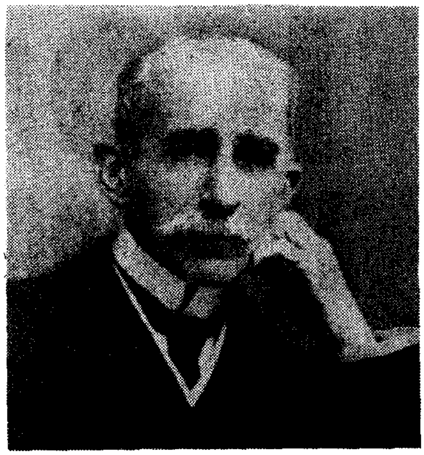
When I Think Back...

by Neville Williams

Sir John Ambrose Fleming: He invented radio valves – or did he?



Sir John Ambrose Fleming – a gifted scientist of his day.

Dr/Professor Sir John Ambrose Fleming is remembered primarily as the inventor of the Fleming thermionic diode and the 'father' of radio valves, which were fundamental to the subsequent development of the industry. Whether or not this is strictly correct is debateable but, either way, Ambrose Fleming made a very considerable contribution to basic electrical and electronic technology.

Curiously, one finds scant mention, in relevant textbooks, of Fleming's personal background or his academic career. Beyond the fact that he was born in 1849, the texts to which I had access make little or no reference to his birthplace, his family or the steps in his career which led to his ultimate knighthood.

The British technical writer/consultant S. Handel comes closest in *The Electronic Revolution* (Penguin Books, UK, 1967). I quote:

At the turn of the century Fleming, then a young professor of electrical engineering at University College in London, was appointed scientific adviser to the Edison Electric Light Company of London and became familiar with Edison's lamp experiments. He subsequently became a consultant to the British Marconi Company which was looking for a better detector of wireless signals than the clumsy and troublesome devices used by Marconi.

It so happens that Handel was, himself, educated at the same University. Clearly, in the 50-odd years between 1849 and the turn of the century, Fleming had earned sufficient recognition at an academic and practical level to commend him as an independent consultant to the Edison & Swan Electric Light group and later (in 1889) to the newly formed British Marconi company.

As a consultant, he had ready access to Edison's lamp technology and to Marconi's pioneering ventures into wireless telegraphy – involvements that complicated subsequent litigation about patent rights in respect to the thermionic diode; but more about that later!

Fleming the academic

Curious about Fleming's academic career, I checked through a number of old reference books in my possession.

First off, a brief entry in a 60-year old Pear's encyclopedia indicated that Fleming's involvement with the University College spanned 40-odd years, from 1885 to 1926, by which time he would have been in his mid '70s.

Next in line was a 1931 copy of the *Admiralty Handbook*. Prompted by the index, I re-discovered several long-forgotten references to Fleming's left-hand and right-hand rules, which correlate current flow, the direction of magnetic flux and the mechanical force in magnetic systems (Fig.1).

The 'Fleming' responsible is not identified by the Admiralty Handbook, but I have little doubt that the 'rules-of-thumb' we were invited to memorise in other days were devised by John Ambrose Fleming, the subject of this present article.

There is no ambiguity, however, about the Dr J.A. Fleming whose work features prominently in another old textbook: *The Calculation and Measurement of Inductance and Capacity*, by W.H. Nottage of the Marconi Works, Chelmsford (Wireless Press, London, 1916).

Nottage quotes basic research into capacitance by Fleming, as described in his book *The Principles of Electric Wave Telegraphy*, 2nd Edition, page 179.

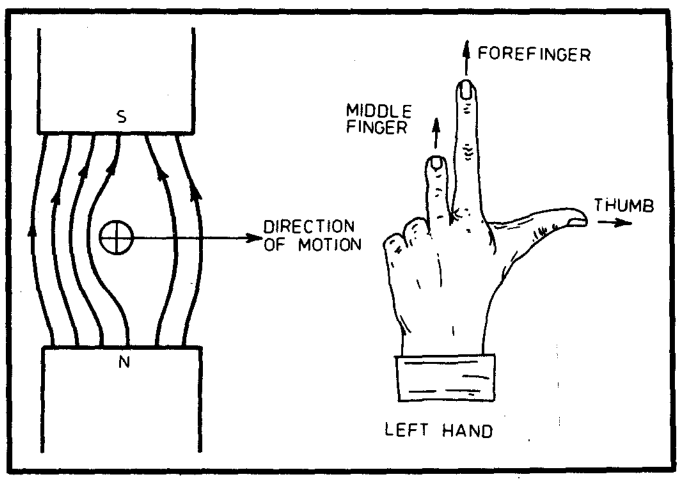


Fig.1: Fleming's left-hand rule for remembering the relationship between motion, magnetic field and induced voltage.

A further reference is to adjustable waveform filters devised by Fleming and Dyke, to facilitate their investigations into power factor and the conductivity of dielectrics. (*J.I.E.E.*, xlix 1912, p.323).

Again, a method of measuring capacitance is described, with a low-resistance battery as a DC source. Attributed to Fleming & Clinton, it used a spinning commutator to pulse charge the unknown capacitance at a rate of typically 100pps and to pulse discharge it alternately at the same rate through a ballistic galvanometer, the readout being interpreted in terms of capacitance. (Fig.2).

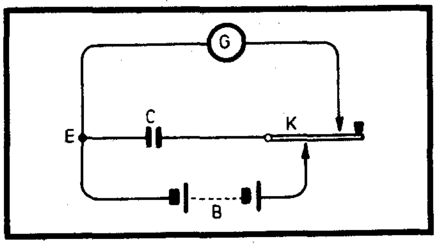


Fig.2: Fleming and Clinton devised this simple system for measuring capacitance, using a galvanometer.

According to Nottage, the method was detailed in Dr Fleming's books: *Wireless Telegraphist's Pocket Book* and *The Principles of Electric Wave Telegraphy and Telephony*, published at the time by Wireless Press, UK.

(A similar contemporary title by Fleming, *An Elementary Manual of Radiotelegraphy and Radiotelephony* was quoted as a reference by Peter Jensen for his article 'Spark: an old-time Induction Coil' in the April and June '89 issues of this magazine).

But back to Nottage: the measurement bridge illustrated in Fig.3 is credited to Fleming and Dyke and was used by them to measure capacitance or, more importantly, in researching power factor and the conductivity of dielectrics.

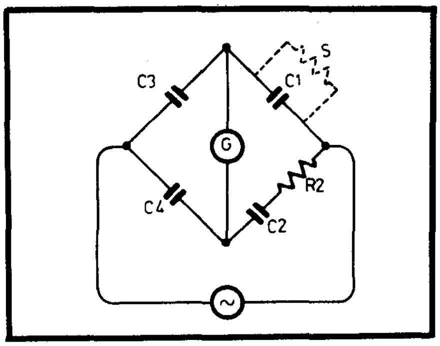


Fig.3: The capacitance measurement bridge attributed to Fleming and Dyke, by Nottage. It also measured dielectric performance.

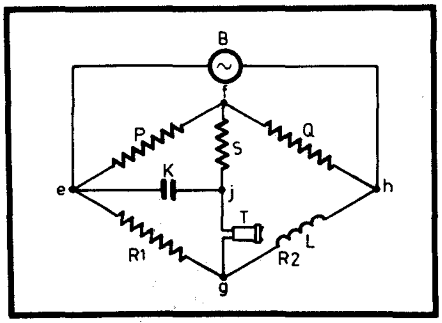


Fig.4: The Fleming-Anderson bridge, developed to measure inductance.

The Fleming-Anderson bridge (Fig.4) provided a means of measuring inductance. According to the text, it could be used with alternating current input or with direct current in conjunction with a buzzer-interrupter or a make-and-break key. It was nulled by adjusting for minumum sound in the phone T, but could reportedly yield more accurate results with the benefit of measurement methodology described in Watson's *Practical Physics*.

Fleming & the diode

While there is ample evidence as above of an active and innovative academic career, the fact remains that most biographical references to Fleming concentrate on his rationalisation of the so-called 'Edison effect' culminating, in November, 1904, in the almost legendary Fleming diode.

For sure, it was an important breakthrough in its in own right, but to acclaim Fleming's elementary thermionic diode as the the original radio valve and the genesis of the electronic revolution may be open to question.

That he was so acclaimed is evidenced by the fact that, in 1927, a landmark year for wireless broadcasting, full-page advertisements in popular wireless magazines for Amplion horn loudspeakers carried a personalised product endorsement by Dr J.A. Fleming, described as 'the original inventor of the thermionic valve' (see illustration).

More recently, on the 60th anniversary of the Fleming diode, the well known English journal *Practical Wireless* for January 1965 published a commemorative article under the heading: 'FLEMING ... AND THE DIODE – 60th Anniversary of the invention of the Thermionic Valve by Sir Ambrose Fleming FRS.'

Quite a few writers insist, however, that some of the credit allocated to Fleming really belongs to others. Again – more about this later!

Fleming's own reaction to the thermionic diode appears to be in relatively low key. A snippet of a letter to Marconi, in his own handwriting, reproduced with the above-mentioned *Practical Wireless* article gives no hint that Fleming's evaluation of the diode extended beyond his immediate area of concern – a potentially useful method of sensing wireless telegraphy signals. It reads:

I have found a method of rectifying electrical oscillations that is making the flow of electricity all in the same direction, so that I can detect them with an ordinary mirror galvanometer.

I have been receiving signals on an aerial with nothing but a galvanometer and my device, but at present only on a laboratory scale.

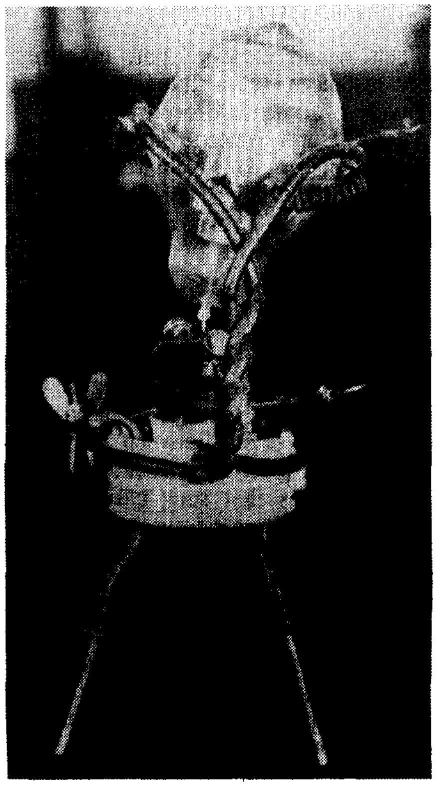
This opens up a wide field of work, as I can now measure exactly the effect of the transmitter.

I have not mentioned this to anyone yet as it may become very useful.

Yours very sincerely,
J.A. Fleming.

Contemporary paper

If the above is more characteristic of an academic than an enthusiast and a visionary, the same goes for his contemporary paper on the thermionic diode, a copy of which was made available to me some time ago by Mr C.H. Scott of Ip-



Fleming's first experimental diode detector valve, developed in 1904. It became the subject of considerable legal argument.

swich, Qld. It comes from *Technics*, a monthly publication from George Newnes, London, dated April 1905.

Contemplating such an innovation, one rather expects a title along the lines of: 'A New and Revolutionary Method of Detecting Wireless Signals'. Instead, we have the bland and predominately academic heading: 'On the Electric Conductivity of a Vacuum' by J.A. Fleming, MA, DSc, FRS.

Perhaps wireless communication and a device based on electron emission was such a non-issue to readers of *Technics* in 1905 that the notion of an electrically conductive vacuum was judged to be more titillating; that's certainly the way it's presented by the author.

In the paper, Fleming envisages a glass tube containing two electrically accessible platinum plates, the whole assembly being sealed and evacuated to one hundred-millionth of an atmosphere. With a gap between the plates of as little as 1mm, he says, no measurable current flows between them, even with an applied potential difference of 100,000 volts.

Equally, a spark coil, which might bridge a gap of several centimetres in air, would produce no evident discharge across the same 1mm in evacuated space.

This would indicate that, in normal circumstances, a vacuum is an exceptionally good insulator.

If the plates were to be replaced by platinmum or carbon wires, or filaments, exactly the same observation would apply – provided the wires remain cold.

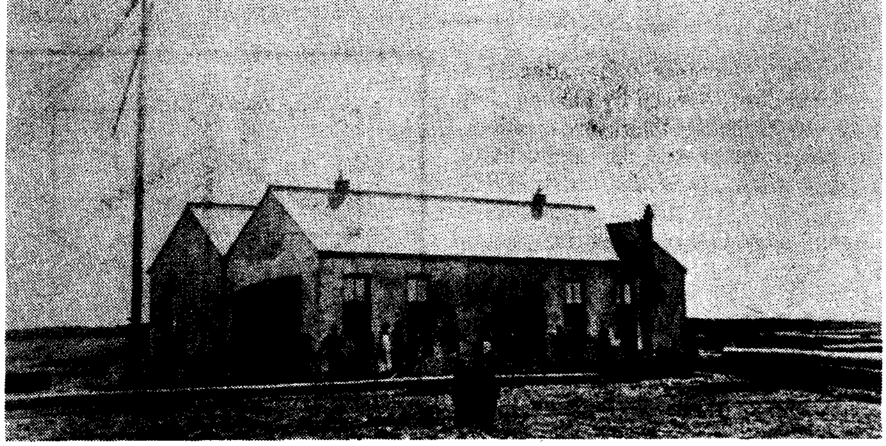
Current in a vacuum

However, continues Fleming, if one of the wires is heated in the manner of a lamp filament by connecting it to a suitably insulated battery, a discharge of current may occur between the wires across the intervening evacuated space.

It transpires that such current flows only when the incandescent filament is negative with respect to the one which is not artificially heated. If an alternator is connected between the two filaments, in series with a galvanometer, the latter will register a steady reading due to the flow of a unidirectional current.

Fleming points out that the rectifying effect is broadly similar to that of the 'Nodon valve', an electrolytic ('slop') rectifier that would be familiar to his readers. I quote:

It is well known that, if a carbon or iron plate is placed, together with an aluminium plate, in some electrolyte yielding oxygen, then a current of positive electricity can pass from the carbon to the aluminium but not in the reverse direction.



The Marconi wireless station at Poldhu, in Cornwall, UK, pictured in 1901. Designed by Fleming, it was used for the first trans-Atlantic communication.

To explain conduction by an evacuated thermionic diode, along with a rectifying action, Fleming says:

In any mass of matter, such as a metal, there must be, in addition to the complete atoms or molecules constituting the mass, a distribution throughout it of free electrons, the percentage of these increasing with the temperature. These electrons cannot escape from the mass when cold because if they did they would leave it positively electrified. If on the other hand, we electrify the mass negatively to a high potential and raise it to a high temperature, electrons can escape freely from it.

Very new concept

Nowadays, any student of high school physics is aware of the molecular/atomic composition of matter, of sub-atomic particles and of electron emission phenomena. But in 1905, it was at the leading edge of new and unfamiliar technology, being expounded as such by eminent physicists like Ambrose Fleming.

In the process, he was already confronted with the apparent conflict between electron flow (negative to positive) and the purely arbitrary convention that electricity flowed from positive to negative. In his explanatory diagram for a diode (Fig.5) he adopts the verbal device of a flow of 'negative electricity'.

Another diagram in his paper (Fig.6) emphasises that conduction through a diode does not obey Ohm's Law, behaving quite differently from a resistive circuit.

At this stage, the author diverges into a broad discussion of electron emission effects, including the influence of the degree of evacuation and the order of the applied voltages, along with phosphorescence and other phenomena to do with Crookes and Roentgen tubes.

He also makes the point that current due to the presence of free electrons can be drawn off by inserting a carbon or water-cooled iron probe into the active, ionised region of an arc.

It is reasonable to suppose, he adds, that free electron phenomena even play an integral part in ordinary combustion in a coal fire, with 'carbon positive ions' (formed by losing free electrons) exhibiting an affinity for 'negative oxygen ions' (having absorbed such electrons) to promote the creation of electrically neutral molecules of carbon dioxide.

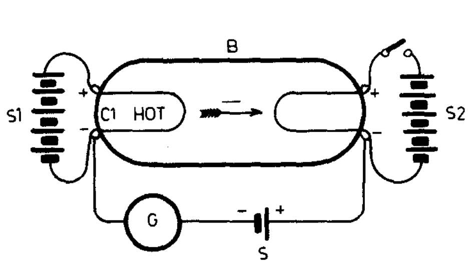
The diode detector

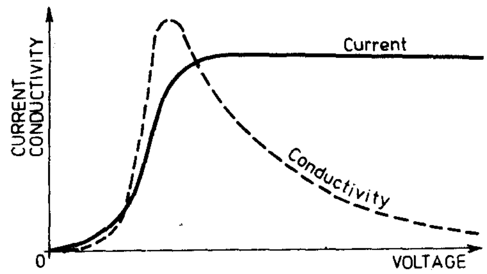
Only towards the end of the 7-page paper does he get around to the use of his diode for detecting wireless telegraphy signals. But even then it is in the context of a laboratory experiment (Fig.7), consistent with his hand-written note to Marconi. For his *Technics* readers he explains:

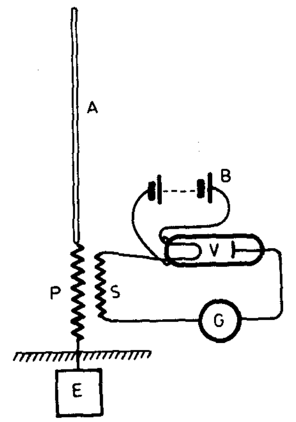
We may, for instance, set up an electric oscillation by the discharge of a condenser in one circuit. Then, at a distance of several feet or several yards, we may set up another circuit including a galvanometer and a vacuum tube, and we may produce a deflection in the galvanometer showing it is transversed by a continuous current when we set up an alternating current in the primary circuit.

Such an arrangement, he adds, can be used as a receiver for wireless signals, at the same time conceding that "it is not so sensitive as the coherer or the magnetic detector".

Even so, Fleming explains, "the galvanometer will give a steady deflection all the time that electric waves are falling on the wire, and if the galvanometer is that kind of instrument called 'a speaking galvanometer' it will give de-







Figs.5 and 6 (above left, right): Diagrams from Fleming's 1905 paper explaining diode operation. Fig.7 (far right): From the same paper, his diagram showing the use of the diode as a detector for wireless signals. Note the lack of any tuning arrangement.

flections larger or smaller in proportion as the wave trains falling upon the aerial are longer or shorter. In this manner, signals in accordance with the Morse Code alphabet may be rendered visible by the deflections of the galvanometer."

(Fleming notes in the following paragraph that speaking galvanometers were currently being used for undersea cable telegraphy).

In evaluating Fleming's apparently low-key attitude to his thermionic detector, the present day reader needs to realise that, in 1905, the role of a 'detector' was to indicate audibly or visually the presence of bursts of unmodulated or randomly modulated arc-sourced wireless energy, sufficient for them to be recognisable as Morse Code.

While Fleming saw his diode as new and potentially useful, he also admitted that it was less sensitive than other currently available devices – a crucial consideration prior to the introduction of receivers using valve type signal amplifiers.

Wireless telephony was also in its infancy and the consequent role of a detector as a demodulator of incoming amplitude modulated speech and music signals was not widely appreciated – perchance even by Fleming in 1905.

In this connection, Marconi was said to have been singularly uninterested in speech communication. His commercial objective was to establish reliable long-distance communication using brute-force, arc-based wireless telegraphy, rather than getting involved in the considerable complications of voice transmission. His attitude would undoubtedly have had a bearing on Fleming's outlook as a consultant to British Marconi.

Diode origins

For their book *From Tin Foil to Stereo – Evolution of the Phonograph* (Howard Sams Inc., 1976) Oliver Read and Walter Welch had occasion to look fairly critically at the history of the thermionic diode; this as background to the evolution of thermionic valves generally and to electronic disc recording and playback.

John W. Stokes did similar research for his book *70 Years of Radio Tubes and Valves* (Vestal Press, N.Y. 1982) and what follows draws on their findings.

They agree that in 1883, Thomas A. Edison realised that charged particles of some sort were being emitted from the incandescent carbon filament in evacuated lamps. His observations were documented by Prof. Edwin J. Houston and became the first paper to be published by the AIEE (American Institute of Electrical Engineers).

In the following year (October 1884) Edison took out a patent, which covered the idea of intercepting the particles with a metallic plate placed within the evacuated envelope and using the resultant current as a method of monitoring the line voltage. The patent had no real practical value for Edison, but was taken out as a purely precautionary cover.

Nevertheless, this discovery, paper and patent, according to Read and Welch, provide the real starting point for what is now known as 'electronics'; this in 1883/4.

While experimenting with one of the tubes, John W. Howell, an associate of Edison in the Harrison laboratory, discovered that it could also be used as a rectifier. This, too, was written up in the AIEE *Transactions*, but was ignored on principle by Edison – a fanatical DC man who would have nothing to do with AC mains, or rectifiers!

In 1885, Edison gave several of the tubes to Sir William Preece (Chief of Engineering, British Post Office) who had arranged the first demonstration of the phonograph in England to a scientific body. Sir William passed one or more of them on to Professor Fleming, describing them, possibly for the first time, as 'Edison Effect' tubes.

Taking advantage of his association with Edison & Swan, Fleming had a number of similar tubes made up for himself. Having verified Edison's and Howell's findings, he put them away in a laboratory cupboard, where they still were in 1897 when J.J. Thompson came up with his electron theory.

In the light of this new concept, and aware of Marconi's need for a more reliable detector, Fleming decided to check out his 'Edison Effect' rectifier tubes in that role. They had their limitations, but worked well enough to justify application for a patent, on the basis of their use with different external circuitry for a totally different purpose: the detection of high frequency wireless waves.

A patent was duly granted in November 1904 and, under the terms of his contract, was assigned to the Marconi Company, with no pecuniary reward to Fleming other than his regular retainer as a consultant.

On the strength of the patent, the Marconi Company began manufacturing thermionic diodes in 1907, mostly with 4-volt filaments, plate connections on the side of the bulb and, ironically, Edison-lamp type bayonet or medium screw bases.

US Federal Court

The tenuous nature of the Fleming/Marconi patent came under scrutiny some time later, when the Marconi Company took action against Lee de Forest in the Federal Court for the Southern District of New York, claiming that his American-built equipment using thermionic diodes and triodes (modified diodes) breached their 1904 patent.

By way of defence, it was put to the

court that the original Edison patent (1884) had clear precedence and that it had lapsed by the passage of time. Marconi/Fleming countered with a disclaimer indicating that their patent related uniquely to high frequencies, as in wireless telegraphy.

De Forest also claimed that his triode operated in the manner of a relay, with the grid controlling the amount of energy being drawn from a supplementary or 'B' supply.

This led to a lengthy examination by the court of other types of wireless detector, and claims that a supplementary voltage had been used before to improve their performance (as in the coherer) – thereby anticipating de Forest's patent.

In the end, and in some degree because Edison was not a party to the action, the Fleming/Marconi patent was allowed to stand.

There was much more to it, which I shrink from trying to include here, but the summation by Read and Welch reads as follows:

There is revealed a great disparity in the philosophy and reasoning of patent reviewers and of the courts in dealing with the relative merits of basic inventions and of contributory inventions and/or new uses.

In this case, although careful distinctions were made between the relative claims of de Forest and Fleming, historic justice was denied Edison, whose research and accomplishment was so unique in this particular instance that the contributions of both Fleming and de Forest are quite secondary.

Considered from this viewpoint, which was tacitly admitted by the court, the contribution of de Forest towards the new use in adding the all-important third element, was the greater of the latter two.

Amongst others, this last observation is supported by E. George Griffith of Pennsylvania State University, in his book *Basic Electronic Devices* (Rinehart Press, San Francisco, 1971). I quote:

When Lee de Forest introduced a third electrode between the cathode and plate of the diode, he started the vast electronics industry that exists today.

John Stokes (*70 Years of Radio Tubes & Valves*) records the above sequence of events, but leaves the reader to ponder a quite different footnote which reads:

In view of an earlier patent by A. Wehnelt in January 1904, the reader is left to judge for himself whether Fleming was justified in claiming to have invented the world's first thermionic valve.

Personally, I am in two minds as to whether the problem lies in what Fleming actually believed and claimed, or what history has thrust upon him.

To a long-time academic and a Fellow of Royal Society, the Edison Effect was a phenomenon that needed to be resolved and written into scientific literature. Under commercial pressure from Marconi, however, he may well have taken the further step of applying for a patent, which might never have been granted if Edison (or Wehnelt?) had seen fit to oppose it.

Morgan E. McMahon (*Vintage Radio*, 2nd Edition, 1973) is supported by John Stokes in adding that Fleming's patent had an unusual personal aspect: a victim of impaired hearing, he had difficulty in coping with the wireless signals which he encountered by reason of his association with the Marconi Company. Because of this, he was especially interested in the rectifying action of the Edison Effect diode and gratified to find that telegraphy signals could be rendered both visible and measurable by using it in conjunction with a galvanometer (Fig.7).

Indications are that, as an inventor, de Forest's expectations for his 1906 Audion tube were much broader and industry-based. Morgan McMahon rates his triode as 'the most important discovery in radio'.

De Forest's triode opened the way to RF and audio amplifiers, and to receivers more sensitive than anyone had ever dreamed of; to vastly improved transmitters, to radio telephony, sound broadcasting and a world of valve-based electronics that reached its peak in the '60s.

Trans-Atlantic wireless

If the foregoing observations appear to diminish Fleming's contribution by way of the thermionic diode, his role in another wireless 'first' is recounted by way of compensation.

In the late 1890s, some five years before the diode patent, Marconi was seized with the idea of bridging the Atlantic by wireless telegraphy – an ambition that many ridiculed, on the grounds that wireless waves could not possibly follow the curvature of the earth. Marconi thought otherwise and, without knowing anything of ionospheric propagation, was willing to back his intuition with his reputation and £50,000 of company funds.

Limited to a simple zero-gain receiver and without the benefit of directional aerials, he knew that his only chance of success was to provide a uniquely powerful signal from the selected transmitting site atop a 37-metre (120ft) granite cliff at Poldhu, on the southwest coast of Cornwall in the UK.

To feed the 70m (200ft) inverted cone antenna, Marconi reckoned that he would need a transmitter input power of around 25kW and an HT voltage of around 20kV, bridging a 50mm (2″) spark gap to excite the resonant 'oscillation coils' to which the antenna was coupled.

The design of a transmitter to satisfy these unheard-of criteria was entrusted to an independant consultant – none other than Professor J. Ambrose Fleming. A photograph in the Marconi Company archives reveals the installation as a major undertaking, bedecked with 'DANGER' and 'STAND CLEAR' notices. But it worked.

Success came at 12.30pm on December 12, 1901. In Marconi's words:

Unmistakably the three little clicks corresponding to three dots sounded in my ear; but I could not be satisfied without collaboration. "Can you hear anything, Mr Kemp?", I said, handing the telephone to my assistant. Mr Kemp heard the same thing as I...

Those words have been reproduced countless times in articles and textbooks, more often than not without any thought of the man who was primarily responsible for the transmitter which radiated the signals in the first place.

Fittingly, in his biography of Guglielmo Marconi, David Gunstan refers to a granite column erected on the cliffs near Poldhu. On the column is a bronze plaque which carries the words:

One hundred yards North East of this column stood from 1900 to 1933 the famous Poldhu wireless station, designed by John Ambrose Fleming and erected by the Marconi Company of London, from which were transmitted the first signals ever conveyed across the Atlantic by wireless telegraphy.

One may well quibble about the genesis and the heritage of the Fleming diode, but it is difficult not to respect a scientist/engineer able to project a signal from Poldhu to Newfoundland using the hazardous, primitive technology of 1901.

Sir Ambrose Fleming died in his 96th year on April 18, 1945 at Sidmouth, UK, where he had spent in retirement the last few years of an intensely active life.