Tricks of the Trade

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In the last ToTT, Ewan Fenn G3RTF provided an overview of AM transmitter developments up to about 1995. Moving forward, it would now be sensible to investigate the systems in more detail. G3RTF touched on advances in valve technology and that is the best place to start as, without these improvements, transmitter efficiencies and advances could not have been expedited. The author is fortunate to have a copy of an article from the GEC Review **[1]** entitled *Power Tubes in Communications and Industry World-wide by Dr Peter Foreman, Ph.D., F.I.E.E.* Peter was a regular visitor to BBC/VoA Woofferton in the mid-1980's during the evaluation of EEV power tetrode equivalents to the Thomson-CSF TH-series of valves. Peter has been most gracious in permitting reproduction in *Signal* of sections from his article.

Is it a tube or a valve?

The American term 'tube' seems now to be the preferred term for the thermionic device, mainly because the word 'valve' is considered old-fashioned. However, both words are used in the following text because the application often dictates which term is easier to understand.

The start in 1947

English Electric Valves, EEV (known now as **e2v**) grew out of Marconi-Osram (M-OV) at what was then the Great Baddow Research Laboratories near Chelmsford. Production later moved to Waterhouse Lane in Chelmsford.

The construction of the valves changed radically over the first 50 years. Initially they were constructed by very skilled craftsmen who would make the piece parts from what could be difficult materials and improvise to achieve the desired result. Today, there is still considerable skill involved but the materials, equipment and techniques now enable assemblies to be made that could not have been contemplated previously.

Much of EEV's business was for the self-oscillating power tube market for industrial heating ovens but there will be those in VMARS who remember the GBR Rugby and GBZ Criggion VLF transmitters that were retro-fitted in the 1960s with the 200 kW BY1144L steam-cooled triodes after they had been first used in the 250 kW HF BD272 senders by Marconi Wireless Telegraph (MWT).

Construction and manufacture

The main features of a modern triode valve are:

- A mesh filament for ruggedness, uniform emission area and good geometry.
- A mesh grid which allows close spacings; resulting in good efficiency and uniform heat dissipation.
- A heavy-walled anode to give good thermal overload capacity.

Filament: The filament is made of carburized thoriated tungsten; carburization is carried out by heating to 2000°C in a suitable hydrocarbon atmosphere. It is this carburization process that lowers the electron emission temperature to a reasonable level but it also makes the valve fragile as it embrittles the tungsten in the same way that steel is embrittled by hardening. Ideally, the life of the valve is determined by the time taken to evaporate the carbon from the carbide layer; the valve is then said to be decarburized. As a result, the voltage applied across the filament is critical – a change of 5% can either halve or double its life.

Grid: The grid consists of a core of refractory wire, typically molybdenum or tungsten which is spot-welded at every intersection. This is done manually because it has proved difficult to automate the process. The wire is then coated with a mixture of zirconium carbide and platinum. These are sintered *in vaccuo* at high temperature to create a dark refractory coating with a high power dissipation capability. The platinum is necessary to prevent primary electron emission from the grid but can alloy with the core wire. This alloying normally occurs at *c.* 1100°C and the resulting distortion greatly limited the dissipation of the grids of earlier valves. The improved grid technology produced durable products capable of withstanding the significant overloads frequently experienced in the industrial market. In a self-oscillating circuit, the valve is biased by the grid current flowing through the grid resistor; should the grid start to emit electrons, then this bias is lost and the valve conducts the whole time with disastrous consequences. Typically, if the anode current trips do not act sufficiently quickly, the copper anode will melt. A further advantage of the modern grid is that it has low secondary emission, *i.e.* the majority of the electrons arriving at the grid are collected and do not result in more electrons being produced, so that the measured grid current is a good indicator of the power being dissipated. Older grid coatings tended to give low currents and so the grid loading would be underestimated, leading to mechanical distortion and short valve life. Secondary emission was used deliberately in transmitting tubes to reduce the drive power requirement but the operating conditions of these tubes were much more controlled. Hence, industrial tubes that are derived from transmitter types tend not to be successful. The transmitter grids were called 'white' grids while the coated grids described above was referred to as 'black' grids to reflect the difference in emissivity and, therefore, their power capability.

Anode: The anode is made of oxygen-free, high conductivity copper for its high electrical and thermal conductivity. The copper has to be oxygen-free to be brazed in a hydrogen atmosphere, otherwise it becomes porous and brittle as a consequence of the formation of steam pockets within the material. Hydrogen is employed to avoid the use of fluxes. The anode may be cooled in three ways; by air, water or steam. Air may be used, up to about 30 kW anode dissipation but, above this level, it becomes impractical. The main advantage of air is that the installation requires only electrical power so it is used where water is not available or for mobile units. Sometimes, the waste hot air is used for space-heating or as an additional resource in the process for which the valve is delivering power. Water cooling is used for the higher powers or where it is required in other processes. Steam (*via* latent heat of vaporisation) is popular with transmitter operators because it gives a quiet and fairly low maintenance system; indeed, the mechanics of it can be arranged so that the water/steam flows are by convection and gravity so pumps are not required (**Figure 1**). Small tubes can be convection/radiation cooled with a carbon anode that may run to red-heat within a glass envelope with possibly air draught cooling on to the glass. The industrial triode with the cooling system described above was the norm for the first 50 years; developments over that time have encompassed new materials, the most important being ceramic-to-metal seals. The earlier glass-to-metal seals were a major complexity and a disaster in the event of a water leak.

Applications

The high-power triodes and tetrodes embodying the features described above find application in the following:

- Broadcast transmitters
- Communication transmitters
- RF generators for industrial use including RF heating
- Magnetic resonance imaging scanners.

Broadcast transmitters

Mention has already been made of one of the largest transmitter triodes, the 200 kW BY1144L; they have average lives of over 20,000 hours and individual lives up to 80,000 hours .A pair in the RF stages was driven by a similar 100 kW pair in the penultimate stage. These valves were made under licence from Telefunken using their black grid process. In 1978, the BBC carried out a major refurbishment of their MF operations using Marconi B6034 50 kW Doherty transmitters. Within these were a pair of air-cooled 80 kW 4CX35000C tetrodes, which achieve lives of 50,000-60,000 hours. This valve is the EEV improved version of an American Eimac design employing now a mesh filament rather than the Eimac loop filament which was prone to mechanical distortion and consequent grid/filament contact and failure. EEV export sales to the USA increased when this tube was made available to users over there.

Mention was made earlier of air cooling versus steam cooling and it is interesting to note that the electrode structure inside the air-cooled 4CX35000C is identical to the structure inside the steam-cooled version, the 4CV100000, demonstrating that more efficient cooling can really alter the characteristics of exactly the same tube.

The CY1172 250 kW steam-cooled tetrode was a favourite amongst the high-power operators in the Arab States but, after Iraq invaded Kuwait, all 24 available valve sockets were lost and the replacements used a competitor's valve. However, the UK Foreign and Commonwealth Office (FCO) continued to use them in Cyprus and at Orfordness.

By 1979, newer designs of HF transmitters had been developed and the French manufacturer Thomson CSF (now known as Thales) supplied a 300 kW (TH537) and later a 500 kW (TH558) output tube. These are essentially water-cooled but use steam generated inside the jacket surrounding the anode in a 'Hypervapotron Cooling System'. The steam, after generation, is immediately condensed back to water within the tube. An EEV version (CW1603J2) of the TH537 (**Figure 2**) was developed and used in the Marconi HF senders from 1983. Ewan G3RTF commented on these tubes with their pyrolytic graphite grids and their ability to not shed wires and distort when hot and not suffer from secondary emission.

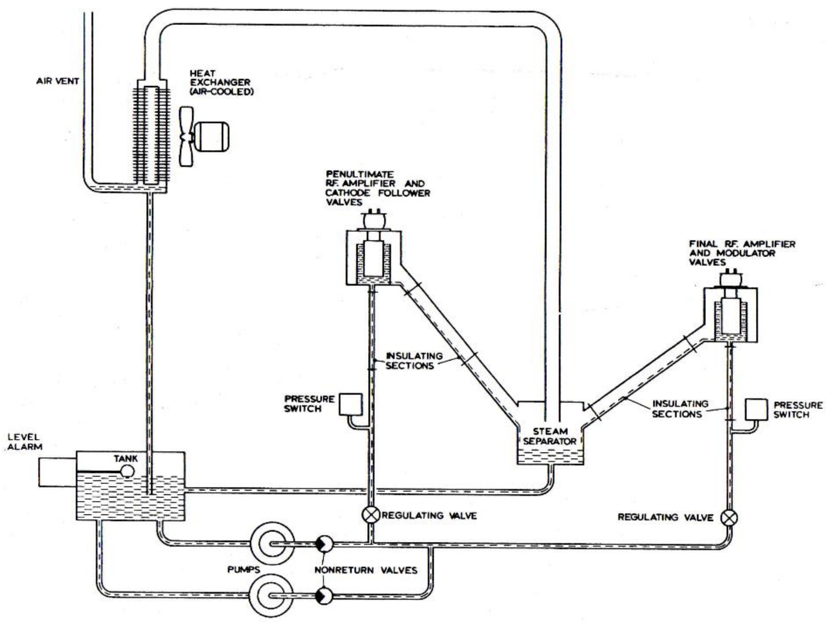

Figure 1. Schematic diagram of vapour cooling system as used on the BD272 transmitter

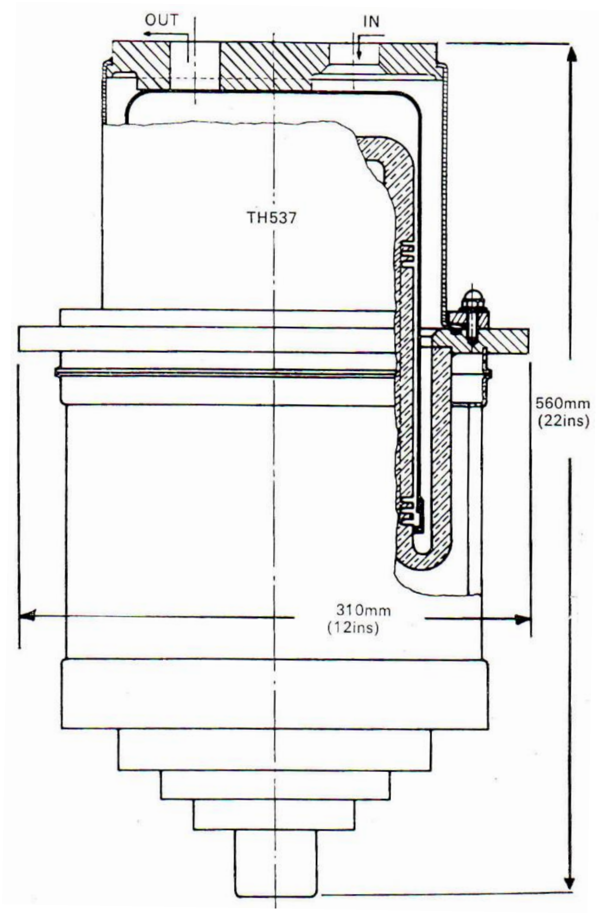

Figure 2. Outline of the TH537 tetrode

In addition to these output tubes for the 300 kW HF senders, EEV developed a water-cooled tetrode, a 4CW25000A, as the driver valve and one example at Woofferton was returned to them after over 200,000 hours in service, a not inconsiderable achievement.

As well as these tubes for HF, EEV made klystrons for UHF TV in the UK from the mid-1960s to the end of the analogue TV era in 2012. The pyrolytic grids are now in service in Inductive Output Tubes (IOT) that are the backbone of the present high-power digital TV services delivered terrestrially.

Communication transmitters

EEV tubes are used at HF for SSB links, *etc*, as well as for VLF service for both military and Government organisations.

Industrial use for metal hardening and tube welding

This application continues to be a major growth area for tube manufacturers with the ever-increasing use of industrial heating machines at higher and higher powers. The operating frequency is normally 200–500 kHz but it can extend to as high as 5 MHz. The power rating of the valves used ranges 10–80 kW; they are generally water-cooled as the induction process uses water anyway.

Industrial use for dielectric heating

The so-called ISM (Industry, Scientific and Medical) bands for these applications are 13, 27 and 40 MHz. At these frequencies the RF affects the bulk of the material by acting on its molecules rather than on the surface as in induction heating. In particular, water is greatly affected and turned into steam, so a major application is in drying. The great advantage over conventional drying is the penetration into the bulk of the material because dielectric materials become insulators as they dry, so conventional external heating over-dries the outside in order to dry the inside. This is important in the textile industry and is also significant in the tobacco, glass-fibre and paper industries.

For biscuits and breakfast cereals 50 kW water-cooled triodes are used in the plants for bulk-drying, sometimes preceded or followed by a conventional oven to make the product visually attractive.

RF is also useful for setting and curing materials such as glue and plastic foams. Very powerful 200–300 kW units are used to produce sectional buildings and plywood panels in multiple batches whilst low-power 8 kW systems are used for edge-gluing the hardwood strips on doors.

Plastic welding

For a material to be suitable for plastic welding it should be uniformly lossy and not rely on its water content to absorb the RF. The plastic to be welded is placed between platens. When the HF current heats the bulk, the areas in contact are welded but the heavy metal platens (which may be cooled) keep the remaining material from melting. The process is used for plastic car roof trims, car seat covers, plastic dinghies, rigid plastic canoes and covers for files and books. The powers used are 10–30 kW.

Semi-conductor manufacture

The 13.56 MHz ISM band is also employed by semi-conductor manufacturers for depositing an insulating thin film on the surface of a semiconductor substrate in a vacuum vessel at an atmosphere of reduced pressure. It is interesting to note here that the old thermionic technology is used in creating the new.

Magnetic resonance imaging scanners

An RF source is used in the MRI scanner. The power of the transmitter is variable, but high-end whole-body scanners may have a peak output power of up to 35 kW and be capable of sustaining average power of 1 kW. The frequencies in use are in the tens of MHz. e2v components are used in this equipment and are a yet another new use for thermionic devices.

Conclusion

Having covered the major transmitting tube improvements over the past 80 years or so, we have arrived at the point where these can be placed in what was effectively the final phase of the high-power broadcast transmitter development. How that impacts on the generation of AM, *etc.* will be explained in the next ToTT.

Reference

1. P Foreman. Power Tubes in Communications and Industry World-wide. *GEC Review* 1997, Vol 12(2).

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