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Birth of the Thermionic Valve

Dr Bruce Taylor HB9ANY relates how chance, ingenuity and conflict created the technology that dominated radio communication for half a century.

In the archives of Marconi's Wireless Telegraph Company for November 1904, there is a handwritten letter that concludes: *"I have not mentioned this to anyone yet, as it may become useful".* The letter is signed by the English scientist **John Ambrose Fleming** and it describes how he had found a method of detecting oscillatory electrical currents in an antenna using a thermionic valve.

"It may become useful" was perhaps the understatement of the century!

While the saga of the thermionic valve had a large cast, the two principal roles were initially played by Fleming and the American experimenter **Lee de Forest**. The characters of these two men could hardly have been more different. De Forest was an enterprising inventor but a flamboyant showman unashamedly motivated by a desire for fame, fortune and a luxurious life style. He was lucky in his discoveries, but not in his private life or his somewhat unethical business practices, and he died in 1961 without achieving the financial success of which he dreamed. Fleming, on the other hand, was the careful archetypal physicist, methodical in his investigations and motivated to earn the esteem and recognition of his peers for advancing scientific knowledge. He achieved his aim, and was knighted in 1929, but he wasn't interested in vigorously exploiting his discoveries and left **Marconi** and others to profit from their commercialisation.

The Edison Effect

The story of the invention that would eventually revolutionise radio had begun 13 years before Marconi came to Britain to seek support for his wireless experiments. For in 1883 **Thomas Edison** fortuitously created a diode valve, by inserting a metal probe into one of his carbon filament incandescent lamps with a view to understanding why the interior of the glass envelope darkened with use. He then discovered that when this anode was charged positively relative to the filament, a current flowed through the device but there was no conduction when the polarity was reversed. In 1884 he patented the device as a means for controlling mains voltage but made no mention of its rectifying properties, for he was promoting DC rather than AC power generation.

The same year, **William Preece** of the British Post Office visited Edison, who gave him a few of these modified lamps to investigate what Preece then named the 'Edison effect'. After experimenting with these samples, he passed them on to Fleming, at that time a consultant to the London Edison Company, who studied the phenomenon further using special lamps that he had made in the Edison-Swan factory in Newcastle. When he published his main results in 1896, Fleming explicitly described the rectification property but made no suggestions whatever about possible applications, and the lamps gathered dust for nine years before he thought of using them again.

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A 1915 advertisement by Elmer Cunningham explains that, unlike the de Forest Audion, his AudioTron can be bought alone.

The Fleming Diode

In 1899, Fleming had been appointed scientific advisor to Marconi and became responsible for the design of part of the high power Poldhu spark transmitter that succeeded in bridging the Atlantic Ocean. But relations between the two men became somewhat strained over the credit for that accomplishment and Fleming's disastrous tuning demonstration at the Royal Institution that was successfully interfered with by **Nevil Maskelyne** [1], so his contract was terminated in December 1903.

Since the relationship with Marconi was important for his nascent wireless laboratory at University College London (UCL), Fleming sought to restore the link by pursuing the development of practical devices that could be useful for wireless telegraphy, such as a novel wavemeter. In 1904, he turned his

attention to the problem of developing an efficient receiving detector. The previous year, an electrolytic detector had been patented by the Canadian-born inventor **Reginald Fessenden** [2]. This was more sensitive than **Branly's** coherer or Marconi's magnetic detector, and unlike these bistable devices it had an analogue output that could be used for signal strength measurement, or even for the demodulation of speech.

It was when looking for an equivalent detector that didn't infringe Fessenden's patent that Fleming had a *"sudden very happy thought"*. Remembering Edison's lamps, he retrieved one from a cabinet in his lab in UCL, tried it in a simple receiving circuit, and was delighted to find that it worked well as a radio frequency detector. Fleming lost no time in filing a provisional patent application on November 16th 1904 and it was granted on September 21st 1905. Although he came close, Fleming failed to take the next step of introducing a control grid between the filament and anode in his valve, and wrote later, *"Sad to say, it did not occur to me…"*.

From 1905, he had the Edison-Swan lamp works make him more experimental diode valves, some of which had low-voltage filaments surrounded by a cylindrical anode, and these were sent to Poldhu for service trials. Although Marconi produced several receivers using later versions of them, and the *Titanic* was equipped with such a set as well as a standard 'maggie' magnetic detector, carborundum crystal detectors were initially more popular with radio amateurs because they were much cheaper and more sensitive, had a longer life and didn't require expensive batteries. The diode valve didn't become the standard radio detector until multi-electrode valves were available that allowed received signals to be amplified to a level that used the more linear part of the diode's characteristic, beyond the knee of the curve. The common-cathode double-diode triode, in which the second diode was used as a rectifier for automatic gain control, then became ubiquitous in radio receivers for many years.

Experimental diode valve used by Ambrose Fleming for early experiments, and in 1904 for radio signal detection.

De Forest

Over in New York, Lee de Forest had been attempting to establish a viable wireless business with little success. One of his first endeavours had been to compete with Marconi in reporting the 1901 international yacht races. Unfortunately, at this time neither inventor had radio apparatus that could be selectively tuned, so the rival transmissions interfered with each other and the result was a dismal failure for both.

De Forest had seen Fessenden's electrolytic detector and devised one that worked on the same principle, without being too obviously an imitation. But after he sold many of them to the US Navy, Fessenden sued him successfully for patent infringement. This led to the demise of his company, which had in any case been surviving Ponzi-style by selling shares rather than equipment or services. A warrant was issued for de Forest's arrest and he narrowly escaped incarceration.

In his search for a replacement detector de Forest read the European scientific literature, and it seems very likely that he was influenced by Fleming's publications. But to Fleming's chagrin, de Forest always carefully avoided any mention of him in later presentations of his work, although he acknowledged other researchers in related fields [3]. Instead, he asserted that his own path towards the invention of the diode valve was an entirely independent and rather curious one.

The Flame Detector

When experimenting in his basement laboratory, de Forest had noticed that when he keyed his spark transmitter, the intensity of the Welsbach gaslight in the room changed, and he believed that he had discovered a new detector of wireless waves. This interpretation proved wrong, for hand clapping produced the same ef-

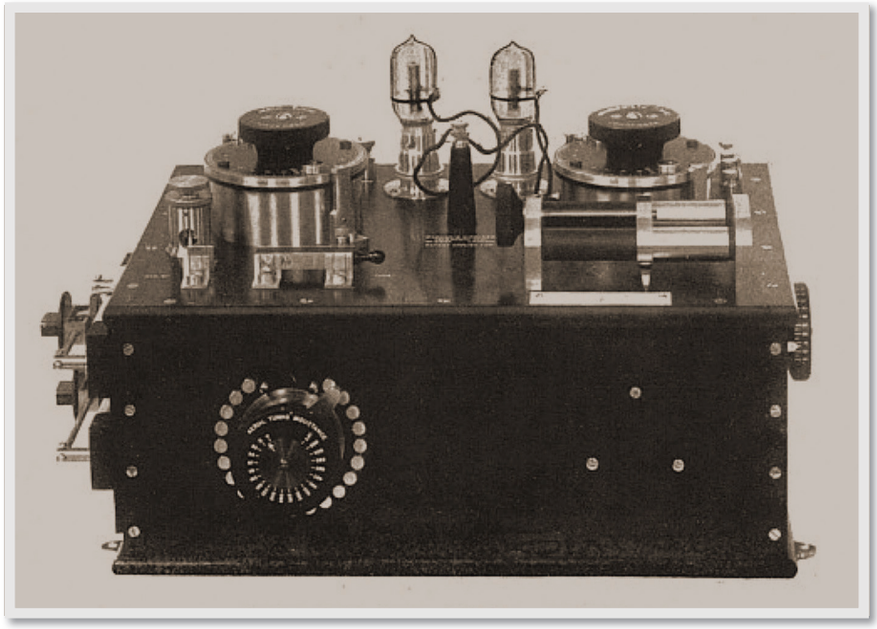
fect, revealing that it was the sound of the sparks, not electromagnetic radiation, that was affecting the flame. But the observation set him on a track of experimenting with ionised gases, first in an open flame and then in a closed envelope. Although it was never used outside the laboratory, in 1905 he patented a device in which antenna and ground wires were connected to platinum electrodes in the flame of a Bunsen burner, and changes in the conductivity of the flame were picked up by a secondary circuit with a battery and earpiece. De Forest claimed that it was a logical step from this setup to a diode valve, in which a heated filament replaced the Bunsen flame and the ionised gas was contained within a glass envelope.

This somewhat contrived reasoning was crucial for de Forest's claim of priority in litigation over the invention of the thermionic valve. His patent application for the flame detector was signed 12 days before Fleming filed his patent for the diode. If the flame detector could be construed as embodying the basic principle of the valve, he held a parent patent that pre-empted Fleming's detector, even though it was physically quite different.

De Forest made the first public announcement of his two-electrode 'Audion' on October 26th 1906 but very few were ever sold. The main difference from Fleming's valve was that its glass bulb was only partially evacuated, because de Forest believed, incorrectly, that residual gas in the envelope was essential for the device to work and that the purpose of the filament was not to liberate free electrons but to heat the gas to ionise it. Just a few weeks later he invented the revolutionary three-electrode structure incorporating a control grid and on December 2nd 1906 he had breakfast with his patent lawyer and sketched a diagram of it on the back of the menu card. The pivotal patent application was filed on January 29th 1907 and subsequently the Audion name was used for that triode device instead of the diode.

The Triode

Considering the huge technological impact that the thermionic valve would have in due course, the interest in the triode during its early years was surprisingly lukewarm. The Audions were expensive, non-uniform and erratic in performance, and had a short life. **H W McCandless**, the manufacturer, preferred to make bulbs for Christmas trees, since they were simpler and resulted in fewer customer complaints than valves. From September 1909 Audions were sold to radio amateurs but only as part of an expensive complete detector instrument. The Audions contained two filaments, the second of which could be brought into service after the first burned out, which was usually after 35-100 hours. To obtain a replacement valve, at least the grid and anode from the broken one had to be returned to the supplier. So, when double-triodes were put on the market, it was common practice to return one set of electrodes and sell the second set to another amateur, so that he could use it to purchase a valve for himself, without the unwanted instrument.

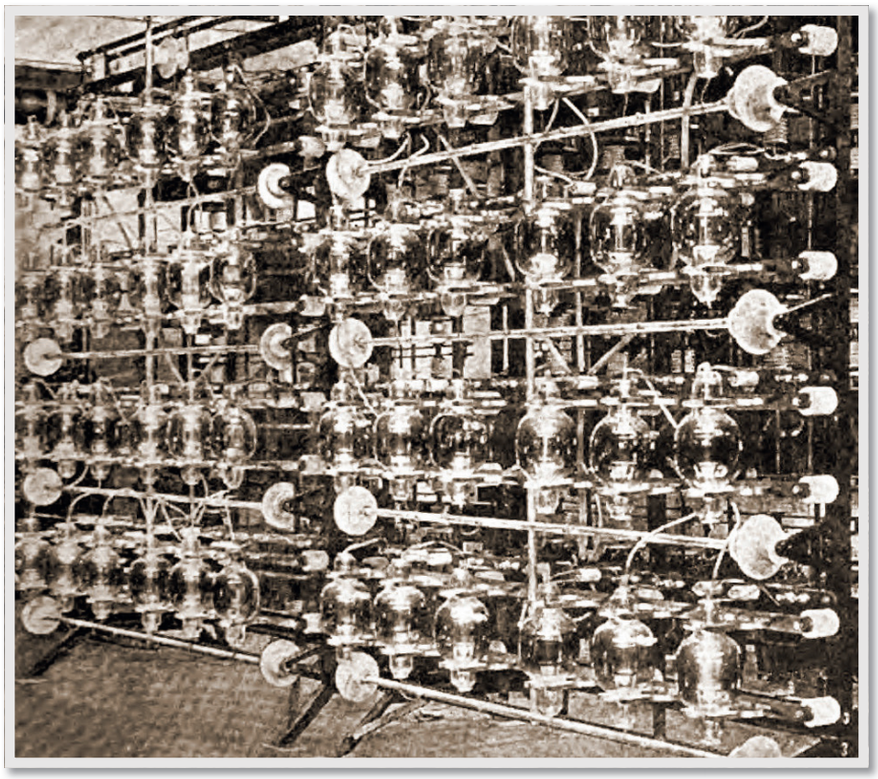


Marconi receiver with two Fleming valves (one spare). The 'short wave' model covered 250 - 750m.

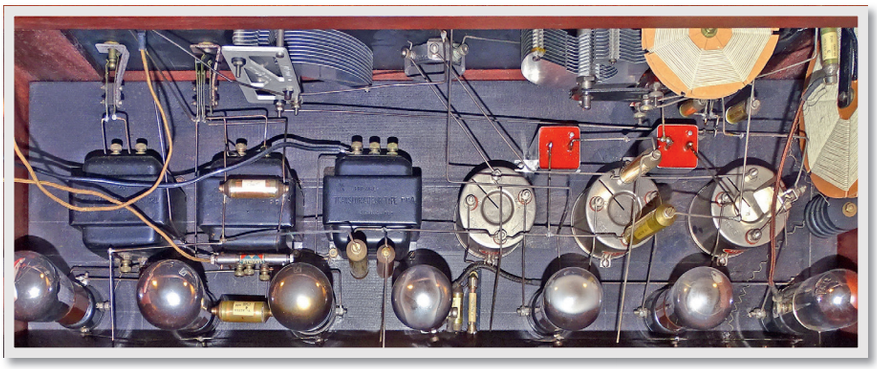
For about five years little was done to improve the triode valve, and the invention wasn't recognised as the forerunner of a new technology that would influence every sphere of human activity from entertainment, education and medicine to industry, commerce and world war. Despite the claims in his patent, de Forest was unable to obtain satisfactory amplification with the Audion, and it was just used as a detector. In 1912 he and his associates were charged with defrauding the public by selling shares in a company whose only assets were patents for *"a strange device called an Audion, which had proven to be worthless and was not even a good lamp"*.

But while he was free on bail, de Forest showed the Audion to AT&T, which had a need for an amplifier for long-distance telephone circuits. When the company's engineers realised that the valve could potentially be developed to do this job, they feigned little interest and had a lawyer acquire the wire telephone rights anonymously for $50,000, assuring de Forest that the purchaser was not AT&T. De Forest was furious when about six weeks later he learned of the subterfuge, and that the company would have been prepared to pay ten times that sum [4].

When AT&T began to see that the Audion could have applications in other fields, such as radiotelephony, they progressively acquired further rights from de Forest, and started to allocate substantial resources to the understanding and development of thermionic valves. AT&T was not the only major corporation developing an interest in valves. In 1913, an Audion was acquired by the research laboratory of General Electric, where **Irving Langmuir**, who was familiar with the theory of electron emission developed by the British physicist **Owen Richardson**, began a more scientific study of the valve and recognised that the main problem with the device was its low vacuum. Soon both GE and AT&T had made high vacuum triodes that were much more stable and sensitive than the de Forest Audion and didn't have its troublesome hysteresis characteristic. In 1915, AT&T demonstrated their progress by transmitting speech and music from Arlington, Virginia, to Paris, using a transmitter with a final amplifier of 500 15W triodes.



In 1921 the 100kW Marconi transmitter at Caernarfon used 48 Henry Round triode valves operating at 12kV. (Radio News)



This European 7-valve superhet covers 200 to 2000m in two ranges. The self oscillating mixer is a rare Radio Technique bi-grid valve.

Competition

With the capital from the sales of rights to AT&T, de Forest engaged **Robert Gowen**, an enthusiastic radio amateur, and equipped his factory with newer machinery to produce transmitter valves that were sold to amateurs. In view of the de Forest Company's policy of only selling receiving Audions in expensive instruments, several other unlicensed manufacturers started producing triodes with similar names, such as the 'AudioTron' and 'AmpliTron', that became popular with amateurs because they could be purchased alone.

One of the most successful of these pirate manufacturers was **Elmer Cunningham** of Los Angeles [5]. Although suit for infringement was filed against Cunningham at different times by both de Forest and RCA, he settled out of court and in 1920 successfully negotiated a licence to sell valves *"for amateur and experimental use only"*. Subsequently he was even authorised to sell RCA valves branded with his own name.

After his invention of the Audion, de Forest lobbied unsuccessfully for a Nobel Prize, and styled himself 'The Father of Radio'. As a publicity stunt, his PR agent mailed a letter addressed to 'The Father of Radio, Hollywood, California', intending to inform the media when it had been delivered. The letter was returned by the Postal Service, marked 'Addressee Unknown'.

Contestation

In Britain, Fleming's diode patent was owned by Marconi, whereas the Audion patent had lapsed on January 11th 1911 when an impoverished de Forest didn't have the funds required to renew it. Hence **Henry Round** of Marconi and Edison-Swan were able to proceed with triode valve development and production without legal hindrance. Considering that the device had originally been invented by Edison, and only its application to the detection of radio signals was novel, Fleming's patent survived remarkably well.

In the US, on the other hand, the Fleming diode patent was owned by American Marconi, while most of de Forest's patents had been acquired by AT&T. In 1915 the courts ruled that the Audion infringed Fleming's patent on the diode valve, but also that Marconi could not use triodes without a de Forest licence from AT&T. In addition to this impasse, both GE and AT&T had filed competing patents on the high-vacuum valve. These conflicts were only resolved by the absorption of American Marconi by GE in the formation of RCA in 1919 and the investment by AT&T in that corporation in 1920 [6].

But this was by no means the only contestation in the field. In 1912, the discovery of regeneration and the use of the triode valve as an oscillator, as well as an amplifier, was made by several experimenters at about the same time. When de Forest found that feedback caused his audio amplifier to howl, he at first considered this just an annoying problem and only much later realised that this oscillation could be exploited for the generation of continuous waves at radio frequencies.

As this discovery became of enormous importance, bitter legal battles were engaged by de Forest, Langmuir, **Edwin Armstrong**, and **Alexander Meissner** over the priority of the invention [7]. The complex and acrimonious litigation between de Forest and Armstrong over regeneration and oscillation lasted for 20 years and while in 1934 the technically baffled Supreme Court eventually sided with de Forest, the better-informed radio engineering community generally did not. When Armstrong tried to return the 1917 medal of honour that he had received for his feedback invention to the Institute of Radio Engineers, the directors strongly affirmed their original award to him. De

50 years after Fleming's valve, diode vacuum tubes were still useful as high voltage rectifiers. This 6X2 can support a peak inverse voltage of 17kV.

The QQV07-40 (829B) push-pull beam power tetrode was popular as a 2m power amplifier. It can deliver an output of over 85W.

Forest's expressions of hostility towards Armstrong continued even after his suicide in 1954.

Industrialisation

During WW1 all amateur radio activity was suspended but there was a massive demand for valves for military equipment, especially by the navy and for air-ground communications. Hence major scientific and industrial resources were allocated to their development, and substantial technical progress was made in their design and manufacture. High vacuum techniques were perfected, more reliable and efficient cathodes were developed and production processes were refined so that triode valves became relatively stable and predictable devices, although inter-electrode capacitance limited the maximum frequency at which they could provide useful gain.

In Britain, Edison-Swan was joined by British Thomson-Houston and five other manufacturers [8], and production ramped up from less than 500 to over 25,000 valves per week. From 1916, variants of the 'R' valve design became particularly popular and their lifetime was progressively increased to over 5000 hours. By the cessation of hostilities in 1918 the technological child that was born from a humble light bulb had come of age. The thermionic valve was poised to spawn the vast field of electronics that would impact the lives, not just of radio enthusiasts, but of everybody on the planet.

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