of course, until recently they were used in CRT TVs!

THE '70S AND ON...

Transistor amplifiers aimed at the hi-fi consumer began to appear in the early 1960s. Still in its infancy, this technology required more complex circuitry, was unreliable, less linear and not well suited to Class A operation. However, transistor amps avoided the need for costly output transformers, could accept higher feedback levels and tended to be more power efficient. By the end of the 1960s, valve amplifiers were mostly considered obsolete, even though some enthusiasts maintained that they sounded better than transistors.

'By the late '60s, valve amps were thought obsolete'

The commercial production of valve amps broadly ended at the turn of the '70s, although a very small number of new models aimed at the high-end user appeared subsequently. It is significant that the valve amplifiers of the '50s and '60s, such as those by Leak, Quad, Dynaco and McIntosh are still highly regarded – unlike transistor equivalents from the 1960s and '70s – even though compromises were made to achieve greater power or lower cost. Even where the valve may have bettered the transistor, it was cast aside by fashion.

Critically such amps, often discovered tucked away in attics, inspired a valve renaissance through the 1980s. As many listeners now had access to more transparent-sounding speakers, the unique qualities of valve amplification could be enjoyed by a new audience.