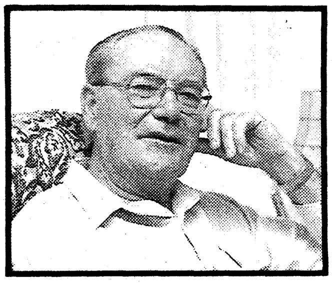


When I Think Back...

by Neville Williams

The rise and fall of thermionic valves or 'tubes' – 1

While radio/electronic technology has given birth to a bewildering array of components, it is probably true to say that, more than any other, thermionic valves provided the key to its early development. The story of valves remains a fascinating one, even though their circuit functions have now been largely taken over by solid-state devices.

As noted in the biography of Professor Sir Ambrose Fleming, thermionic valve technology dates back at least to Thomas Alva Edison, one of the pioneers of reticulated electric power and lighting.

In the early 1880s, worried by a cumulative blackening effect within the bulb of his carbon-filament lamps, Edison reasoned that minute, possibly charged, particles were being emitted from the incandescent filament.

To confirm this, he sealed into a number of lamps a small metal plate with a lead-out wire attached. Sure enough, when the lead-out wire was connected to the positive side of the DC filament supply through a galvanometer, it registered a flow of current through the circuit – therefore across the evacuated space inside the lamp. Curiously, when connected to the negative side of the supply, there was no current.

The exact nature of the particles and the polarity-sensitive current was not to be explained until April 1897, when Professor J.J. Thompson of Cambridge University propounded the *electron theory* to the Royal Institution, picking up in the process decades of scientific 'loose ends'.

In the meantime, in October 1884, Edison had taken out a patent to authenticate his discovery – suggesting, as a practical application, that his modified lamp, used in conjunction with a galvanometer, could serve as a means of monitoring the line voltage. It was a rather pointless application because, with Edison's DC mains, the same result could have been achieved by using a series resistor instead.

Ironically, John Howell in Edison's Harrison laboratory later realised that the modified lamp could also function as a rectifier, and his findings were written up in the *Transactions* of the AIEE (American Institute of Electrical Engineers). Used with AC mains, it would usefully have complemented the 1884 patent, but Edison did not support it with a further application – presumably because of his near-fanatical opposition to the alternating current systems being promoted by Nicola Tesla and George Westinghouse.

The Fleming diode

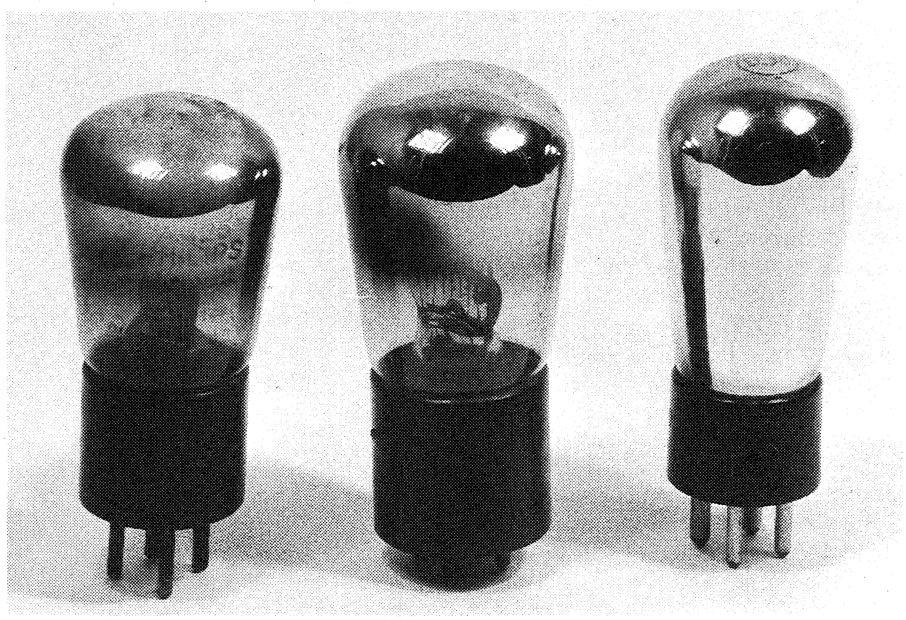
It was left to Ambrose Fleming (1849-1945) to exploit the rectifying capability of Edison's modified lamp by adapting it to serve as a rectifier – or detector – of incoming high frequency (Hertzian) signals in wireless telegraphy receivers. (See Fig.1 and panel).

Despite the original Edison patent, prior publication of the rectification effect by Howell, and a parallel application by Wehnelt a few months earlier, Fleming was granted a patent for his thermionic high frequency detector in November, 1904. It was assigned to British Marconi, however, under the terms of Fleming's contract as a paid consultant to that company.

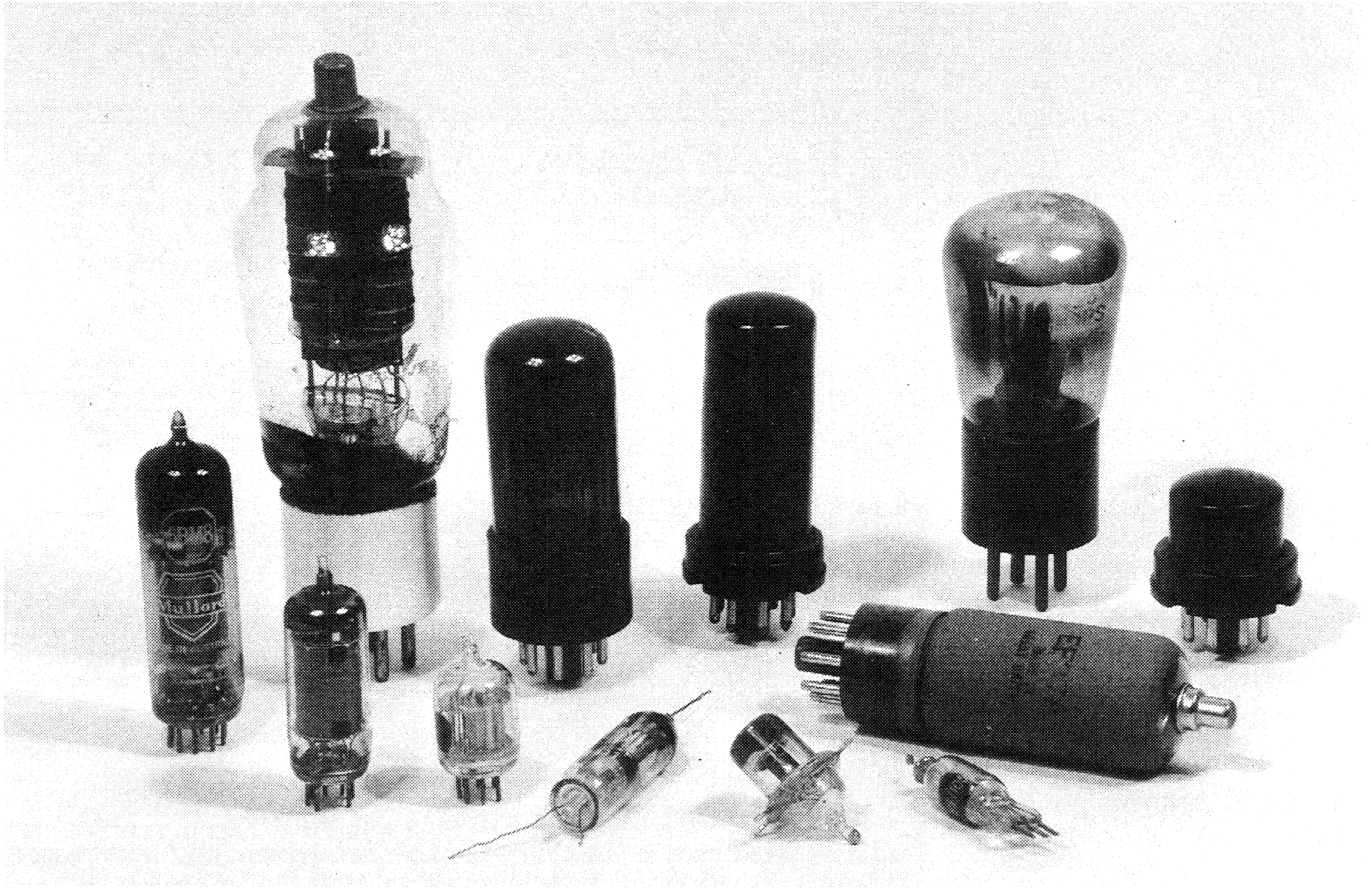
Fleming's detector went into production in 1907 – a device still based on lamp technology, but deliberately exploiting electron emission for the first time to process wireless/radio signals.

For his part in translating the 'Edison Effect' lamp into a thermionic diode detector, Fleming has been widely acclaimed as the 'father' of radio valves – 'tubes' or 'toobs' in American parlance – but not without argument by those who feel that some of the credit belongs to others, as mentioned.

Another body of opinion supports the subsequent contribution of the American pioneer Lee de Forest, who introduced the three-element 'Audion' (triode) in 1906. This ultimately enabled



Three early battery valves. Left, a Philips A425 triode (higher-mu version of the A409), with the 'B4' base; centre, a Condor PR41 triode with the 'UV' base; and right, an RCA type 30 with the 'UX' base.



Valves came in a wide variety of shapes and sizes, as this montage demonstrates. At rear left is a large 807 beam tetrode output valve for audio and HF use, while the tiny valves at front right were used at UHF.

the electronic processing of radio signals to take over from the inefficient and essentially mechanical methods to which it had previously been limited.

De Forest's 'Audion'

Triode valves and others which evolved from them could directly generate spectrally clean and continuous radio signals for wireless telegraphy, modulate them for wireless telephony, amplify them in receivers, detect or demodulate them and amplify them again at audio frequency, to achieve an adequate listening level from headphones or loudspeakers.

This, along with other roles in electronic test equipment, contributed enormously to an understanding of wireless/radio technology and set in train the electronic revolution that now permeates all facets of modern scientific research.

With hindsight, the triode was probably inevitable as a successor to Fleming's elementary diode, with parallel development by Lieben and Reisz in Vienna (ref. *Communication Through the Ages*, Alfred Still, Rinehart & Co Inc, 1946). Even so, de Forest is commonly credited with the step that opened the technological flood gates.

Typically, the October 1923 issue of the *Australasian Wireless Review* carried a front-cover picture of Dr Lee de Forest, by then Professor of Physics at Cambridge University, UK. The supporting article outlines his contribution to communication and broadcasting, adding: 'without Dr Lee de Forest's valve, all this would have been impossible and the world is very much enriched by his genius'.

In the article, as elsewhere, de Forest is quoted as claiming that his discovery

THE DIODE – rectifier or detector

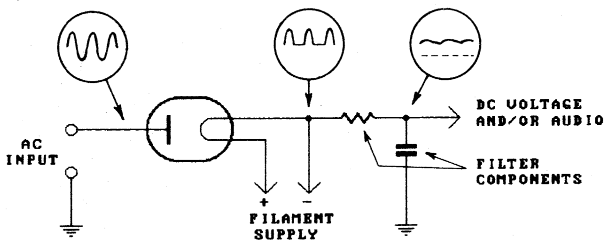


Fig.1: In modern terms – and very briefly – the action of a thermionic diode as a rectifier or detector can be explained as follows:

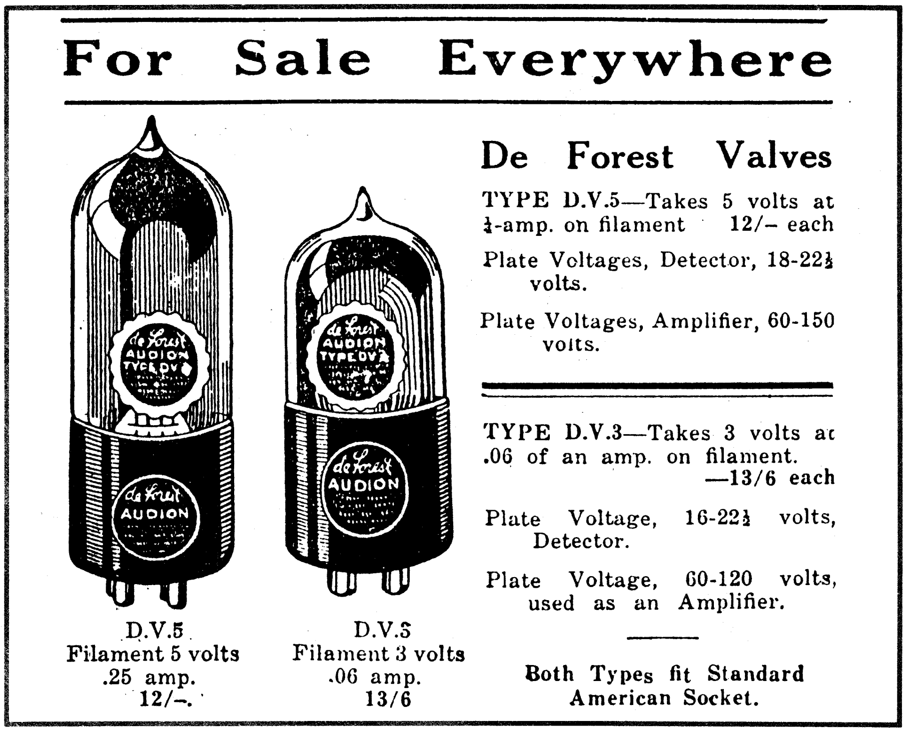
The AC voltage is typically fed to the plate (or anode) via an isolating transformer in the case of a mains voltage, or a high frequency transformer or capacitor in the case of a radio signal.

During each positive-going input half cycle, electrons are attracted away from the heated filament (or cathode) the cyclic loss of electrons appearing as a sequence of positive-going pulses at the cathode, as indicated.

These can be merged into a continuous DC voltage by the use of a series resistor (or inductor) and a storage capacitor serving as an electrical filter. Relatively large values are necessary to filter the pulses from 50Hz mains into pure DC to power electronic equipment.

Where a diode is being used to rectify (or demodulate or 'detect') amplitude modulated radio signals, the filter components are normally much smaller values, selected so that they will smooth out the pulses of the high frequency carrier without unduly attenuating the much lower frequency voice (or code) modulation.

In practical equipment, diode rectifier detector circuits are configured in a variety of ways for design convenience, but the basic principles remain as shown.



Also imported from the USA in 1927 were these genuine de Forest 'Audion' triodes, with differing filament ratings but both with the 'UV' base.

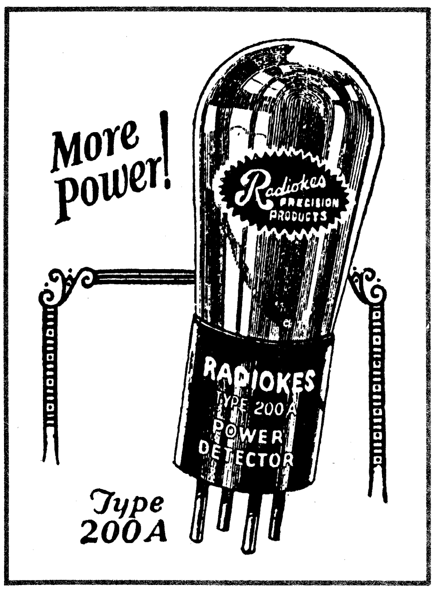
was the outcome of a personal quest for a radio detector unencumbered by patents. It had led him from independent research into gas-flame devices to the use of incandescent filaments, experiments with 'soft' (inert gas) Edison effect diodes with supplementary batteries, and ultimately to a lamp with two internal plates – one to collect emitted electrons and the other to inject the incoming wireless signals into the ionised gas environment.

From there it was but a short step to a 'grid' of wire to interpose the signals directly into the electron stream. All of this, it would appear, was in the context of seeking a patent-free detector, with little immediate appreciation of the Audion's potential as a signal generator or amplifier in its own right. (For a simple explanation of the triode valve see Fig.2 and the associated panel).

Patents & brands

Unfortunately for de Forest, his elaborate explanation of how he developed the Audion 'detector' did not impress the court. The Audion was held to be a significant improvement on the Fleming diode – a ruling that left de Forest and Fleming/Marconi with interlocking patent obligations.

With a high level of sensitivity about patent rights in the infant wireless communications industry, the end effect of the ruling was to inhibit production and research into thermionic devices, both by the patent holders and by independent companies that might otherwise have become involved under a less ambiguous licence situation.



Radiokes claimed that its type 200A detector offered 'more power', in this advertisement from the July 29, 1927 issue of 'Wireless Weekly'. It would have been imported, probably from the USA.

With the outbreak of war in 1914, the critical need for improved communications gradually overtook patent restrictions to the point where US authorities legislated immunity from patent obligations for any indigenous manufacturer able and willing to produce 'tubes' for military use. Apart from encouraging new manufacturing techniques, the invitation made it necessary to standardise tube types and specifications needed for military and other essential equipment.

After the war (1919) the US government was keen to see the American radio industry retained as an independendent, self-sufficient entity, with radio tube manufacture as a core activity.

With this in view and with Government blessing, RCA (Radio Corporation of America) was formed to take over the interests of the Marconi Wireless Telegraph Co of America. Twelve months later, in July 1920, RCA concluded a landmark cross-licensing agreement with AT&T (who had earlier acquired de Forest's patents), GE, and subsequently Westinghouse, setting the scene for the production of standardised American radio tubes by the above companies and by independents under licence. The agreement had important ramifications worldwide, and certainly for Australia, right up until the end of the valve era.

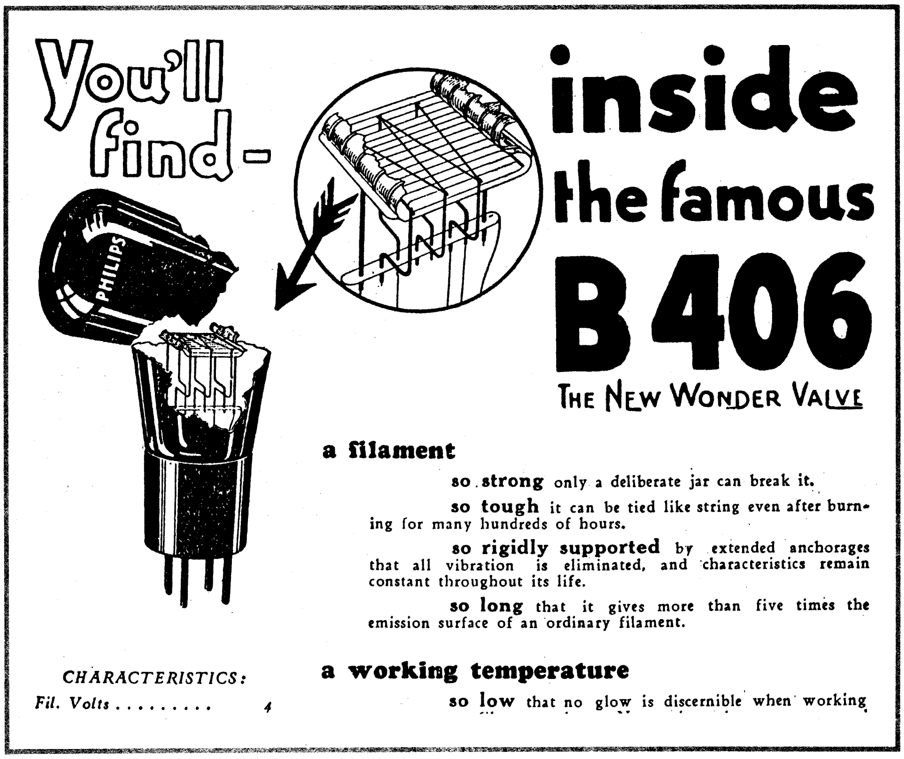
In Britain

The British valve industry, on the other hand, was far less structured. This resulted in a confusing proliferation of valve types, in sharp contrast to the American marketing scene.

Fleming's thermionic detectors – arguably the first-ever wireless valves – were assembled by the Edison and Swan Electric Light Company (Ediswan). During the war and into the 1920's, other companies got into the act, all producing valves reflecting their independently evolving technology – with different design, different type numbers and different specifications.

In the late 1920's Ediswan merged with BTH and Metropolitan Vickers, and valves which had been marketed as 'Ediswan', 'BTH' and 'Cosmos' were phased out, rationalised and relaunched under the one brand name: 'Mazda'.

While the objective was praiseworthy, it was compromised by a dogged determination to establish and maintain a standard range that would be uniquely British. One anomalous result was the adoption by Mazda in the mid 1930's of an octal (8-pin) base that looked identical at first glance to the American octal, but with dimensions sufficiently different to render them incompatible. In the



Philips' were rather proud of their B406 Dutch-made 'wonder valve' in 1927. Note the internal construction, and the modest amplification factor. Like the A425 it used the European 'B4' base.

marketplace, it was interpreted as yet another example of British 'bloody-mindedness'.

The end result was that the British valve market finished up as confused as ever, with the uniquely British Mazda range, Mullard with overseas connections but mainly following the lead of Philips in Eindhoven, and the STC/IT&T group making and marketing American types under the 'Brimar' label. Over and above these were a dozen or more independents still doing their own thing, plus an assortment of other brands and types coming in from across the Channel.

It may well be that other nations had similar problems, but Australian enthusiasts were conscious of the British and American scene because, up until the early 1930's, most of our valves came from those two sources.

If I appear to be more than usually conscious of the diversity of valve types, it is not without reason.

Back in the mid 1930's, one of my jobs in the Applications section of the Amalgamated Wireless Valve Co was to keep track of every valve type mentioned in technical literature, irrespective of age, application or country of origin. The Company reasoned that, so informed, they would be in a better position to help customers contrive substitutes for unfamiliar valves in overseas equipment.

In this computer age, the task would be reasonably manageable with a PC and an ordinary database program. But in the 1930's, it required manual entries in a jumbo-size loose-leaf journal, and was one of the most tedious tasks one could possibly inherit. But I'm getting ahead of myself.

Personal memories

As a lad in the country, during the 1920's, the only wireless receivers I saw were traditional battery sets, assembled on a baseboard and black bakelite panel, and housed in a polished wooden box with a hinged top lid.

Lift the lid and you'd be faced with a couple of tuning condensers (capacitors), tuning coils (if not mounted on the front panel), a couple of interstage audio transformers and two or three rheostats (variable resistors) controlling the filament voltages. More importantly, there'd be the *valves*, always the glamour components: three in a small

THE TRIODE – signal amplifier

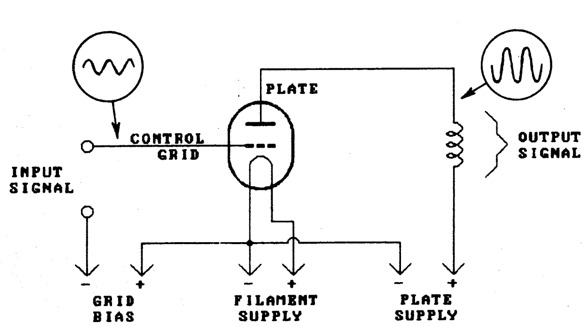


FIG.2

Fig.2: Triodes require an appropriate filament supply voltage, a considerably higher DC ('HT') voltage for the plate, and provision to maintain the grid at a suitably small negative potential (or 'bias') relative to the filament. The voltages vary with the valve type and the desired operating conditions, and are normally specified in valve makers' manuals and charts.

Incoming low or high frequency signals, applied to the grid via an input transformer or coupling capacitor, are superimposed on the bias voltage, causing it to vary in cyclic fashion around its mean value.

Typically, a positive-going half-cycle of signal reduces the negative bias, allowing more electrons through to the plate. The extra plate current through the output load – a transformer or resistor – results in a downward half-cycle in plate voltage.

Negative-going signal excursions produce exactly the reverse effect.

Assuming that the circuit is operating as normal, the overall output waveform will be a replica of the input, but much larger in amplitude and effective power level. In short, the input signal will have been *amplified* without significant waveform distortion, allowing it more effectively to drive a loudspeaker, or excite an aerial system in the case of a transmitter.

As mentioned in the text, triode valves can also be used to sustain oscillation in resonant circuits, thereby generating relatively pure signals over a wide range of audio and radio frequencies.

set, four in the average family model and five or more where the owners could afford that many and the cost of the batteries to run them.

The most impressive valves at the time were those with clear glass envelopes, gleaming metallic electrodes and a filament that lit up like a torch globe. They certainly looked the part, but they also consumed a lot of energy from the 'A' (filament) battery, necessitating frequent visits to the local garage to have it re-charged.

I was to learn later than those early 'bright emitter' valves used pure tungsten filaments, which had to be run at white heat to ensure sufficient electron emission. They needed 4 to 5 watts of power to reach the required temperature, and were only able to produce an emission current of around 1 milliamp per watt – enough for detectors and general purpose amplifiers, but insufficient for valves called upon to drive a loudspeaker. So-called 'power' valves required an even larger and hungrier filament.

Then, in 1923, a fortuitous production error at the American GE factory resulted in a batch of general-purpose triodes being fitted with a filament fashioned from the tungsten normally used for lamp making – which contained a small quantity of 'thoria', a slightly radioactive rare earth. To everyone's surprise, the flawed tubes exhibited a marked increase in emission efficiency.

Subsequent investigation showed that 'thoriated' tungsten had a potential emission efficiency of 25mA per watt – but, against that, it was extremely sensitive to the presence of residual oxygen in the envelope. Before it could be used in valves, GE had to include a pellet of magnesium to serve as a 'getter' to absorb stray oxygen molecules. When the pellet was vapourised during final evacuation, a thin layer of metallic magnesium condensed on the inner surface of the bulb, giving these valves a characteristic mirror-like appearance.

Lower drain

In Australia, the best known type using a thoriated tungsten filament was the 201-A, a general-purpose triode made by several American manufacturers and fitted with a filament rated at 5V/0.25A – intended to operate from a 6-volt storage battery via a filament rheostat, as mentioned earlier.

The 201-A was a plug-in replacement for the earlier bright emitter type 201, but while it offered lower filament drain, it was still far from economical, with four valves adding up to a total of 1 amp.

As it happened, further research established that a dramatically greater emission efficiency of around 250mA per watt could be achieved by using a light gauge filament, coated with certain alkaline earth compounds. This kind of filament could operate, in practice, at a dull red heat, often being barely visible in dim light through the getter-coated envelope.

British and continental manufacturers grabbed a large slice of the Australian market during the 1920's with a steady stream of the new 'dull emitter' valves, notable for their low filament drain but more vulnerable than their earlier and more rugged American counterparts. The very frail filaments did not take kindly to vibration and jarring, or to inadvertent voltage overload.

Microphonic effects were also commonplace, with receivers emitting howling noises when vibration caused relative movement between the filament and the grid. This, in turn, gave rise to anti-noise sockets, using rubber suspension or springs to cushion the valve concerned – most frequently the detector.

Even so, I still look back with considerable respect on valves like the Philips A409 general purpose triode, A415 high-gain detector and contemporary types from Mullard, on which many Australian enthusiasts came to rely.

Advertising hype

Throughout the 1920's, radio magazines carried valve advertisements exploiting every conceivable marketing 'angle'.

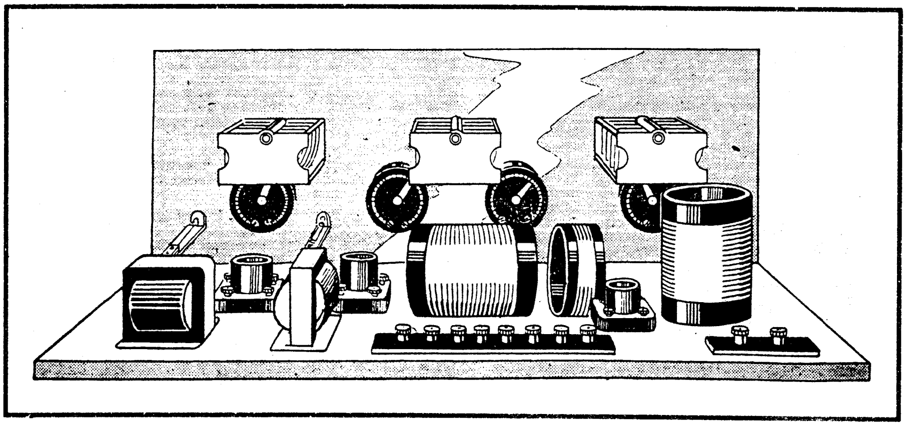
'Sweet', 'quiet', 'noise-free', 'non-microphonic', 'long-distance' reception were par for the course. Cossor got it all together in a 1923 *Wireless World*, describing its new red-top P-2 triode as "Like a magic carpet – transports you everywhere". "It will enable you to pick up stations", they said, "which were previously out of your reach. Your set will be more stable and less liable to self-oscillation, and you will notice a marked absence of distortion and microphonic noises".

GWI, 'the valve with a silver lining', featured a 'non-vibrating anode and grid'. Lustrolux boasted their non-dependence on filament rheostats, emphasising 'simplicity of control'. Clearatron offered the presumed attraction of American design coupled with fabrication in a British factory.

Louden boasted an economical filament which also 'enjoys long life because the harmful charges which would otherwise continually bombard it are forced through the spiral anode out of harm's way'. That sounds like a most desirable attribute, except that, even now, I haven't the faintest idea of what they were talking about!

Back in the country, my father and others of his generation would study such advertisements and wonder how much better their wireless sets might be, if they could be re-equipped with valves like that. Just occasionally, someone would save up enough to indulge their fancy, triggering a round of 'horse-trading' for the ones that were no longer required.

Swapping valves around in those days was easy enough, provided one didn't overlook the filament voltage. Most sets used tubular bakelite bayonet sockets, with standard filament, grid and plate connections and one could plug in almost any 4-pin valve with a UV or UX base. By the time you'd done that a few times you were accepted as an experimenter!



As this rear-view sketch of the 'Marco Four' receiver of 1927 shows, there was little to early sets apart from coils, tuning capacitors, transformer and valves – here shown missing from their sockets.