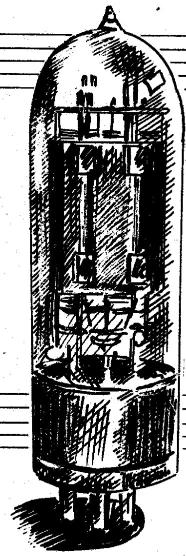
Special Feature



THE MAGIC LAMP

PETE ROBERTS

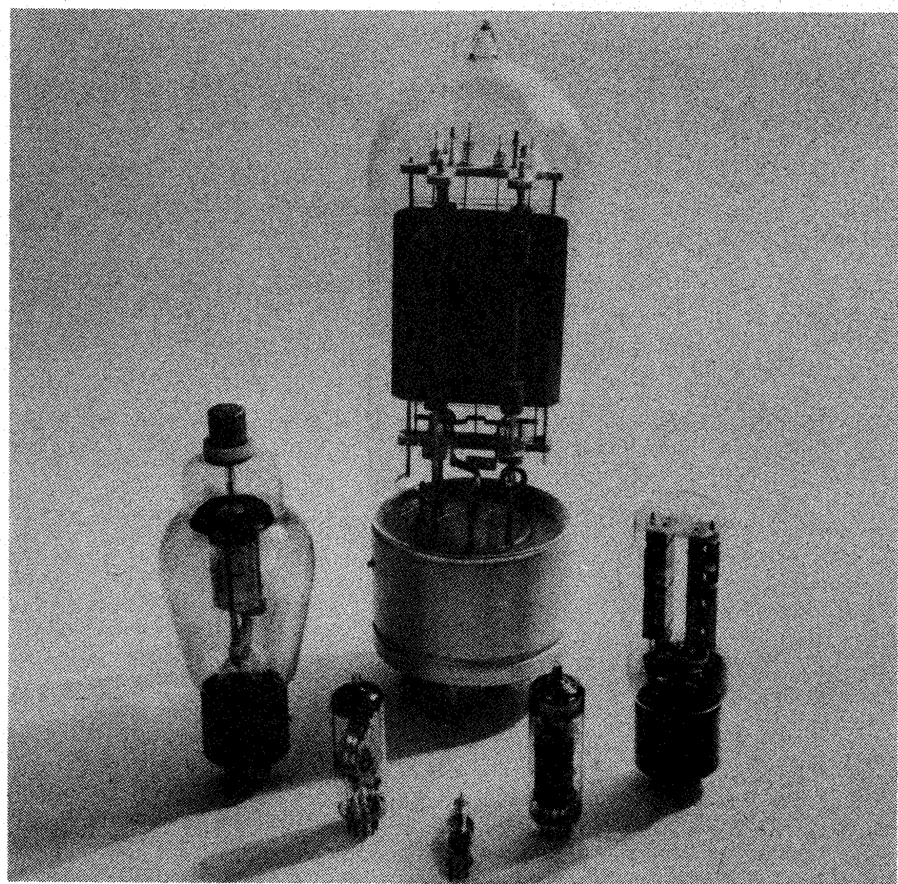
No, the title is not a misnomer. It describes the derivative of the domestic light bulb that started the entire field of electronics at the turn of the century; the thermionic valve. Far from being obsolete, valves are still extensively used in high power applications, particularly in professional audio power amplifiers and radio and TV broadcast transmitters.

EDISON

Valve action was accidentally discovered by Thomas Edison, the inventor of the electric lamp. Light bulbs of the time used a tungsten filament sealed into a highly evacuated bulb, and suffered premature blackening of the inside of the glass.

In an attempt to find the cause Edison sealed a small metal plate into the bulb near the lamp's filament and subsequently found that a current could be made to flow between filament and plate when the plate was made positive with respect to the filament, but not when the polarities were reversed. A phenomenon that came to be known as the "Edison Effect".

Soon after, J. A. Fleming developed the theory of thermionic emission, explaining the Edison Effect. Heating a conductor to a high temperature dislodges electrons from the surface. When surrounded by a vacuum these electrons can "boil off", forming a cloud of electrons. This cloud is known as the "space charge".



Examples of valves in order of size: one very large anonymous triode, a 866 mercury vapour rectifier, 5Z4 type full wave rectifier, an EL84 output pentode, a EM87 magic eye, and a EA50 submin. detector diode.

When a nearby plate is made positive, electrons from the fringes of the space charge are attracted across the intervening space, setting up a flow of current. Electrons lost from the space charge are replenished by fresh emission from the filament. Conversely a negatively charged plate repels electrons resulting in no current flow. This arrangement of filament and plate was called a "diode" — meaning two electrode. It was, and still is, used for demodulation of radio signals and power rectification. It was the one-way action of the diode that led to the generic term "valve".

TRIODE

Soon after the diode valve came the triode (three electrode), invented by Dr. Lee de Forest. He found that a metal mesh interposed between the filament and plate allowed control of the electron flow — charging the grid positively increased current flow, whilst a negative charge would reduce, or even cut off, the plate current, see Fig. 1. The important point to note is that a small change in grid voltage caused a large change in plate current, in other words amplification.

Triode valves could also be used as oscillators, allowing the generation of steady r.f. carriers, rather than bursts

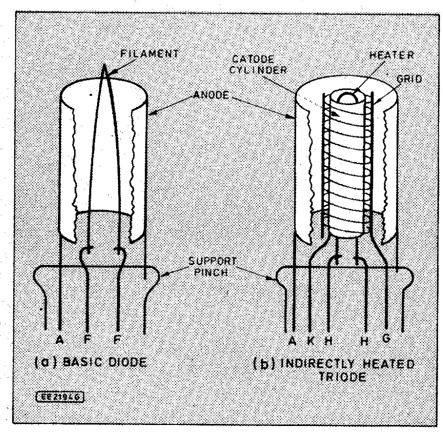


Fig. 1. Simplified diode and triode construction.

of r.f. energy produced by the spark transmitters in use at the time. In fact, the first broadcast station — 2LO — started only a few years after the invention of the triode.

Valves are voltage controlled devices. Also, in most cases they operate at fairly high voltages and correspondingly low currents compared with transistorised circuitry. Unlike transistors, valves can be made with any number of electrodes allowing some fairly unconventional circuits by today's standards.

HEATING

The circuit symbols for the diode and triode are shown in Fig.2. The plate is now known as the anode, with the filament becoming the cathode. In most cases filaments have given way to indirectly heated cathodes. Filament valves can only be used satisfactorily when a d.c. filament supply is available, i.e. from batteries. Where a.c. supplies are used a 100Hz hum is impressed upon any signal that the valve is handling.

The indirectly heated cathode comprises a tungsten cylinder into which an insulated tungsten heater is inserted. As hum in filament valves is caused by the filament temperature fluctuating in sympathy with the a.c voltage, the much larger thermal mass

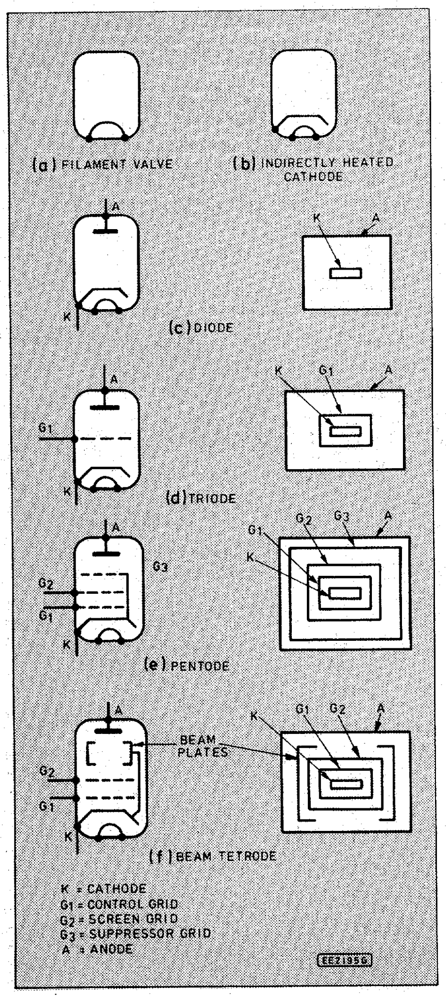


Fig. 2. Basic valve type with scematics.

of the indirectly heated arrangement eliminates the problem. As the cathode is also insulated from the heater, it is possible to design circuits where the cathode potential can be different from that of other valves in the equipment and independent of the (usually grounded) heater supply.

Valve manufacturers soon found that coating the cathode with a mixture of rare earth oxides (usually of strontium, caesium and calcium — each maker having his own secret recipe) allowed copious emission of electrons at a dull red heat and this, together with the larger surface area of the cylindrical cathode, allowed the design of valves capable of handling reasonable power.

DISADVANTAGES

It wasn't long before triodes were found to have certain disadvantages. When the grid is driven positive by the signal the anode current increases. With a resistive load (which is usual) this causes a drop in anode voltage, with a corresponding drop in anode current. Conversely during negative going portions of the signal, the anode current falls, increasing anode voltage which in turn tries to increase the anode current.

This is effectively a form of negative feedback which reduces the valve's gain (known as the amplification factor or μ). Also, at high frequencies, the fairly large parasitic capacity between anode and grid can cause circuit designers some headaches.

While these problems were overcome in multi-grid valves, of which more very shortly, modern triodes still give a good account of themselves, particularly in medium level audio amplifier circuits. Some of you may have come across the ECC83 double triode, a good example of modern valve design.

TETRODE

The next development was the tetrode valve, with two grids. The first (signal) grid is now called the control grid (G1) while the new grid (G2) is designated the screen. The screen grid is similar in construction to the control grid; a fairly tight spiral of fine wire. The screen is mounted concentrically, and close to, the control grid (Fig. 2). It is usually held at or close to the mean anode voltage.

The effect of the screen is to make the anode current almost completely independent of anode voltage, removing the degenerative feedback that triodes suffer from. The screen also breaks the capacitive coupling between the anode and control grid, simplifying the design of r.f. circuits. As usual though, Sod's law raised its head and curing one problem led to another.

SECONDARY EMISSION

In all valves, the electrons comprising the anode current don't just drift across from the cathode at a gentle walking pace. They whip across at speeds approaching that of light, literally smashing into the anode. Not surprisingly these high speed impacts knock electrons out of the anode; a phenomenon known as secondary emission.

At certain combinations of electrode voltages any increase in anode voltage caused more electrons to be knocked out of the anode than actually arrived from the cathode. Furthermore, most of these electrons were captured by the screen grid, resulting in a fall of anode current when the anode voltage increased. This, of course, is a negative resistance characteristic which in turn means instability. Tetrode valves would "take off" into oscillation quite happily with no warning. Obviously, something had to be done.

This problem was overcome in two ways. It was found that a third grid, with wide spacing, mounted near to the anode and maintained at cathode potential would repel any secondarily emitted electrons back to the anode, removing the negative resistance "kink".

This third grid, numbered G3, is known as the suppressor. The suppressor grid is usually connected to the cathode internally, although in some valves it is brought out to a separate pin. The new five electrode valve is called a pentode, and is the most commonly used type.

BEAMS AND MORE GRIDS

The other development used cathode ray tube technology where the tetrode electrode assembly was fitted with a pair of deflection plates, one each side of the screen grid (Fig.2). These plates, which are always connected to the cathode, form the electron stream into beams which repel any stray electrons back to the anode. The resulting valve type is known as a beam tetrode and finds service in high power audio work and r.f. power amplifiers in transmitters.

As a matter of interest, the two best known power output valves, the EL34 and KT88, are pentode and beam tetrode respectively.

There are valves made with even more grids for special applications; the heptode frequency changer springing to mind. Many modern valves are multiple types with two or more separate electrode assemblies in one bulb.

Some readers may also remember the magic eye, a cross between valve and CRT which indicates voltage levels by altering the area of the shadow on a fluorescent display. Magic eyes were extensively used as tuning indicators (by measuring the voltage on a receiver's a.g.c. line) and recording level indicators in tape recorders. An example of such a valve is the EM87.

NOMENCLATURE

As we hope to present the occasional valve project in the future, it would be a good idea to introduce the system of valve nomenclature. Like

Fig. 3. European Pro-Electron valve coding.

First letter — heater type.
D — 1.5 volt filament.
E — 6.3 volt heater, undefined current.
G — 5 volt heater.
P — 300mA heater, undefined voltage.
U — 100mA heater, undefined voltage.

Second and subsequent letters
A — Signal diode, single.
B — Signal diode, double.
C — Triode.
F — Pentode.
H — Heptode.
L — Power output, pentode or beam tetrode.
M — Magic eye voltage indicator.
Y — Single diode half wave power rectifier.
Z — Double diode full wave power rectifier.

Number
30+ series — International Octal base.
40+ series — B8A skirted base.
50+ & 60+ series — Miscellaneous bases and wired in.
80+ series — B9A miniature base.
90+ series — B7G miniature base.

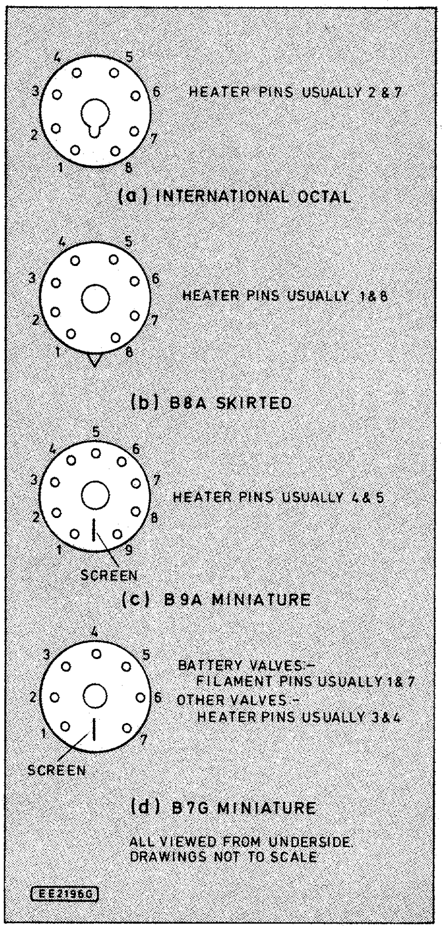


Fig. 4. Common valve bases.

American transistors, American valves have an arbitrary numbering system. Usually, but not always, the first part of the valve number (usually comprising both letters and numbers) indicates the filament or heater voltage. The European Pro-Electron system is far easier to understand with each valve number having two or more letters and a number.

Referring to Fig.3 the first letter indicates the heater voltage, or current where the valve heaters are designed to be used in a series heater chain. Note that the "D" coding signifies a filament valve usually designed for battery operation.

The next letter denotes the valve type; extra letters here represent a multiple valve. The number indicates the valve base used (see Fig. 4) as well as the "family" to which the valve belongs.

For example, an EF80 is a signal pentode with 6.3 volt heater and a B9A base. An ECL86 is a triode output pentode again with a 6.3 volt heater and B9A base.

CIRCUITS

A glance at Fig. 5 will emphasise the differences between valve and transistor circuits of similar function. Compare the values of resistors, capacitors and voltages between the two. Valves are high impedance devices and are voltage, not current controlled.

Valve circuit design is also simplified by the fact that characteristics vary very little between specimens of a given type. Also, valves do not need stabilising against temperature changes as do transistors, and they are fairly difficult to damage by accidental abuse.

Valves are being re-introduced into military equipment as they are immune to damage from electromagnetic pulse (EMP). Bear in mind that in the event of a nuclear war breaking out an airburst 100 miles high over the North Sea could destroy ALL semiconductor equipment in Britain and Western Europe! Valves are also making a comeback in hi-fi circles as valve power amplifiers "sound nicer", to put is crudely.

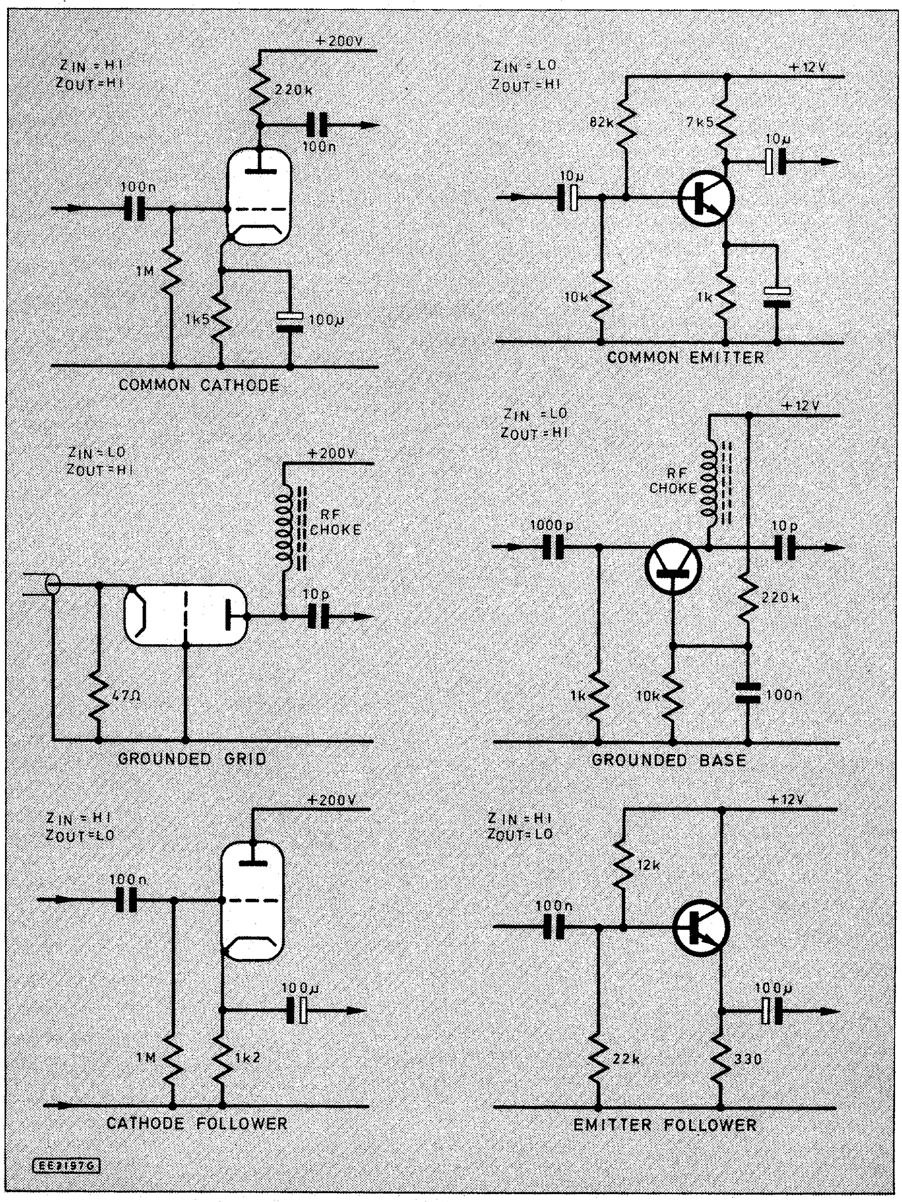


Fig. 5. Basic circuit comparison.

There are some really odd valves used at v.h.f. and microwave frequencies, these include the cavity magnetron (used in radar as well as the domestic microwave oven), klystrons, used as power amplifiers in u.h.f. TV transmitters, and travelling wave tubes, found in satellite transponder output stages. These devices are beyond the scope of this short article as their design and use owes more to a mixture of plumbing and magic rather than conventional design techniques!

Finally, should anyone still believe that valve technology belongs in the Dark Ages, bear in mind that almost every signal you pick up on the latest digitally synthesised radio, together with teletext and satellite TV, has originated in some form of thermionic valve.

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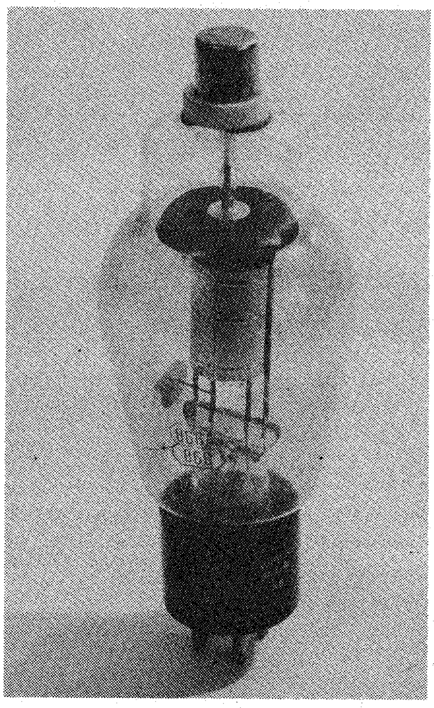
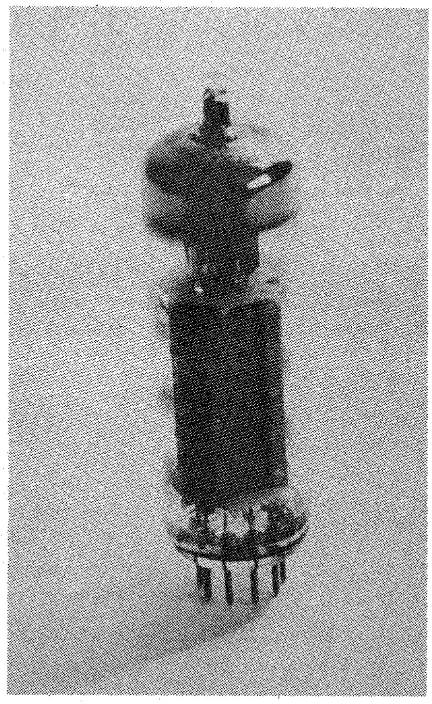


A 5Z4 type full wave rectifier.

No it isn't....



The EL84 a well known output pentode.