'Technical Shorts'

by Gerry O'Hara, VE7GUH/G8GUH

'Technical Shorts' is a series of (fairly) short articles prepared for the Eddystone User Group (EUG) website, each focussing on a technical issue of relevance in repairing, restoring or using Eddystone valve radios. However, much of the content is also applicable to non-Eddystone valve receivers. The articles are the author's personal opinion, based on his experience and are meant to be of interest or help to the novice or hobbyist – they are not meant to be a definitive or exhaustive treatise on the topic under discussion…. References are provided for those wishing to explore the subjects discussed in more depth. The author encourages feedback and discussion on any topic covered through the EUG forum.

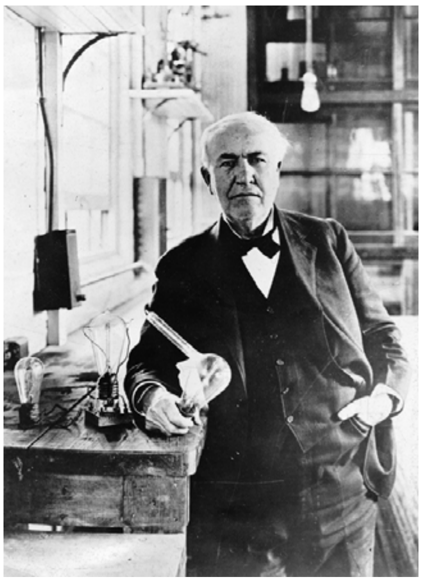
Valve Types and Characteristics

Introduction

The Technical Short on 'Valve Lore' deals with using valves in receivers in general terms – their evolution through the years, types and general application in Eddystone receivers, as well as tips on sourcing valves and testing them. The Technical Shorts on 'Eddystone Circuit Elements' and 'Receiver Front-Ends' take a closer look at how valves are selected and used in particular circuits within Eddystone valve receivers. In preparing these articles, it occurred to me that an insight into some of the basics underlying the selection of a particular valve for an application in a receiver would be useful. In order to do this, some consideration of valve 'fundamentals' is necessary and how these influence their application and use in receivers. So here I deal mainly with the basics of valve construction and design and then their electrical parameters and important operating characteristics.

History and all that bunk…

There are many books on the development of the vacuum tube/valve – I have read quite a few over the years, and I list several in the bibliography at the end of this article. I particularly like 'Wireless Valves Simply Explained' by John Scott-Taggart, written in 1922 (an amazing snapshot of application of thermionic technology in the immediate post WWI years), also, the 'Saga of the Vacuum Tube' by Gerald Tyne is a good read if you want to know how valves (mainly diodes and triodes) developed in different parts of the globe (pun intended) and, of course, anyone interested in valves should have a copy of the RCA 'Radiotron Designers Handbook' on their bookshelf (the 4th Ed. of 1953 is by far the most comprehensive - and most expensive when they come for sale - but there is a lot of good stuff in the much thinner and cheaper 3rd Ed. of 1941). These and other references provide much detail and all I will cover here is a brief chronology of events that led to the first commonly-used valves being developed and brought into general use by the public in broadcast receivers (I would note that this subject is rather controversial and many dates and claims found in the literature are contradictory and that often parallel lines of research and development were being undertaken by several companies and researchers at the same time in different countries – if you become 'hooked' on the story, please refer to the many books devoted entirely to this fascinating topic):

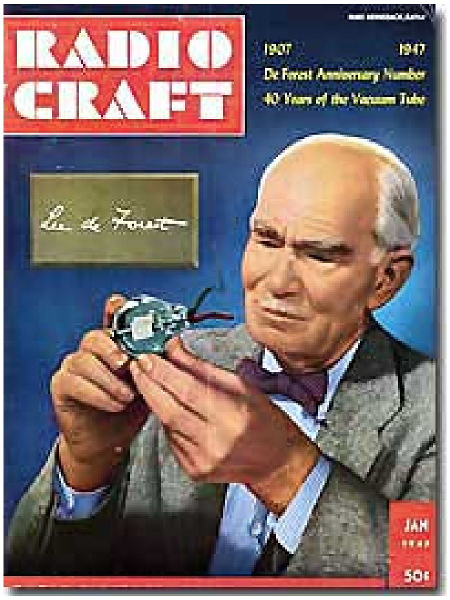


1879 – Edison invents the incandescent electric lamp. He later installed a metal plate in some of his bulbs to investigate the 'shadow' observed in the discolouration that occurred inside the glass envelope. In October, 1883, he noted that a current could flow through the vacuous space when the plate was connected to the positive heater element and not if connected to the negative heater element – this would later be termed the 'Edison effect' (I don't suppose he coined the term personally as there must have been lots of other 'Edison-related' effects…). He used the effect in a patent on his 'Electrical Indicator' but apparently did not realize the value of his invention (a crude diode) as he did not see any other application at the time (a solution without a problem – a bit like chewing gum);

1882 – John Ambrose Fleming also noted the shadow in incandescent lamps (the one in the anglepoise in his study I expect, as it was probably annoying him) and so, as any scientist worth his salt would have done, he studied the Edison effect a bit more, made some notes, but then put his bulbs and his notes in a drawer and forgot about them (for 14 years – as you do…);

1896 – Fleming demonstrated that the Edison effect could be used as a 'rectifier' for alternating current, but he also did not pursue this any further (presumably he had bought a new, upgraded, light bulb for his anglepoise by then);

1904 – Fleming, now working for the Marconi Wireless Telegraph Co. Ltd., while looking for an improved way of rectifying radio frequency oscillations for that company, remembered his work with the light bulbs and filed a patent for the 'oscillation valve', the diode used to rectify electrical oscillations. The diode valve entered commercial service in 1905 and was offered for sale to the public in 1909. These early diodes only lasted between 35 and 100 hours before the filament burned out, so a cunning version with two filaments was introduced in 1908;

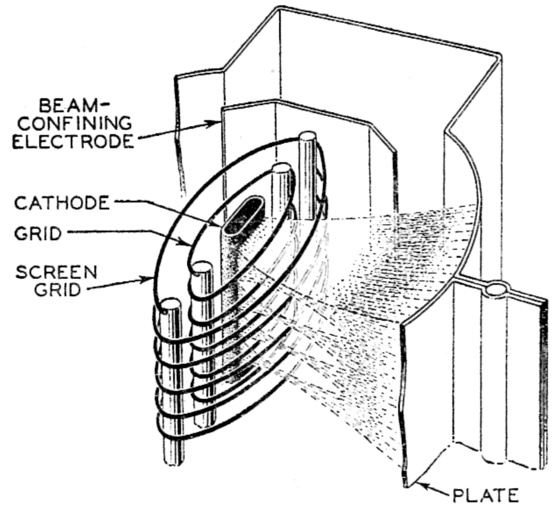


Is he going to play it or smoke it?

1906 – Lee deForest presents his two-electrode 'Audion' valve that had electrostatic control of the electron flow, followed by the patent of the internal grid Audion (triode) in 1907;
1912 – Lee deForest succeeded in using the Audion for audio frequency amplification (and so, the 'Golden Ears' brigade of audiophiles was born… no doubt he was soon selling gold-plated carbon-free copper prong versions at a premium to those fellows). These valves first entered service as telephone repeater amplifiers in 1913;
1913 – Irving Langmuire, working at General Electric developed triodes that would operate at radio frequencies. He also conceived of a type of tetrode valve but with the fourth electrode placed between the cathode and control grid (oops !);
1915 – Suggestion of using a fourth electrode (the screen grid) between the control grid and the anode by Walter Schottky to improve amplification by overcoming the 'Miller effect', these ideas being further developed by Hull and Williams in the US and a patent applied for by Hiroshi Ando in Japan in 1919. However, the screen grid valve (tetrode) was not developed into a practical valve until 1926 by Henry Round in the UK, and then introduced commercially in 1927. The tetrode allowed greater and more stable amplification at radio frequencies without careful neutralization. The tetrode was found to have a disadvantage though: when the anode voltage is low, electrons colliding against the anode produce secondary emissions. These electrons are absorbed by the screen grid which results in a decrease in anode current and non-linear operation;
1925 – earliest multiple valves contained in one envelope[1];
1926 – Invention of the pentode by Bernhard Tellegen working for Philips in Holland, this valve design incorporating a suppressor grid to reduce the above-noted undesirable secondary emission, with the patent submission in 1928 and commercial introduction in the early-1930's;
1933 - 1934 – development of various multiple grid valves for use as mixers and 'frequency changers' in superheterodyne receivers,

The 'Emerson Mulitvalve' (triple triode, circa. 1926)

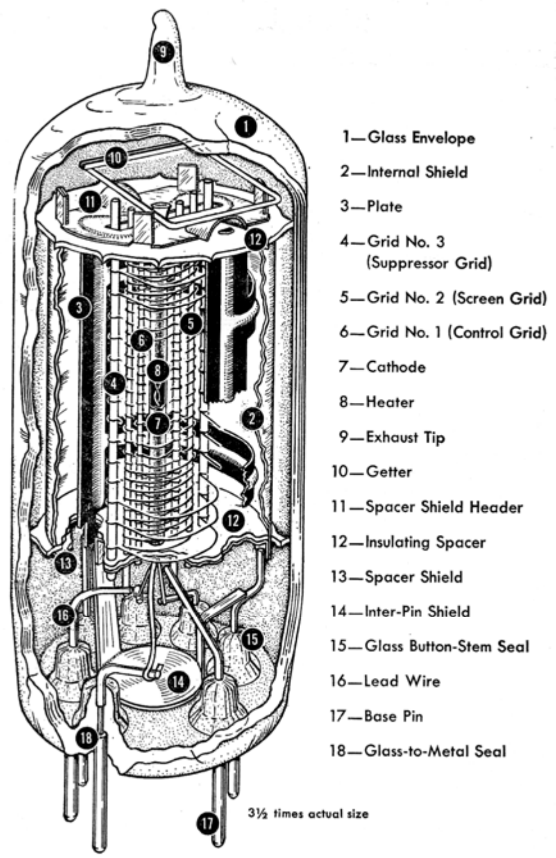
[1] I have a one valve set containing an 'Emerson Multivalve' – a triple-triode, manufactured by the Clearton Vacuum Tube Co. in 1927. Unfortunately the valve has the tip snapped off and is vacuum-less…



including the hexode (four grids), the 'pentagrid' (heptode) and Octode;
1936 – Owen Harries in the UK noted that pentode-like characteristics could be obtained from a tetrode when the distance between the screen grid and the anode was expanded (the 'Harries Critical Distance Valve'): in this configuration, the potential between them reduces due to space charge and secondary electrons cannot go to the screen grid. Another technique used to overcome problems with secondary emission in tetrodes is to focus electrons towards specific targets on the anode and away from other areas, such as the supporting rods by a combination of the grid and screen grids being wound with the same pitch (and in optical alignment) and the placing of beam-forming plates that direct the electron beams. Later that year Otto Schade of RCA developed this idea into the 'beam-power tube' (a sexy name if ever there was one… connotations of Star Trek or what? – "…, ok, beam me up Schade").

Valve Construction

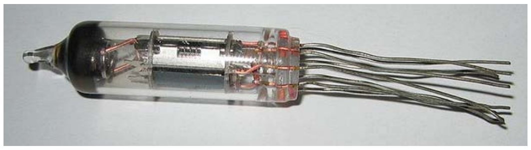
I find the construction aspects of valves very interesting – each one is a marvel of miniature engineering built to very fine tolerances and to withstand amazingly adverse conditions: high voltages, high vacuum, high temperatures, thousands of heating-cooling cycles etc. To do this reliably was the culmination of many lines of early-mid 20th century engineering and scientific endeavour, metallurgy, chemistry, mechanical design and accurate machining, assembly-line techniques and electronic design, but most of all, human ingenuity to overcome issues inherent in different applications valve technology was applied to. To see how it was done by the best, take a look at this video: http://www.techtubevalves.com/about_us/film_reels.php (or you can have a go yourself – see the YouTube links at the end of this article).



Structure of a Miniature Tube

Valves consist of a number of basic

constructional elements: electrodes, comprising a cathode and an anode, which may have one or more elements in between (termed 'control', 'screen' and 'suppressor' grids – see below), all mounted on suitable supporting structures and contained in a vessel of glass or metal, with the electrodes being connected to the outside world by connecting to pins (sometimes termed 'prongs') on the valve base, and sometimes to a top cap(s) – refer to diagram on previous page. The vessel is evacuated of air such that a vacuum of a high degree is formed, although some valve types may have an inert gas or mercury vapour deliberately introduced at low pressure to provide desirable characteristics. Most valves are designed to be easily replaced by being inserted into a socket, although some types were designed to be wired into the circuit in which they operate (photo, right). More than one valve assembly can be included within one envelope for convenience, compactness and economy. The following provides some basic information on the electrodes:

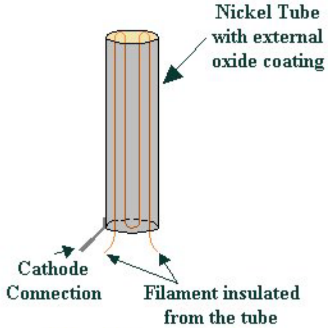


Cathode

The ARDE from Ediswan was introduced in 1923 as a general purpose valve. 'ARDE' stands for 'Amateur Radio Dull Emitter'

Early cathodes comprised a directly-heated filament (as in its cousin, the incandescent light bulb), made from tungsten and operating at a temperature around 2,000 C. The earlier types were termed 'bright emitters' (not surprisingly). Later directly-heated types were termed 'dull emitters', operating at lower temperatures. These were composed of thoriated tungsten, a process which stabilizes the emission if electrons and increases the surface resistance to gas-poisoning. Later dull emitter types also had a tungsten filaments but these were coated in a mixture of calcium, strontium and barium oxides, which emit electrons easily at much lower temperatures due to a monolayer of mixed alkali earth metals coating the tungsten when the cathode is heated to about 800-1000 C.

Indirectly heated cathodes were developed in the early-mid-1920's to allow AC current to flow in the filament circuit to more easily allow AC operation of radio equipment and dispense with the inconvenience of large batteries for the filament supply. This step also encouraged more experimentation in the materials and construction used for the cathode electrode to improve electron-emitting performance and longevity. In this design, the cathode usually consists of a nickel tube, coated

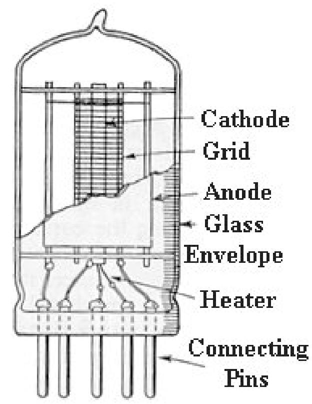


Indirectly Heated Cathode

on the outside with the same strontium, calcium, barium oxide mix used in the dull emitter directly-heated types, and fitted with a tungsten filament inside the tube to heat it. This tungsten filament is usually uncoiled and coated in a layer of alumina, (aluminium oxide), to insulate it from the nickel tube of the actual cathode. This allows a much greater electron emitting area to be formed and, because the heater is insulated from the cathode, the cathode can be positioned in a circuit at up to 150 volts more positive than the heater or 50 volts more negative than the heater for most common types. It also allows all the heaters to be simply wired in series or parallel rather than some requiring isolated power supplies with specially insulated windings on power transformers or separate batteries.

Grids

Grids are usually made from molybdenum wire wound in grooves on supporting posts. Alternate, less expensive materials have included iron, nichrome, iron-nickel and manganese-nickel. The spacing of the grid wires (aperture) is critical in the valve design. By having wider spacing at the outer ends of the grid structure (and tighter in the middle) greater control of the amplification factor (μ) of the valve can be obtained by varying the DC bias applied to the control grid – the so-called 'remote cut-off' design so important to good AGC performance in radios. Designs with linear grid apertures are termed 'sharp cut-off'.



A modern type of triode valve

In some later valve designs, precision control and screen grids, called 'frame grids', offered enhanced performance. Here, instead of the typically elliptical fine-gauge wire supported by two posts, a frame grid can be a metal stamping with rectangular openings that surrounded the cathode. Here, the grid wires are in a plane defined by the stamping, and the control grid placed much closer to the cathode surface than traditional construction would permit. This allows the valve to have a greater slope and shorter electron transit time.

It is important to prevent the grid from becoming over-heated. This may be prevented by carbonizing the grid wires and/or attaching cooling fins to the support structures. Gold or platinum plating may be used to avoid grid emission at higher temperatures.

Anodes (a great quote in 'Wireless Valves Simply Explained' by John Scott-Taggart: '…*The reader may be a little confused at first by the various names given to valves and the various synonymous terms employed when dealing with valve circuits. He will learn that some speak of valves (a popular but often inaccurate name), others of vacuum tubes; some speak of "plates" (and apparently mean cylinders), while others always refer to "anodes*"…")

The anodes of small signal valves are usually made from nickel, nickel-plated steel or iron, pressed out of sheet metal that is crimped or flanged to increase its mechanical rigidity, sometimes blackened, or in higher-power types, finned, to increase its heat-radiating efficiency, mounted on stout supports connected to the base pins. Valves designed for higher power use and hence higher temperatures may also use molybdenum, carbon, tantalum or zirconium in their construction.

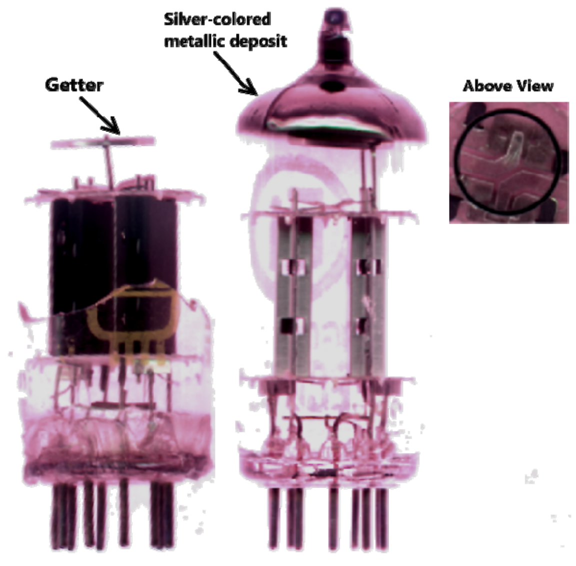
Other Bits

The envelope is usually made from lime glass, though other materials can be used, eg. metal and/or ceramic. In the early-mid 1930's, GE developed the 'all metal tube', originally as a valve to be hard-wired into a radio, but which turned into an octal-based valve manufactured by RCA (it's a long story - see the article by Patrick Dowd attached as an appendix). The critical issue is obtaining a good, long-lasting seal to the wires/pins exiting the envelope (sealing technology was the main problem in developing the all metal valve).

Once valve technology became 'commercial', the need for easy and convenient replacement was identified given that the functional life of a valve was (usually) significantly less than that of the equipment it was installed in. A variety of bases were thus introduced over the years to accommodate this need, the number of pins increasing over the years and the size of the pins and base generally decreasing with a view to 'miniaturization'. The earlier bases, through to the Octal design of the early 1930's generally used a Bakelite moulding, eventually dispensed with by the introduction of the miniature valves in 1938. The Technical Short on 'Valve Lore' deals with this subject in a little more detail.

Vacuum (how can I talk about something that is not there?...)

The vacuum inside the envelope must be as perfect, or 'hard', as possible as any remaining gas atoms remaining might be ionized at operating voltages and conduct electricity between the elements in an uncontrolled manner. This effect leads to unstable operation and/or even catastrophic destruction of the valve. The condition may be recognized by the gas ionizing and becoming visible as a blue to pink-purple glow discharge between the valve's elements.

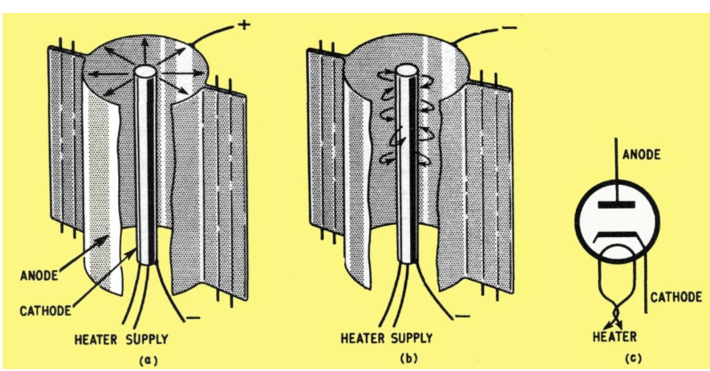


To prevent remnant air being a problem, most valves are constructed with 'getters' in their design, which are usually small structures in the envelope filled with metals that oxidize quickly, with barium being the most common. While the envelope is being evacuated of air, the internal parts except the getter are heated by RF induction to extract any remaining gases from the metal. The valve is then sealed and the getter is heated to a high temperature, causing the material to evaporate, absorbing/reacting with any residual gases and usually leaving a silver-brown coloured metallic deposit on the inside of the envelope of the valve. The getter continues to absorb any gas molecules that leak into the valve during its working life. If a valve develops a crack in the envelope, this deposit turns a white color when it reacts with atmospheric oxygen.

Valve Types

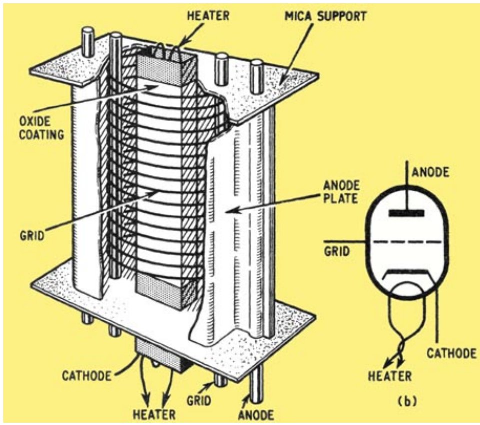
There are literally thousands of valve 'types', ie. valves that have different designations. However, these mostly fall within a series of major classes, depending on the number of electrodes present within the envelope: diodes, triodes, tetrodes, pentodes, hexodes, heptodes and octodes. As noted above, more than one valve assembly can be included within one envelope, giving rise to types such as dual-diode triode, triode-hexode and dual triodes.

Diodes:



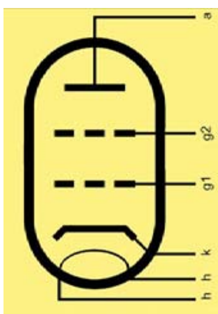
In thermionic valve diodes, a current through the heater filament directly or indirectly heats the cathode. The heat causes thermionic emission of electrons into the vacuum. In forward operation, a surrounding metal electrode called the anode is positively charged so that it electrostatically attracts the emitted electrons. However, electrons are not easily released from the unheated anode surface when the voltage polarity is reversed. Hence, any reverse flow is negligible and the valve is a one-way route for electrons, allowing it to rectify an AC current.

Triodes:



The grid nearest the cathode is usually termed the 'control grid'. The voltage applied to this grid causes the anode current to vary. In normal operation, with a resistive load, this varying current will result in varying (AC) voltage measured at the anode. With proper biasing, this voltage will be an amplified (but inverted) version of the AC voltage applied to the control grid, thus the triode can provide voltage gain.

Tetrodes:



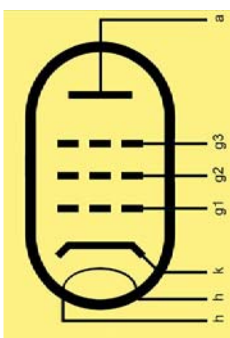
In a tetrode, a second grid, called the 'screen grid' provides a screening effect, isolating the control grid from the anode. This helps to suppress unwanted oscillation, and to reduce an undesirable effect present in triodes termed the 'Miller effect', where the gain of the valve causes a feedback that increases the apparent capacitance of the grid, limiting the valve's high-frequency gain and causing instability. In normal operation the screen grid is connected to a positive voltage, somewhat less than the anode, bypassed to the cathode with a capacitor. This shields the grid from the anode, reducing Miller capacitance to a very low level and improving the valve's available gain at high frequencies. When the tetrode was introduced in the late-1920's, a typical triode had an input capacitance of about 5 pF, but the screen grid reduced this capacitance to about 0.01 pF.

The positive influence of the screen grid in the vicinity of the control grid allows a designer to shift the control grid operating voltage range entirely into the negative region. If the input signal causes the control grid to become positive (where current flow begins), nonlinearity is to be expected (the control grid draws no current while negative but draws current while positive). With the control grid operating entirely in the negative region, and with the shielding afforded by the screen grid, the tetrode input impedance is quite high, even at high frequencies, and its gain is linear.

However, the tetrode has some problems: in any valve, electrons strike the anode hard enough to knock out secondary electrons. In a triode these (less energetic) electrons cannot reach the grid or cathode, and are re-captured by the anode, however in a tetrode, they can be captured by the screen grid, reducing the anode current and the amplification of the valve. Since secondary electrons can outnumber the primary electrons, in the worst case, particularly when the anode voltage dips below the screen voltage, the anode current can actually go down with increasing plate voltage. This effect gives rise to the 'tetrode kink'. Another consequence of this effect is that under severe overload, the current collected by the screen grid can cause it to overheat and melt, destroying the valve.

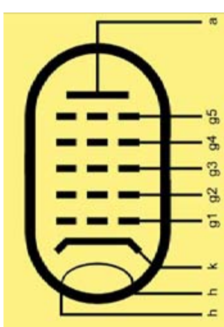
The beam-power valve is usually a tetrode with the addition of optically-aligned control grid and screen grid windings and two angled beam-forming plates, which take the place of the suppressor grid in a pentode (see below). The angled plates focus the electron stream onto targets on the anode which can withstand the heat generated by the impact of massive numbers of electrons, while also providing pentode behaviour. The positioning of the elements in a beam-power valve construction uses a design called 'critical-distance geometry', which minimizes the 'tetrode kink', plate-grid capacitance, screen-grid current, and secondary emission effects from the anode, thus increasing power conversion efficiency.

Pentodes:



The earlier solution to the problems inherent in the tetrode design was to add another grid, called a suppressor grid, making the design into a three grid construction, termed a 'pentode'. This third grid is biased at either ground or cathode voltage and its negative voltage (relative to the anode) electrostatically suppressed the secondary electrons by repelling them back toward the anode. The pentode can be operated with much larger voltage swings than the tetrode without distortion.

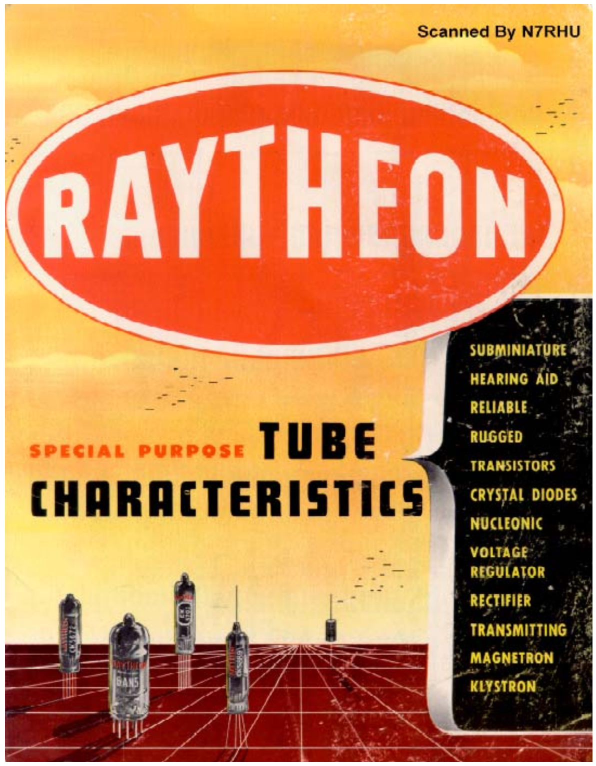
Multiple Grids:



Frequency conversion can be accomplished by various methods in superheterodyne receivers. Valves with five grids, termed pentagrid converters (or heptodes), were often used for this function, especially in the US. In the pentagrid, one grid was used for the signal, another two as part of the local oscillator circuit and the remainder as a screen to reduce unwanted coupling between the local oscillator function and the input signal. Alternatives to the pentagrid were also introduced, such as using a combination of a triode with a hexode in the same envelope or the octode (refer to the Technical Short on 'Receiver Front-Ends' for more discussion on this topic). As for the pentagrid, the additional grids are either control grids, with different signals applied to each one, or screen grids. In many designs, a special grid acted as a second 'leaky' anode to provide a built-in oscillator valve, which then mixed this signal with the incoming radio signal. These signals create a single, combined effect on the anode current (and thus the signal output) of the mixer circuit. The useful component of the output was the difference frequency between that of the incoming signal and that of the oscillator.

Special types

Some special-purpose valves are constructed with particular gases in the envelope. For instance, voltage regulator valves contain various inert gases such as argon, helium or neon, and exploit the fact that these gases ionize at predictable voltages. The thyratron is a special-purpose valve filled with low-pressure gas or mercury, some of which vaporizes. Like other valves, it contains a hot cathode and an anode, but also a control electrode, which behaves somewhat like the grid of a triode. However, when the control electrode starts conduction, the gas ionizes, and the control electrode no longer can stop the current; the valve thus 'latches' into conduction. Removing anode voltage lets the gas de-ionize, restoring its non-conductive state.



Of course, there are many other special-purpose valves – klystrons, magnetrons, travelling wave tubes etc, however, they are not found in Eddystone sets and will not be covered in this general article on receiving valve types and characteristics.

Valve Parameters & Characteristic Curves

Any valve has a number of electrical parameters that can be measured and presented as a series of 'characteristic curves' that illustrate how the valve will perform under static conditions or applied voltages to the anode and grid. The main parameters are presented below along with some representative characteristic curves.

Mutual Conductance

The ratio of the change in anode current to the change in grid voltage for a constant anode voltage in a valve is termed the 'mutual conductance' (g_m) or 'slope' of the valve and is expressed in mA/V or 'micromhos' (1mA/V = 1000 micromhos).

Amplification Factor and Impedance

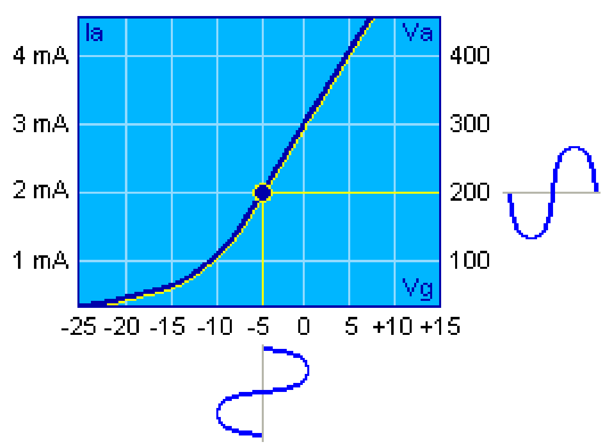
The ratio of change of anode voltage to change in grid voltage for a constant anode current is termed the 'amplification factor' (μ) of the valve. Valves are frequently classed as low-μ (<10), medium-μ (10-50), and high-μ (>50). If the anode voltage of a valve is changed and the grid voltage kept constant, the anode current will change. The ratio of change of anode voltage to change in anode current for a constant grid voltage is known as the 'impedance' (Ra), 'AC resistance' or 'slope resistance' of the valve. The impedance, mutual conductance and amplification factor of a valve are related by the equation:

Impedance (ohms) = (Amplification Factor/Mutual Conductance (mA/V)) x 1000

Thus, mutual conductance and impedance are equal to the slopes of the anode current/grid voltage and of the anode voltage/grid current characteristics respectively.

The valve's impedance may be considered to be similar to the internal resistance of a battery. It must not be confused with the external 'load impedance' (R) of the anode circuit into which the valve is connected. For a triode, the load impedance would be in the range 1 to 10 times the valve impedance.

When an increasing negative voltage is applied to the control grid of a valve, the anode current falls. The grid voltage at which the anode current falls to a particular low value is known as the 'cut-off point'. The part of the anode current/grid voltage curve prior to reaching this point is often referred to as the 'tail', and a valve may be designed to have a sharp cut-off or a slow cut-off (usually termed 'remote' cut-off), depending on its intended use. The reduction in anode current towards cut-off is accompanied by a reduction in mutual conductance (ie. gain) – a gradual slope towards cut-off is desirable for applications such as in receiver stages that are controlled by the AGC. Valves having these characteristics are known as 'variable-μ' or remote cut-off valves, where the cut-off point is normally defined as the grid voltage when the anode current drops to 1/100th of its normal operating value.



In a voltage amplifier stage, the gain is proportional to the ratio of the external load impedance (R) to the internal valve (Ra) and external load impedances:

Voltage Gain = μ x (R/(R + Ra))

Input Impedance and Input Admittance

When used in a resonant circuit, the resistive and reactive (capacitance and inductance) components of the valves characteristics modify the circuits behaviour. The effect of the resistive component reduces with increasing frequency and the reactive component then dominates (at a rate of the square of the frequency) and inversely to the mutual conductance of the valve. This effect is sometimes termed the 'input impedance' or 'admittance' characteristic of the valve. The reactive component is largely due to the capacitance between the grid and other electrodes ('input capacitance'). The effective input capacitance can be affected by the anode load – as the signals on the grid and anode are opposite in phase, an (AC) current can flow through the input capacitance – the higher the anode load, the greater the amplification and the higher the effective capacitance becomes. This is the 'Miller effect' mentioned earlier.

Characteristic Curves

Each valve design has a set of characteristic curves associated with it that define how it will perform in a circuit and that can be referenced by the circuit designer to ensure the correct valve is selected for a particular application and that the correct operating conditions are presented in the circuit by selecting appropriate values of passive components that set bias conditions, anode and screen voltages, decoupling, etc.

As discussed earlier, there are three independent variables affecting operation of a triode, ie. cathode temperature, anode voltage and grid voltage, as well as two dependant variables, these being the anode current and grid current. By varying any one of the independent variables while holding the other two constant and plotting the resulting dependant variables on a series of curves will define the static characteristics of a particular valve. Cathode temperature is not usually considered a variable (except in some 1920's TRF sets where gain could be adjusted with a filament rheostat) – normally it is necessary to be sure that the total cathode emission be several times the normal anode current of the valve.

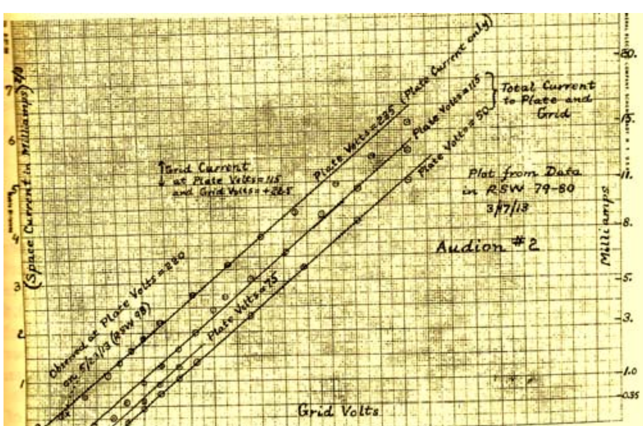
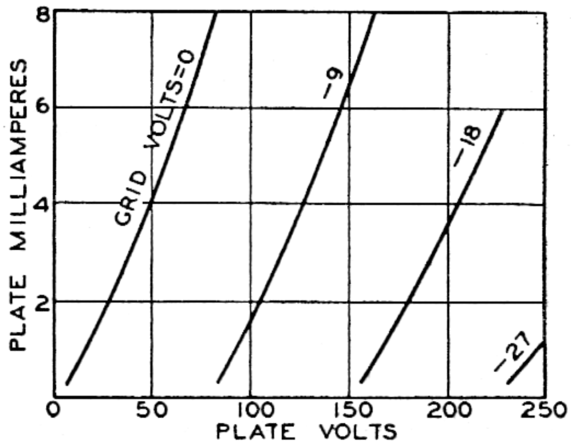
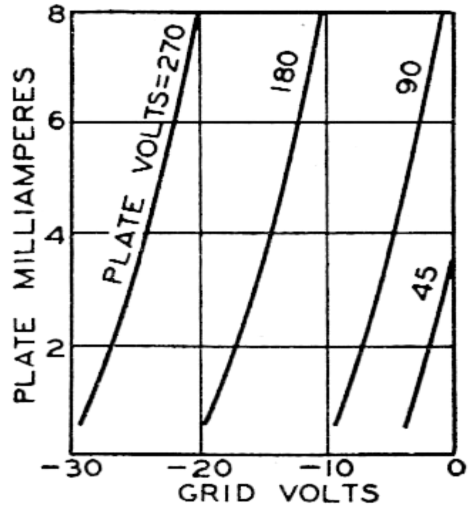


Fig. 8-3. Characteristic curves of tungsten-wire Audion #2 at various plate voltages. (Reproduced from transcript of record, General Electric Company vs. De Forest Radio Company, U.S. Circuit Court of Appeals, 3rd District, Nos. 3799, 3800, March Term, 1928, Vol. 4, p. 46.)

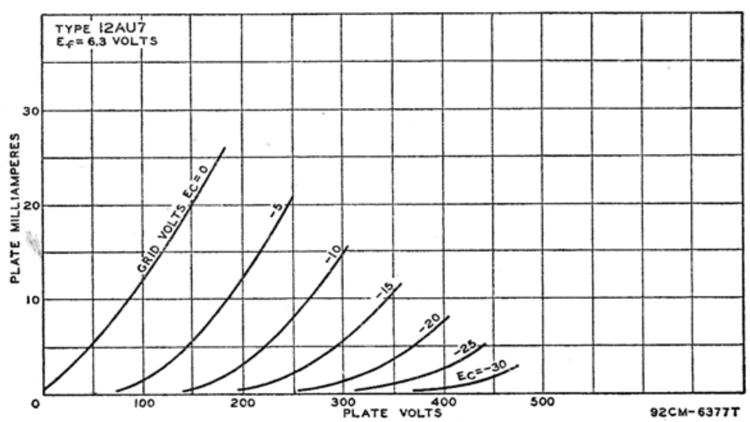
These are generally termed the valves 'static characteristics' and may be illustrated by 'anode characteristic curves' and 'transfer (mutual) characteristic curves'. These curves present the same information but in two different forms to increase its usefulness: the anode characteristic curve is obtained by varying the anode voltage and measuring the anode current for a range of grid (bias) voltages, whereas the transfer characteristic curve is obtained by varying the grid (bias) voltage and measuring anode current for a range of anode voltages. The two plots below illustrate this:



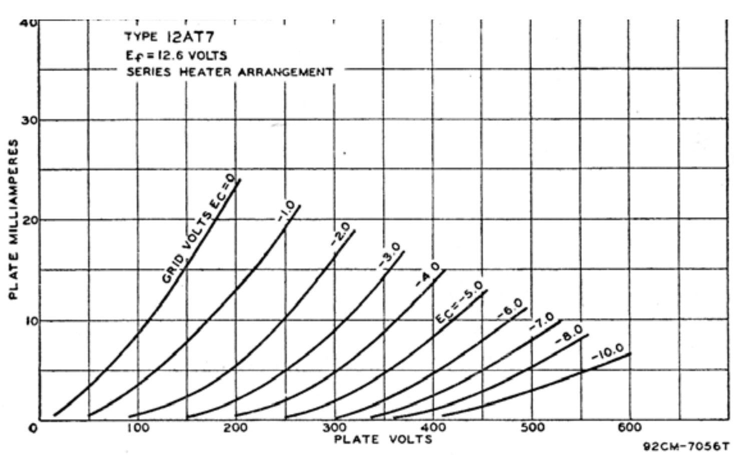


Above left: Anode-characteristic set of curves. Above right: transfer (mutual)-characteristic curves for the same valve

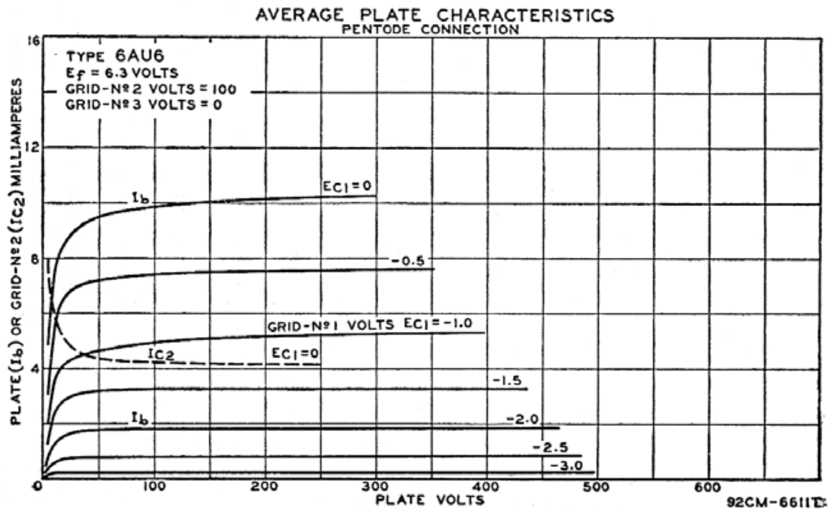
The most commonly illustrated curves are the anode characteristic curves. Typical examples are illustrated below for two different valve types.

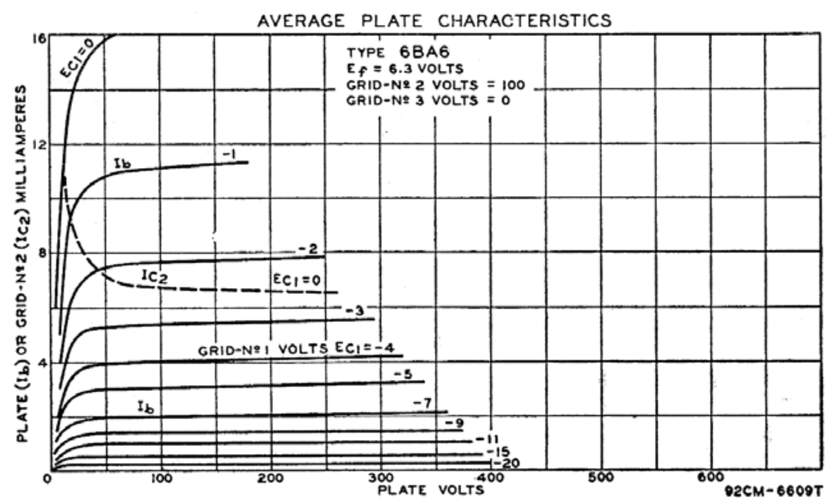


The figures shown above and below illustrate a set ('family') of anode current v grid voltage curves for two popular triodes: one a medium-μ (12AU7), the other a high-μ type (12AT7).



The two figures below show a family of anode current v grid voltage curves for two pentodes: one a popular sharp cut-off type (6AU6), the other a popular remote cut-off type (6BA6). Note the much greater range of bias voltage on the control grid (grid 1) for the remote cut-off type.





In addition to the static characteristics, valves also have 'dynamic characteristics', which include amplification factor, anode resistance, control grid-anode transconductance[2] (mutual conductance, g_m) and conversion transconductance (in mixer applications, Sc), as discussed earlier in this article.

Noise

Slight fluctuations in the rate at which electrons arrive at the anode result in noise being generated in a valve. This noise is termed 'shot noise'. It is convenient to express the noise thus generated as that in a resistor ('Johnson noise'). For a valve, this is equivalent

[2] Transconductance is the incremental change in current to any electrode divided by the incremental change in voltage to another electrode. Grid to anode transconductance is termed the mutual conductance (g_m).

to the noise produced in an (imaginary) resistor placed in series with the grid and is termed the 'equivalent noise resistance' (R_{eq}). For a triode, this may be calculated from:

$R_{eq} = 2.5/g_m$ Kohms

Shot noise is generally independent of frequency through the operating range of a particular valve type as it relates to the valve characteristics.

The shot noise generated in multigrid valves (eg. heptodes) is much higher than for a pentode due to the partition effect of the anode and screen grid currents caused by the random behaviours of the electrons flowing as to which element in the valve it reaches.

In addition to shot noise, electrostatic charges induced in the control grid by the passage of electrons through it on their way to the anode induce a thermal noise in the valve – this effect is negligible at low and medium frequencies, but at much higher frequencies it can be an important consideration.

Hum is a particular type of noise that can be transferred from a heater in a valve to the signal circuit by inter-electrode capacitance and leakage, particularly when the cathode is poorly-designed or is suffering from breakdown.

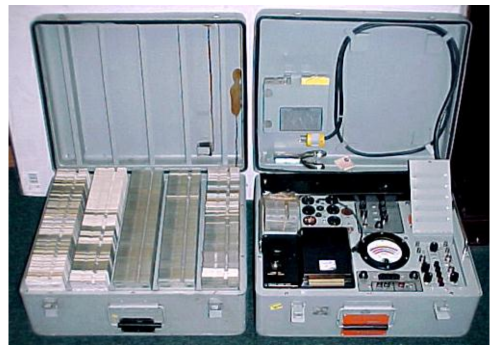
Measuring Valve Parameters

So, with valves being subject to extremes of temperature, cathode material evaporating etc, they are just bound to give up the ghost eventually are they not? Well yes, but if they are used in circuits that provide working conditions that keep the valve within its design parameters, most will last a surprisingly long time – far longer than we would expect in many cases. Even so, it is sometimes necessary to 'test' a valve, ie. to compare it with it with the performance of a new valve of the same type. The best test is arguably to substitute a known good valve into the circuit where the valve is suspect, however, that is not always possible (we don't all carry a large inventory of known good valves) and sometimes we need to test for other reasons, eg. to match a pair of output valves.

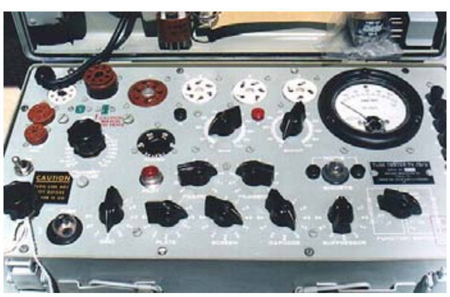
But some words of caution I found in a comment on the Leeds Components (New York) Website (http://www.leedsradio.com/):

> *"You can see it many places tubes are sold, whether on Ebay or dealers' websites and sales literature; "used, tests like new". Unfortunately there is no such thing. The data shown in tube manufacturers data books such as the RCA RC-30 for characteristics are 'bogey' values. Langford-Smith's "Radiotron Designer's Handbook, 4th Edition", defines bogey as:*
>
> > *"Each individual characteristic in the manufacturing specification is normally prescribed as a bogey value with plus or minus tolerances. The bogey value is the exact value specified for that characteristic by the valve manufacturing specifications."*
>
> *What Langford-Smith doesn't address is how wide the piece to piece variation from bogey can be. Take just one parameter, and this happens to be the most often thrown about parameter - g_m, or mutual conductance. Mutual conductance can be affected by many parts of the manufacturing*

process, for example how closely the grid wires are wound to the manufacturer's design target. If the wires are more closely wound the g_m will be higher and if the spacing is larger, lower. All other things being equal, the tube with the higher g_m will NOT have a longer service life than the one with the lower g_m. Cathode to plate spacing can also have an affect without any detrimental affect on service life. Mutual conductance for newly manufactured tubes in a given lot will be distributed on a skewed normal (bell shaped) curve. It is skewed to the left because most manufacturers were overly optimistic in stating the bogey value. For American-made 12AX7A's for example a corrected, and more realistic bogey is about 0.75 times the specification. You can expect that a batch of new, good tubes to be distributed over the range from .66 time bogey to 1.33 times bogey. The manufacturers themselves considered a NEW tube GOOD if the g_m was as low as 66% of bogey, which is why if you look closely at tube testers you will see that they have a reject line on the meter at 66% of nominal. Hickok Cardmatic 118A testers [photo, right], the type used most often at Leeds, have a full scale deflection for 12AX7 at 1600 micromhos, and reject at 1056 micromhos. Please note that other testers may have different bogey and reject values due to having different test conditions. Tube testers, at least good quality ones, do not have 'used' listed as a parameter on the meter.

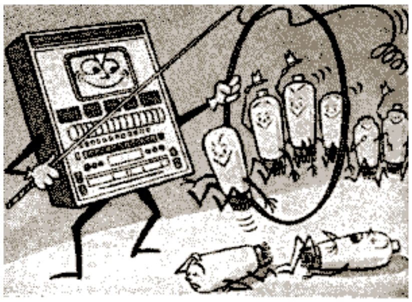


Twenty years ago, I tested more than 300 General Electric 6CA7 fat bottle tubes that were all from one lot. The g_m data for those tubes also showed the characteristic mentioned above - a left skewed normal curve centering around .75 of bogey value, with 95% of tubes falling within +/-33 percent of that corrected bogey. Tube users who still believe that there is a "tests as new" standard should ask themselves why it would ever be necessary to match tubes if that were true. If it were, all one would have to do is purchase tubes from the same lot from the same manufacturer and all would match. Anyone who has ever done this immediately recognizes that it isn't the case…".



So, what can we expect from a valve tester? – it really depends on what sort of tester you are using. Most of the lower-cost types only test the valve emission by heating the cathode with the correct voltage, strapping all the grids to the anode (effectively making a diode out of the valve) and applying a voltage between the cathode and anode, measuring the current that flows – not very sophisticated and not surprisingly it tells you nothing about the valves characteristics, only that the heater functions and the valve allows electrons to flow. More sophisticated testers, often termed 'dynamic' testers, attempt to simulate the working conditions of a valve by applying a bias to the grid instead of strapping it to the anode, thus providing a more controlled testing environment. It is still fairly crude though and, while better than the simple 'emission tester' it cannot be used to measure valve parameters, only compare the performance with pre-determined characteristics of the same valve when 'factory fresh' (bear in mind the comments above regarding bogey values). I own such a tester and it works fine most of the time, and can certainly weed out the duds in a batch of valves, spotting inter-electrode shorts and leaks, poor emission and low mutual conductance. However, if you want to actually measure the characteristics of a valve, then you really have to go for a much more sophisticated

device, such as the AVO Mk2 or Mk 4. Expect to pay serious money for one in good, working condition (and be prepared to spend many a happy hour with it setting up, recording, etc) – not for the casual user really…



These sophisticated valve testers can measure all the important valve parameters and can be used to plot the characteristic curves as discussed earlier in this article. You really must have a keen interest in doing this to undertake such measurements as it takes time and skill, and most folks therefore settle for a simpler (and much cheaper) dynamic tester. I have the best of both worlds at the moment – a couple of dynamic testers at home and the use of an AVO Mk2 at the SPARC museum if I feel inclined to explore further.

Closure

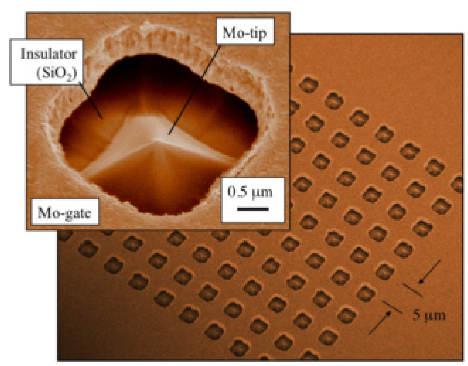
I often wonder how electronics would have developed if advances in solid-state technology had progressed ahead of 'hot cathode' technology as they could well have done – maybe all the low-power valve applications would have been skipped-over and only high-power applications would have been pursued – magnetrons, high-power beam tetrodes for commercial transmitters and the like? We will never know of course, but I am really glad the electronics world worked out in the way that it did! By the same token, as much as I love valve technology, I am also grateful for semiconductors every day - preparing this article, typing it, copying it and distributing it the 'old-fashioned' way would be a nightmare, so much so it just would not happen: everything has its place in the world, as long as we have the choice, I am ok with that.

So, where will hot cathode technology go next? I really do not know. The renaissance of the cathode ray tube in the boom of the PC revolution and for TV sets is now long gone with the advent of LCD and other display technologies. High-power radio transmitter applications often still rely on valves, as do specialist. 'golden ear' HiFi amplifiers, guitar amplifiers and the like – will these fads last? – I hope so, as they do provide sufficient a market for several valve manufacturing plants in Russia and China to go on producing small signal amplifiers, rectifiers and audio output valves, even if for a very limited range of types supported by these specialist markets. There are, of course, millions of radio valves still around that were manufactured in the heyday of the valve industry – many 'new old stock' (NOS) and working-used (recovered from scrapped radios) – enough to last me out in repairing and restoring valve radios no doubt, but some types are becoming rarer and more expensive – valves like Type 42 audio output valves for example (introduced in the early-1930's and still popular in the audiophile world).

Where will it end? – not as soon as 2012 as some would have us believe, but depressingly, I think I am of the last generation that will really care – in my opinion , valve radios will lose their appeal as working historical artefacts for a number of reasons in the coming years: one reason is that they are becoming of less practical use and relevance as time progresses (as any radio is that is designed for AM broadcast reception), as fewer and fewer stations broadcast anything of any value on AM. It will likely not be long (a decade or two) before the only countries broadcasting on AM will be those without well-developed infrastructure that can provide fast internet connections to its population. As my generation passes into history, so will the memories of using valve radios and the nostalgia factor of their simplicity and character – including 'the smell of hot varnish' as mentioned recently on the EUG forum. The technical skills associated with these radios will also eventually be lost and the sets relegated once again to the scrapheap except for a few sets in exceptional condition and those as curios in museums. I therefore fear that the desirability of valve sets will plummet, including my beloved Eddystones, and that will be that. So, enjoy the current renaissance while we can. Maybe the sunset years of the valves time-line will be like this:

1974 – last Eddystone valve set produced (S950). The end of an era;
2005 – the last bastion of the CRT – the computer monitor – goes LCD;
2025 – all remaining high-power applications for valves replaced with solid state devices;
2045 – the last technical skills pertaining to valve radios die out. Millions of NOS and used valves clutter warehouses and no-one knows what to do with them. RIP hot cathode technology, aged ~166 years.

I am just pleased that I was born when I was, where I was, with a reasonable amount of intellect, a passion for radio and into a world where valve technology was still alive…



But wait, all is not lost! - I hear that in the early years of the 21st century there has been renewed interest in electron emitter technology, but this time with the electron emitter formed on a flat silicon substrate, as in integrated circuit technology, this being termed 'Vacuum Nanoelectronics'. The most common nanoelectronic design uses a cold cathode in the form of a large-area field electron source. With these devices, electrons are field-emitted from a large number of closely spaced individual emission sites. Their claimed advantages include greatly enhanced robustness combined with the ability to provide high power outputs at low power consumptions. Operating on the same principles as traditional valves, prototype device cathodes have been fabricated in several different ways. The literature indicates that such integrated 'microvalves' may find application in microwave devices including more efficient mobile phones, Bluetooth and Wi-Fi transmissions, in radar and for satellite communication. Somehow it is just not the same as a glowing cathode though… but I guess that's progress.

Some Useful/Interesting References

Copies of those marked with an asterisk can be bought from Antique Electronic Supply (www.tubesandmore.com)

- Fundamentals of Vacuum Tubes, Austin Eastman, 1941
- Saga of the Vacuum Tube, Gerald Tyne, 1977 (a researcher at the Smithsonian – this guy really knew his 'tubes')*
- History of Electron Tubes, S Okamura, 1994
- History and Development of the All-Metal Radio Tube, Patrick Dowd
- Saga of Marconi Osram Valve, Barry Vyse & George Jessop*
- Radio Communications Handbook, 4th Ed. RSGB, 1968, Chapters 2 and 4
- The Radio Amateurs Handbook, 31st Ed. 1954 (though others through to around 1970 are all good references for valves)
- Radio Engineering, F. Terman, 1947, (3rd Ed. Chapter, 6, 7 and 8)
- Radio and Television Receiver Circuitry and Operation, Ghirardi & Johnson, 1951 (Chapter 4)
- Radiotron Designers Handbook, RCA, Langford Smith, 3rd Ed. 1940 (Chapters 14 and 15)
- Radiotron Designers Handbook, RCA, Langford Smith, 4th Ed. 1953 (Chapters 23, 24 and 25)
- Inside the Vacuum Tube, John Rider*
- Electronics One-Seven, Edited by Harry Mileaf, Hayden Book Co., 1967, Chapters 3and 5
- Receiving Tube Manual(s) – RCA (annual publications: late-1950's/early-1960's editions are the best) (*1973 edition) – see Classification Chart from the 1959 issue edition below – useful stuff…
- Tube Lore: A Reference for Users and Collectors, Ludwell Sibley*
- Principles of Electron Tubes, Herbert Reich*
- Wireless Valves Simply Explained, John Scott-Taggart, 1922
- Collectors Vacuum Tube Handbook , Robert Millard*
- 'Valve Data and General Information' CD ROM, Paul Stenning, 2001 (http://www.vintage –radio.com)
- 'The National Valve Museum' DVD ROM (http://valve-museum.org)
- 'Valve Technique' (1948), RSGB, reprinted 2006
- Getting the Most out of Vacuum Tubes, Robert Tomer, 1960 (great reference on failure modes of valves and what was done to 'toughen 'em up…)* - I have an author-signed copy…
- Vintage Radio 1887-1929, 2nd. Ed. Harold Greenwood, revised, edited and expanded by Morgan E. McMahon (my copy signed by Morgan)
- Some YouTube videos you simply must see:
    - http://www.techtubevalves.com/about_us/film_reels.php (Mullard Blackburn Factory film)
    - http://www.youtube.com/watch?v=8_eLO0exato&feature=related (reproducing a Fleming valve)

    - http://www.youtube.com/watch?v=gl-QMuUQhVM&feature=related and http://www.youtube.com/watch?v=9S5OwqOXen8&feature=related (do it yourself!)
    - http://www.youtube.com/user/AllAmericanFiveRadio#p/u/12/ZT0i5iprLos
- http://www.cjseymour.plus.com/elec/valves/valves.htm
- http://en.wikipedia.org/wiki/Vacuum_tube#History_of_development
- http://www.vacuumtubes.net/How_Vacuum_Tubes_Work.htm
- http://lmn.web.psi.ch/vacuum_nanoelectronics/index.html
- http://mysite.du.edu/~etuttle/electron/elect27.htm
- http://www.john-a-harper.com/tubes201/ (how valves really work)
- http://www.mit.edu/~klund/papers/jmiller.pdf (Miller effect simply explained (!))
- http://www.angelfire.com/planet/funwithtransistors/Book_CHAP-4A.html (no, it's valves, honestly!)
- http://www.jacmusic.com/Tube-testers/index.html
- http://members.iquest.net/~finchum/hickok.html

RCA Receiving Tube Classification Chart

RCA receiving tubes are classified in the following chart according to function and filament or heater voltage. Types having similar electrical characteristics are grouped in brackets. For more complete data on these types, refer to the TUBE TYPES SECTION. When choosing a tube type, refer to information on *Preferred Types* and the listing of *Types Not Recommended for New Equipment Design* on the inside back cover.
refer

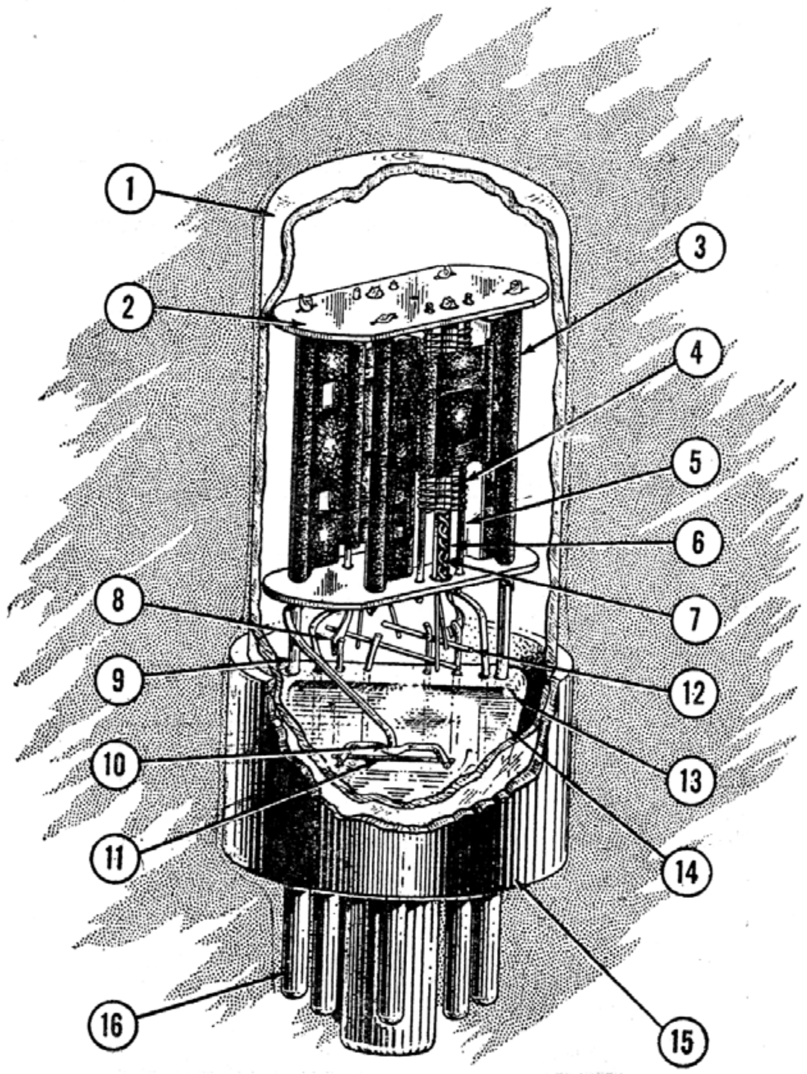
Filament or Heater Volts			1.25—1.4		2.0—5.0			6.3—117.0		
			Miniature	Other	Octal	Other	Miniature	Miniature	Octal	Other
RECTIFIERS *(For rectifiers with amplifier units, see POWER AMPLIFIERS).*										
Half-Wave	vacuum	Peak Inverse Volts							6AX4-GT 6W4-GT 12AX4-GTA‡ 17AX4-GT* 25AX4-GT	1-v
		Below 1500						35W4 117Z3	25W4-GT 35Z4-GT 35Z5-GT	35Y4 35Z3
		Above 1500	1AX2 1V2 1X2-A 1X2-B	1B3-GT 1G3-GT/ 1B3-GT	3A3 3B2		3A2	6V3-A	6BL4 6BY5-GA 6AU4-GTA 19AU4	
Full-Wave	vacuum	Below 1500			5Z4 5Y3-GT 5Y4-GT 5V4-G	5AZ4 80 83-V		6X4 12X4	6X5-GT 6AX5-GT	7Y4 7Z4 84/6Z4
		Above 1500			5AS4 5T4 5U4-G 5U4-GB 5X4-G	5Z3				
	gas	Below 1500			Cold-Cathode Types OZ4, OZ4-G					
Doubler	vacuum	Below 1500							25Z6-GT 50Y6-GT 50Y7-GT 117Z6-GT	25Z5 50X6
DIODE DETECTORS *(For diode detectors with amplifier units, see VOLTAGE AMPLIFIERS and also POWER AMPLIFIERS).*										
One Diode			1A3							
Two Diodes							3AL5‡	6AL5 12AL5	6H6 12H6	7A6
Three Diodes								6BC7		
POWER AMPLIFIERS *with and without Rectifiers, Diode Detectors, and Voltage Amplifiers.*										
Triodes	low-mu	single unit				2A3 45			6B4-G	
	high-mu	single unit						6BC4	6AC5-GT	
		twin unit							6AQ7-GT 6N7, 6N7-GT	
Beam Tubes	single unit			3Q5-GT* 3LF4			3BN6‡ 5AQ5‡ 5CZ5‡ 12R5‡	6BN6 6AQ5 6AQ5-A 6AS5 6BK5 6CU5 6CZ5 6DS5 12AB5§ 12AQ5 12CA5‡ 12CU5‡ 25CA5 35B5 35C5 50B5 50C5	6AU5-GT 6AV5-GA 6BG6-GA 6BQ6-GT 6BQ6-GTB/6CU6 6CB5 6CB5-A 6CD6-GA 6DG6-GT 6DQ5 6DQ6-A 6L6 6L6-G 6L6-GB 6V6 6V6-GT 6W6-GT 6Y6-G 12BQ6-GTB/12CU6‡ 12DQ6-A‡ 12L6-GT‡ 12V6-GT 12W6-GT‡ 17BQ6-GTB• 17DQ6-A• 25BQ6-GTB/25CU6 25CD6-GA‡ 25CD6-GB‡ 25L6 25L6-GT 35L6-GT 50C6-G 50L6-GT	7A5 7C5 35A5 50A5
	with rectifier								70L7-GT 117L7/M7-GT 117P7-GT 117N7-GT	

Filament or Heater Volts			1.25—1.4		2.0—5.0			6.3—117.0		
			Miniature	Other	Octal	Other	Miniature	Miniature	Octal	Other
POWER AMPLIFIERS *with and without Rectifiers, Diode Detectors, and Voltage Amplifiers.*										
Pentodes	single unit		1S4 3S4• 3Q4• 3V4•	1A5-GT 1C5-GT 1LB4		47		6CL6 6AK6 6AR5	6AG7 6G6-G 6F6, 6F6-G, 6F6-GT 6K6-GT	7B5 7AD7 42 41 43
	with medium-mu triode								6AD7-G	
CONVERTERS & MIXERS *(For other types used as Mixers, see VOLTAGE AMPLIFIERS).*										
Converters	pentagrid		1E8† 1L6 1R5	1A7-GT 1LA6 1LC6			3BE6‡	6BE6 12BE6 12AD6° 12BA7 6BA7	6SA7 6SA7-GT 12SA7 12SA7-GT 6SB7-Y 6A8, 6A8-G 6A8-GT 12A8-G7	6A7 7B8 7Q7 14Q7
	triode-pentode						5AT8‡ 5CG8‡ 5X8‡ 5U8‡	6AT8, 6AT8-A• 6CG8, 6CG8-A• 6X8 6U8, 6U8-A• 19X8		
	triode-hexode								6K8, 12K8	
	triode-heptode									7J7
	octode									7A8
Mixers	pentagrid								6L7	
ELECTRON-RAY TUBES										
Single	with remote-cutoff triode									6AB5/6N5 6U5
	with sharp-cutoff triode									6E5
Twin	without triode								6AF6-G	
Triple	without triode								6AL7-GT	
VOLTAGE AMPLIFIERS with and without Diode Detectors; **TRIODE, TETRODE, AND PENTODE DETECTORS; OSCILLATORS.**										
Triodes	medium-mu	single unit		1LE3		27	2AF4-A‡ 3AF4-A• 2BN4‡	6AF4, 6AF4-A 6BN4, 6C4 6S4, 6S4-A‡ 6T4 12B4-A▲‡	6AH4-GT 6C5, 6C5-GT 6J5, 6J5-GT 12J5-GT	7A4
		with pentode					5AN8‡ 5AV8‡ 5BR8‡	6AU8‡ 6BH8‡ 6AN8 6CH8 6AZ8 6BA8-A‡ 6BR8 6CU8•	6F7 6AD7-G	
		with tetrode					5CQ8‡	6CQ8•		
		with two diodes						12AE6° 6BF6 12AJ6° 12BF6	6R7 6SR7 12SR7	
		twin unit					4BQ7-A‡ 4BS8‡ 4BC8‡ 4BZ7‡ 5BK7-A‡ 5BQ7-A• 5J6‡	6BC8 6BK7-A, 6BQ7-A 6BS8 6BZ7 6BK7-B• 6J6 6CG7‡ 7AU7●‡ 8CG7• 12AU7-A▲ 12AV7▲ 12BH7-A▲‡ 19J6	6BL7-GT 6BX7-GT 6C8-G 6F8-G 6SN7-GTB‡ 12AH7-GT 12SN7-GT	7AF7 7F8 7N7 14AF7 14F8
		dual unit■						6CM7‡ 8CM7• 10DE7△‡		
	high-mu	single unit						6AB4 6AM4 6AN4	6F5, 6F5-GT 6SF5, 6SF5-GT 12SF5	7B4
		with diode		1H5-GT 1LH4						
		with two diodes					3AV6‡	6BN8‡ 6AT6 6CN7 6AQ6 12AT6 6AV6 12AV6 12BR7▲	6Q7, 6Q7-GT 6SZ7 6SQ7, 6SQ7-GT 12Q7-GT 12SQ7, 12SQ7-GT	7B6 7C6 7K7 7X7 14B6 75
		with three diodes					5T8‡	6T8 19T8	6S8-GT	
		twin unit						6DT8 12AX7▲ 12AT7▲ 12AZ7▲ 12DT8 12BZ7▲	6SC7 6SL7-GT 12SC7 12SL7-GT	7F7 14F7
		with rf pentode						6AW8‡, 6AW8-A‡ 8AW8-A•		

Filament or Heater Volts			1.25—1.4		2.0—5.0			6.3—117.0		
			Miniature	Other	Octal	Other	Miniature	Miniature	Octal	Other
VOLTAGE AMPLIFIERS with and without Diode Detectors; TRIODE, TETRODE, AND PENTODE DETECTORS; OSCILLATORS.										
Tetrodes	sharp-cutoff	single unit				24-A				
Tetrodes	sharp-cutoff	with triode					5CQ8‡	6CQ8‡		
Tetrodes	power							12K5°		
Pentodes	remote-cutoff	single unit	1T4	1LG5				6BJ6 6BD6 12BD6 6BA6 12BA6 12AF6° 12BL6°	6SK7 6SK7-GT 12SK7, 6SG7 12SG7 6SS7 6K7 6K7-GT 12SK7-GT 6AB7 6S7 12K7-GT	78 6D6 7A7 7AH7 7B7 7H7 14A7
Pentodes	remote-cutoff	with triode								6F7
Pentodes	remote-cutoff	with diode	1DN5					12CR6	6SF7 12SF7	
Pentodes	remote-cutoff	with two diodes						12F8°	6B8 12C8	7E7 7R7 14R7
Pentodes	semi-remote-cutoff	single unit					3BZ6‡	6BZ6 6DC6		
Pentodes	semi-remote-cutoff	with triode						6AZ8		
Pentodes	sharp-cutoff	single unit	1AD5† 1L4 1U4	1LC5 1LN5 1N5-GT			3AU6‡ 3BC5‡ 3CB6‡ 3CF6‡ 3DT6‡ 4AU6• 4CB6• 4DT6•	6AG5 6AK5 6BC5 6CB6 6CF6 6AH6 6AU6 12AU6 6DE6 6BH6 6DT6 12AW6 12BV7▲ 12BY7-A▲‡	6J7, 6J7-GT, 6W7-G 6SH7 12SH7	6C6 7AG7 7C7 7G7 7L7 7V7 7W7 14C7
Pentodes	sharp-cutoff	twin unit					3BU8	6BU8		
Pentodes	sharp-cutoff	with triode					5AN8‡ 5AV8‡ 5BR8‡	6AN8 6AU8 6CH8 6BH8‡ 6AW8‡, 6AW8-A‡ 6BR8 6CU8• 8AW8-A•		
Pentodes	sharp-cutoff	with diode	1S5 1U5	1LD5			5AM8‡ 5AN8‡ 5AS8‡	6AM8, 6AM8-A• 6AS8		
HORIZONTAL AND VERTICAL AMPLIFIERS AND OSCILLATORS *(for TV Receivers)*										
Triodes	medium-mu	single unit						6S4, 6S4-A‡ 12B4-A▲‡	6AH4-GT	
Triodes	medium-mu	twin unit						6CG7‡ 7AU7•‡ 8CG7• 12AU7-A▲ 12BH7-A▲‡	6BL7-GT 6BX7-GT 6SN7-GTB‡	
Triodes	medium-mu	dual unit■						6CM7‡ 8CM7• 10DE7∆‡		
Beam Tubes	single unit						5CZ5‡	6CZ5 12R5	6AU5-GT 6AV5-GA 6BG6-G, 6BG6-GA 6BQ6-GT 6BQ6-GTB/6CU6 6CB5 6CB5-A 6CD6-GA 6DQ5 6DQ6-A 6W6-GT 12BQ6-GTB/12CU6‡ 12DQ6-A‡ 17BQ6-GTB• 17DQ6-A• 19BG6-GA 25BQ6-GTB/25CU6 25CD6-GA‡ 25CD6-GB‡	
Pentode	single unit								6K6-GT (Triode connected)	
GATED AMPLIFIERS										
Pentagrid Amplifier							3BY6‡ 3CS6‡	6BY6 6CS6		
SHUNT VOLTAGE REGULATORS										
Beam Triode									6BD4-A 6BK4	

† Subminiature type.
■ With dissimilar triode units.
‡ 600-milliampere heater type having controlled warm-up time for use in series-string TV receivers.
▲ Heater arranged for 6.3- or 12.6-volt operation.
● Heater arranged for 3.5- or 7.0-volt operation.
∆ Mu-factor is 17.5 for Unit No. 1, 6 for Unit No. 2.

* Filament arranged for 1.4- or 2.8-volt operation.
⁎450-milliampere heater type having controlled warm-up time for use in series-string TV receivers.
° For use in "hybrid" receivers in which tubes and transistors operate from a 12.6-volt battery.
§ For use in automobile receivers operating from 12-volt storage batteries.



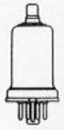
Tube-Part Materials in Typical RCA Electron Tube

1. *ENVELOPE*—Lime glass
2. *SPACER*—Mica sprayed with magnesium oxide
3. *PLATE*—Carbonized nickel or nickel-plated steel
4. *GRID WIRES*—Manganese-nickel or molybdenum
5. *GRID SIDE-RODS*—Chrome copper, nickel, or nickel-plated iron
6. *CATHODE*—Nickel coated with barium-calcium-strontium carbonates
7. *HEATER*—Tungsten or tungsten-molybdenum alloy with insulating coating of alundum
8. *CATHODE TAB*—Nickel
9. *MOUNT SUPPORT*—Nickel or nickel-plated iron
10. *GETTER SUPPORT AND LOOP*—Nickel or nickel-plated iron
11. *GETTER*—Barium-magnesium alloys
12. *HEATER CONNECTOR*—Nickel or nickel-plated iron
13. *STEM LEAD-IN WIRES*—Nickel, dumet, copper
14. *PRESSED STEM*—Lead glass
15. *BASE*—Bakelite
16. *BASE PINS*—Nickel-plated brass

HISTORY AND DEVELOPMENT OF THE

ALL-METAL RADIO TUBE

Bro. Patrick Dowd, W2GK
Science Instructor,
Paramus Catholic High School



Editor's Comment: It has been a practice in recent years to restrict material in the Bulletin to 3 pages. This article is an exception. AWA is proud to be able to print the first serious historical research on the development of the All-Metal tube. The Author made numerous field trips [and interviews] in order to obtain first-hand reliable information. Member's attending the 1975 Conference had the opportunity of seeing his original documentation. Don't let the title of the article deceive you for he tells about other tube development including the Nuvistor.-- B.K.

Although orphaned shortly after birth when, conceived by one company, she was raised by another, this spunky little tube not only survived but lived to make history. Her birth ushered in the modern age of tube technology when the umbilical cord binding her to the Incandescent Lamp heritage was severed. History positioned her arrival mid-way between the birth of the vacuum tube and its incipient decline. The announcement of her birth sparked more publicity and controversy than any prior or subsequent tube. It is ironical that the very technology that occasioned her birth and cured her childhood ills was ultimately to cause her demise.

Unfortunately, this "depression baby" after a history-making childhood, a dedicated adult life, and distinguish service in WW II was all but forgotten in later life. It is only fitting that, in her old age and before death of her species, this "plain jane" of the tube world, long neglected by collectors and historians alike, be restored to her rightful place in history and be given some of the recognition denied her throughout her adult life.

The all-metal tube made its debut forty years ago last September. It was originally conceived as an unique selling point to mark the return of General Electric Company to the radio-receiver and receiving-tube fields after an absence of five and half years. G.E. timed its re-entry for the fall of '35 when it planned to unveil its new receiver line featuring its 'eternal' all-metal receiving tube.

The G.E. engineers developed the idea of the all-metal tube, which was to be unbased and wired directly into the sets, and planned to make it so durable that it would last the life of the receiver. Although they had initiated and perfected most of the early manufacturing techniques, G.E. was unable, because of its long absence from this field, to produce the all-metal tubes economically and on time. Consequently, they turned over the manufacturing job to RCA on October 9th, 1934.

To place the above remarks in perspective, it is necessary to go back to the late twenties when radio's big four: RCA, G.E., Westinghouse and A.T. & T. (Western Electric), engaged in some hard-nosed negotiations designed, for economic reasons, to prevent needless duplication of research and manufacturing efforts and to avoid unnecessary competition.

As a result of these negotiations: the RCA Radiotron Company was formed as of January 1st, 1930 and the G.E. Harrison, N.J. Lamp Works was turned over to RCA at this time. RCA agreed to limit its research development and manufacturing efforts to radio receivers and receiving tubes. G.E. and Westinghouse agreed to confine their efforts to radio transmitters, transmitting tubes and to the application of vacuum tubes to industrial uses.

In May, 1930, the government brought suit against RCA claiming these agreements constituted a 'Restriction of Trade'. The suit dragged on until November 21st, 1932 when, the now famous 'Consent Decree' was handed down. This decree permitted the concerned companies, after a lapse of two and a half years, to engage in competition in all fields as of May 21st, 1935.

In the interim, G.E. had dismantled its radio receiver and receiving tube engineering departments at Schenectady and the personnel from these departments sought work elsewhere. At this time Messrs. J.C. Warner, B.J. Thompson and G.M. Rose joined RCA at Harrison.

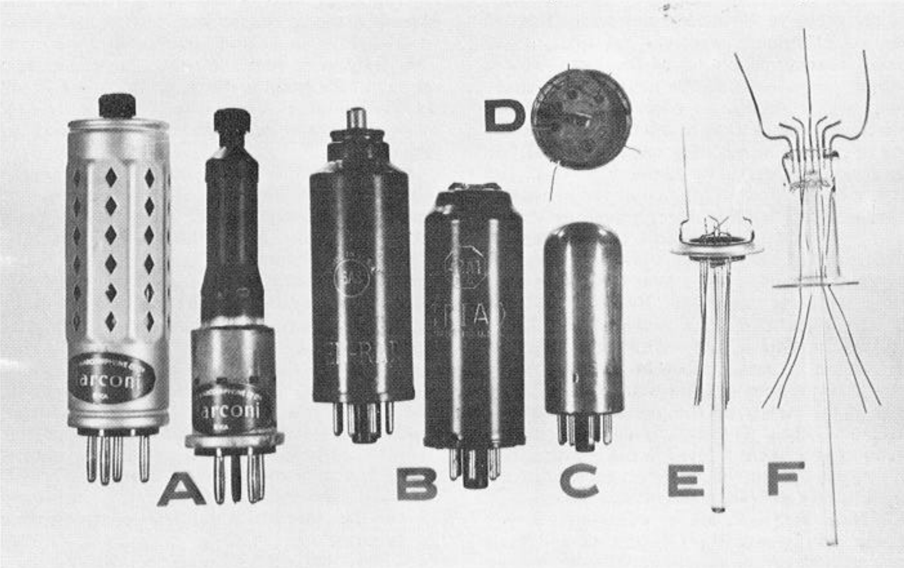
In preparation for its resumption of activities, it was necessary for G.E. to reorganize these departments. This it did as of January 1st, 1933 and Mr. C.F. Metcalf was appointed to head the new Vacuum Tube Engineering Department. He was joined shortly thereafter by Mr. J.M. Cage and Messrs. J.E. Beggs in April and by R.J. Bondley in November. These are the men who, together with W.C. White, were responsible for the all-metal receiving tube.

In January '33, at the first meeting of the newly formed departments, the determination was made to develop something radically novel if they were to have a marketing edge in the competitive receiver field upon their return in '35.

During the first few months of '33 they did considerable research on the electron-beam tube and on small glass tubes for high-frequency use. In April, Mr. Metcalf had built a sample receiving tube with a copper anode forming part of the container similiar to the water-cooled transmitting tubes of the day and to the recently released British Catkin tube.

Nolte was specifically directed to investigate this matter. By May 25, 1932, he had built, exhausted and tested the first all-metal tube (tin-can shell as anode, two refrigerator seals for filament wire feed-through, a coated ribbon filament and a copper seal-off tube lined inside with solder).

During the next few months a number of similar tin-can tubes were completed and tested. These were followed by a series of copper-can tubes. Although many difficulties were experienced with these tubes, none were considered to be of fundamental nature.



(A) Catkin tubes (B) MG tubes (C) Bullet (D) Early metal tube header (E) Glass button stem header (F) Old style press seal.

The results of these experiments convinced them that they must look elsewhere if they were to find a satisfactory answer to their problems. To understand why the group had not considered the idea of an all-metal receiving tube prior to this time, or at least why they did not pursue the idea even though G.E. was then very much involved with the production of an all-metal tube, we must go back several years.

The idea of an all-metal tube was not new -- patents and dockets pre-date 1915. However, the technology was not available for practical production. From 1919 through the early twenties the technology for the manufacture of high power 'glass-metal' transmitting tubes was developed and perfected. Unfortunately, this technology had no practical application in the production of an all-metal tube.

In November, 1931, W.C. White (the Father of the all-metal vacuum tube) suggested to the staff members of G.E.'s Vacuum Tube Development that they consider the idea of developing an all-metal Phanatron or Thyratron vacuum tube. A short time later, Mr. H.J. Nolte was specifically directed to investigate this matter.

Between January and June '33, the G.E. engineers found the solution to the remaining major technical problems that has previously prevented them from producing a practical and economical all-metal tube. In rapid succession; Thyratron controlled welding was successfully investigated and Fernico, an alloy with the same coefficient of expansion as 'AJ' glass, was developed. The 'eyelet seal' for low current tubes and the 'pedestal seal' for high current tubes were perfected. Although much work still remained to be done before a practical and economical all-metal tube could be produced, the goal was in sight.

When the members of the Vacuum Tube Engineering Department met in July, it was only natural, in the light of recent events, that the subject of an 'all-metal' receiving tube should be discussed. In August, pursuing an idea he initiated at the July meeting, Mr. Beggs completed the design of the first all-metal receiving tube. On September 7th, he successfully built, exhausted, tested and demonstrated the first steel-shell model of this design. The design of this first tube was so well conceived that it served as a model for the design of other tube types.

The designs of these early tubes, virtually unchanged, were the designs used by RCA when they went into production almost two years later. Mr. J.E. Beggs truly deserves great credit for the many novel and ingenious developments which made the all-metal receiving tube a success.

Messrs. White and Metcalf were most favorably impressed with the demonstration of the first sample all-metal tube and agreed it was most promising. Mr. R.J. Bondley joined the group in November and was assigned the task of finding practical solutions to the manufacturing problems of the new tubes. During the course of the next year he made many highly significant contributions to this new technology, either by initiating new methods or perfecting existing ones, especially in the field of welding. By January '34 G.E. was firmly committed to the use of the all-metal tube in their receiver development program.

In April '34, G.E. made two apparently contradictory moves. Messrs. Metcalf, Beggs and Bondley were sent to Ohio to work under the direction of Mr. Pritchard. Their job was to ready G.E.'s Incandescent Lamp Factory at Nela Park, Cleveland, for the production of metal tubes in quantity. G.E. then entered into negotiations with RCA to have them take over the manufacture of the all-metal tubes! The first move was probably made to give them a lever in the negotiations and also to protect themselves should the negotiations with RCA fail.

In May, Mr. H.F. Mayer completed development on the pencil-rectifier tube and built several successful samples. This work lead directly to the development of the unique designed 5Z4 power rectifier. By July '34, Nela Park completed the first batch of all-metal tube protypes. Throughout the summer the top-secret negotiations between G.E. and RCA continued and were known only to the upper administrative echelon in each company. The proposed permanent component aspect of the new metal tubes must have been one of the stumbling blocks in these negotiations because, G.E. in September, decided to use terminal boards to accommodate the tube leads.

Finally, on October 9th, 1934, a contract between G.E. and RCA was signed. As a result of this RCA assumed the full responsibility for the manufacture of the first all-metal receiving tubes. Two days later at their Nela Park plant, G.E. released their plans, designs and samples of the all-metal tubes to Mr. J.C. Warner of RCA. On October 23rd, RCA announced its plan to base the metal tubes with their newly developed "octal base".

Plans were made immediately to equip "Factory #1" at Harrison, N.J. for the manufacture of the metal tubes. A section of the factory was boarded off and all activities carried out in utmost secrecy. RCA assigned men from their Engineering Research and Production Departments to this project together with advisors from G.E. By the end of November the machinery was setup and ready to operate. The first working samples were produced in early December. George "Wally" Crawford was in charge of the metal tube production. Fortunately, he kept a personal diary giving an almost daily history of the trials and initial successes encountered in the manufacture of the first production of metal tubes.

It is a fine tribute to the skill, patience and perservance of these men that were able to successfully meet their deadlines. By March '35, they were ready to send a large number of each tube types to the G.E. Receiver Plant in Bridgewater, Conn. for testing in their new receivers scheduled to be released in the fall.

On April 1st, 1935, G.E. and RCA unveiled their revolutionary all-metal receiving tube at the Annual I.R.E. Show in New York City. Their big secret had been apparently well kept. Although the 'grapevine' had leaked some vague rumors the vacuum tube and radio receiver manufacturers were totally unprepared for this bombshell. There was good reason for their panic since by this late date they were already committed to their fall line. The all-out publicity of the next few months was effective. By the end of June over twenty-five companies had joined the metal tube bandwagon and more were to follow. The announcement of the metal tube sparked reams of coverage in the literature of the day some of which was controversial or negative.

Many of the smaller manufacturing companies could not afford to compete in the metal tube market because of the expensive equipment required. During the course of the next year a number of these companies developed MG (Metal-Glass) tubes to solve their problems. These were tubular glass-shell tubes with close fitting aluminum shields crimped over the base and were painted black to resemble metal tubes. Although somewhat larger and different in shape, these tubes were widely accepted as 'metal tubes'.

After the fanfare that preceded the coming of the metal tubes their arrival in the early fall of '35 was anticlimatic. Nine tubes were released in the original set of tubes. By June of '36, more new tubes were added to this list. The metal tubes were here to stay. Improved manufacturing techniques permitted RCA to lower the selling price by an average of 20% at the end of the first year. As background for the next stage in the all metal tube history it is necessary to retrace our steps slightly.

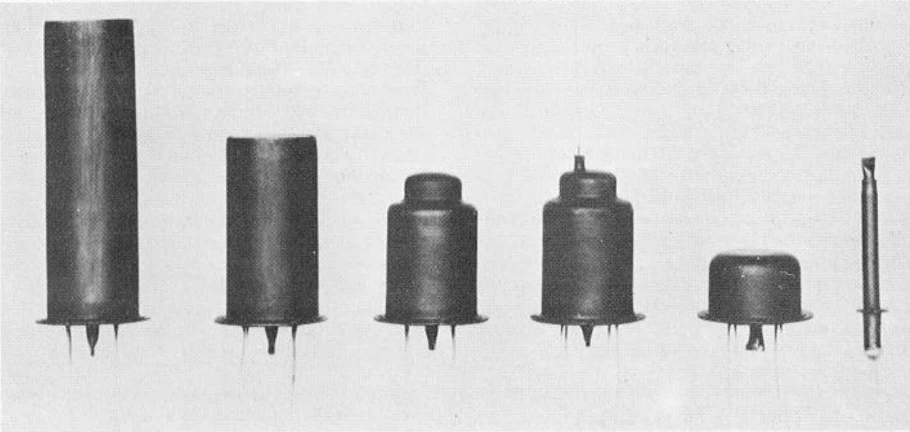
In late '33 or early '34, rumors reached RCA about the wonderful all-metal receiving tube that G.E. had developed. This caused some concern at RCA and set the wheels in motion for a total effort to develop a tube that could be competitive with the all-metal tube.

Early in '33, as a prelude to this work, Mr. George M. Rose of the Tube Research and Development Department, having just completed the developmental work on the 'Acron' tube with B. J. Thompson, decided to follow-up on an idea he had for improving the glass vacuum tube. He felt he could eliminate the 'Parallel-Flat-Press' method of exhaust tube and lead-wire sealing in the base of the glass tube by arranging the lead-wires in a circle with the exhaust tube at the center and pressing the glass 'button shape' at right angles to the lead-wires and exhaust tubes. This required only an eighth of an inch or so of glass to be in contact with each lead-wire in the seal permitting the lead-wires to be made considerably shorter. The circular arrangement of the wires also allowed for better spacing. Both of these improvements increased the high frequency capabilities and enabled the tube to be made much smaller. This later became known as the 'Glass-Button-Stem'.

In April of '33 he built a few samples to 'show the engineers it could be done'. The first samples used soft lead-wires. Shortly after this he made another batch of the 'glass-button-stems' using heavy gage wires so that the lead-wires might double as 'pins'. A few of these samples were exhausted after a small tubular glass shell had been sealed to the outer rim of the button-stem. These latter samples were the direct forerunner of the miniature glass tubes which would not make their appearance for another seven or eight years! The only difference between them was that the miniature tubes were top exhausted permitting the 'pin-ring' to be made slightly smaller. This idea was then filed for future use.

When work was started to develop a tube to compete with G. E.'s metal tube, the 'glass-button-stem' was resurrected. A small tube was designed to take advantage of the new stem and it was sealed with a tubular round-topped glass shell (less than an inch in diameter and two inches long). A special close fitting brass shield was made to cover the glass envelope and the tube was then fitted with a six-prong bakelite base.

To further capitalize on the compactness of the 'bullet tube', it was decided to design a special base. Mr. T. M. Schraeder developed the 'octal base' equipped with a special orientating key. The final version of the 'bullet tube' was fitted with a close-fitting aluminum shield crimped over the base. At the completion of this project, Mr. E. W. Ritter informed George Rose that he was satisfied that the bullet tube was the answer to G. E.'s metal tube and that it would be put into production if the need arose. At this time the rank and file were still unaware of the GE-RCA negotiations relative to the metal tube. Although the 'bullet tube' never went into production it is most significant. It was the first of the MG (Metal Glass) tubes. The first tube to use the 'glass button stem' and the first tube to use the 'octal base'. All of these points played an important roll in RCA's contributions to the all-metal tube.



All-metal tubes produced by G. E. at Nela Park, Cleveland in July, 1934 and turned over to RCA on October 9th, 1934.

In May '34 Wally Crawford, unaware of the existing GE-RCA negotiations, was sent to England to study the manufacturing processes involved in the production of the British Catkin tube. When he returned home in June he brought with him a large quantity of these tubes. The Engineering and Research Departments at Harrison made a thorough analysis of these tubes. In July, George Rose designed a special 'glass button stem' and succeeded in building an RCA-Catkin which was considerably smaller than the British version and which could be truly called an all-metal tube. Again, apparently nothing ever came of this investigation. However, the evidence seems to indicate that the idea for the perforated metal shell used by RCA in the original 5Z4's was copied directly from the design of the British Catkin tube.

In the late summer or early fall of '35 the 'glass button stem' was again recalled from obscurity. This time it was to come to the rescue of the metal tube. This recall came as a result of a cost-analysis meeting held at Harrison to examine the production costs of the metal tube. The relatively high cost of the metal tube header (the structural base of tube) was discussed at length. At this meeting George Rose indicated that he was reasonably certain that the 'glass button stem' could be adapted to the metal tube header. This would eliminate the need for the Fernico eyelets, glass beads, and copper rings then used to seal the lead-wire and result in a consequent reduction in cost. Mr. Rose was directed to investigate this matter immediately. In February '36, a patent was obtained for the application of the 'glass button stem' to the metal tube header. During the remainder of the year over one hundred thousand metal tubes with the new 'glass button stem' header were manufactured and subjected to rigorous laboratory and field tests. The test results were most successful and plans were made to place them in production. Messrs. J.C. and E.W. Ritter confided to George Rose that the 'glass button stem' had 'saved the metal tube' by reducing the header cost from 7-1/2 to 2-1/2 cents. The first tube with the new header was released in March 1937.

The advent of the single-ended tube late in '38 marked the last of the pre-WW II metal tube major changes. The "S" tube series enabled all the grid leads in multi-grid tubes to exit through the base of the tube. This was accomplished by special shielding and, except in very special cases, eliminated the need for top-grid cap tubes.

Only two of the conventional type metal tubes were registered by RCA during the War and another half-dozen after the War. During the late forties and throughout the fifties, the metal tubes were gradually replaced by the miniature tube family in new equipment. Starting in the late fifties and throughout the sixties, and early seventies at an increasing rate, the miniature tubes suffered the same fate at the hands of the transistor. The Compactron made its appearance in the early sixties and after putting up a valiant fight over a decade it also is fighting a losing battle with the transistor and the latest arrival on the scene -- the integrated circuit.

The rugged all-metal tube did not give up without a struggle. Shortly after WW II George Rose was given the task of developing an efficient UHF tube. The metal 'pencil' tube resulted from this development work. This pencil tube replaced the temperamental 'lighthouse' tube and enjoyed great popularity for a number of years particularly in aviation communication. In the mid-fifties when it was evident that the transistor was making headway, Mr. Rose was assigned the task of developing a tube to compete with the transistor. In 1960, the last and smallest of the all-metal receiving tubes appeared. Christened the "nuvistor", it was a direct descendant of the 'pencil' tube and was credited with saving the RCA Color TV receiver. Its days are also numbered and its demise will mark the end of an era in the history of radio communication.

NEXT ISSUE OF OTB:
All-metal tubes a Collector's item?
Identifying the original All-Metal receiving tubes. Dating pre-WW II metal tubes.

HOUCK AWARD

The Awards Committee wishes again to remind members that it is time for nominations for the 1976 Houck Awards. The primary award is for historical documentation in the field of radio communication. This can be in the form of written history or historical personages or events recorded on tape or other aural recordings. Special significance attached to history which but for the action of the author might have been lost.

A collectors award is given for collection and preservation of equipment or documents in AWA's field of interest which have special significance especially to historians of the future.

Nominations for both historical and collectors awards may be made by any AWA member. Such nominations should include as much information relating to the nominee as possible to aid the Awards Committee in making the recommendations. Nominations should be sent not later than May 15, 1976 to the Awards Chairman: Robert Morris RD #1, 60 Sunset Lake Rd., Sparta, New Jersey 07871

EDWIN HOWARD ARMSTRONG

Do you listen to one of the many FM stations on the nationwide Educational Network ? If so, you may have heard a program dedicated to Maj. Armstrong on his birthday (Dec. 18). A fair amount of the material for this nationwide broadcast was supplied by A.W.A.

9 Z N

Old time radio amateurs may be interested in knowing that R.H.G. Matthews, ex-9ZN is now retired and living in Mexico. Your Secretary has been corresponding with "Matty" off-and-on for several years. He is still very much interested in radio and regrets that being a U.S. citizen he cannot readily obtain an amateur license.