

## *Inventing the History of an Invention: J. A. Fleming's Route to the Valve*

Engineers often recall their inventions. These recollections provide important narratives for the history of technology. Historians, however, are well aware that these recollections should not be taken literally. Engineers' memories of what happened, say, twenty years ago are not always exactly correct. They sometimes put too much emphasis on the novelties they introduced, while devaluing others' contributions. Recollections may give the engineer a psychological satisfaction, or may provide an intellectual glue to hold the engineering community together, but they sometimes serve a more direct purpose. When the 'authorship' of a technology is at stake in a court, recalling how one invented, or made a contribution to the invention, the technology in dispute is an important strategy for patent litigation. In this case, the engineer may well stress radical differences of his technology from that of others. The engineer may also stress the origins of that technology in his previous work, providing a smooth continuity between his past work and the later invention. The simultaneous existence of discontinuity (from others' work) and continuity (to his own work) frequently characterizes an engineer's recollections on the invention of novel artifacts.<sup>1</sup>

We can find a similar plot in John Ambrose Fleming's recollection of the invention of the thermionic valve in 1904. In a series of well-known recollections, Fleming remembered that he transformed the Edison effect into the valve in 1904, when a sensitive signal detector was badly needed for wireless telegraphy. The Edison effect was a curious effect that Edison and his assistants discovered in the early 1880s inside a specially constructed light bulb. In 1889 Fleming performed a series of experiments on the Edison effect and conceptualized it in terms of unilateral conductivity in the vacuum inside the bulb. Some of the lamps that Fleming used in 1889 are shown in Figure 1 and Figure 2.

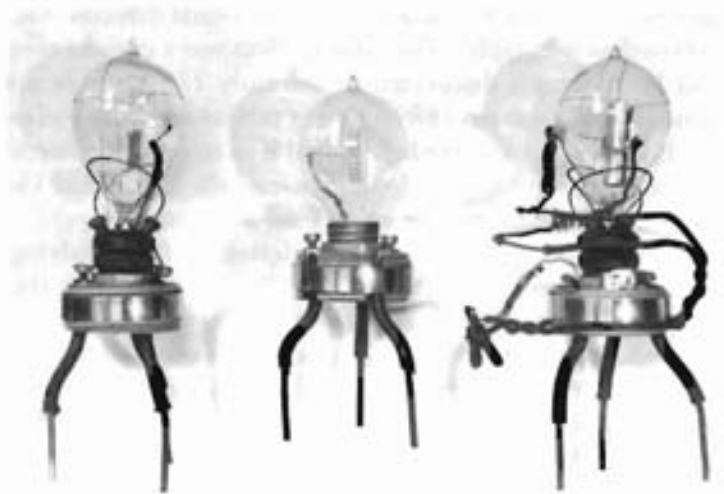
Unlike Edison who did not understand its underlying mechanism, Fleming investigated it and eventually transformed it into the valve, a sensitive and convenient signal detector for wireless telegraphy, in 1904. When he came up with the idea of utilizing unilateral conductivity for wireless detectors, he took one of the old lamps (Figure 1 and Figure 2), which he had used 15 years previously, from his cupboard and tested its performance as a wireless detector. By doing so, Fleming is said to have mediated between lamp and radio engineering, as well as between physics and technology. Yet Fleming began to recall his invention of the valve at a

Figure 1. A specially constructed lamp that Fleming used for his experiments on the Edison effect and unilateral conductivity in 1889.

Picture source: Science Museum, London.



Figure 2. Other lamps that Fleming used in 1889. Note that the lamp in the middle has a zigzag wire anode, while the other lamps have a metal plate anode. He later recalled that it never occurred to him to put a metal plate and a zigzag wire in the same lamp and use the latter to control the electron flow from the filament to the metal plate as Lee de Forest did. The value that Fleming placed on these lamps as evidence for his claims to priority can be adduced from two letters from Fleming to Henry Lyons, Director of the Science Museum (preserved in the Archives of the museum), which were brought to my attention by Robert Bud. In one, dated 19 October 1925, he stated, 'You have such a valuable collection of original priceless apparatus that it ought to include the original thermionic valves which are the progenitors of all others.' In the other, dated 25 October 1925, he wrote, 'I see no objection to this [exhibition] provided they are marked so as to make it clear that these valves are my original valves and the progenitors of all other thermionic valves of whatever kind.' Picture source: Science Museum, London.



time when he and the Marconi Company were fighting over the patent on the vacuum tube with Lee de Forest who invented the audion (or the triode). To support the important claim that his valve, not de Forest's triode, was a breakthrough in the history of vacuum-tube technology, Fleming, I will assert, highlighted the inevitability and smoothness of the transition from the Edison effect to the valve, the importance of his scientific advisorship to Marconi as a context in which the invention was made, and a well-defined usage of the valve as a detector in wireless telegraphy in 1904.<sup>2</sup>

This paper aims critically to analyze Fleming's own narrative of his invention of the valve. Instead of stressing inevitability and continuity, I will focus on local and temporal complexities and contingencies specific to Fleming around 1904. I will also show that the termination of Fleming's scientific advisorship to the Marconi Company in December 1903, as well as his efforts to regain his connection to it, rather than his alleged scientific advisorship to Marconi, was a crucial factor that led him to the invention of the valve. Finally, I will show that the use of the valve was not clear when it was first made. Fleming actually intended it to be a high-frequency alternating current (AC) measuring instrument for use in the laboratory. Marconi, not Fleming, transformed the valve into a practical detector that was actually used in wireless telegraphy in the field.

### **Fleming's Recollection of the Invention of the Valve: the Canonical Story and its Problems**

In his Friday Lecture at the Royal Institution in 1920, Fleming recalled the invention of the valve by mentioning problems in existing detectors.

Before 1904 only three kinds of detectors were in practical use in wireless telegraphy—viz. the coherer, or metallic filings detector, the magnetic-wire detector, and the electrolytic detector. ...

The coherer and the electrolytic detectors were both rather troublesome to work with on account of the frequent adjustments required. The magnetic detector was far more satisfactory, and in the form given to it by Senator Marconi is still used. It is not, however, very sensitive, and it requires attention at frequent intervals to wind up the clockwork which derives the moving iron wire band. In or about 1904 many wireless telegraphists were seeking for new and improved detectors.

He then discussed his failed efforts to solve the problem.

I was anxious to find one which, while more sensitive and less capricious than the coherer, could be used to record the signals by optical means, and also for a personal reason I wished to find one which would appeal to the eye and not the ear only through the telephone. Our electrical instruments for detecting feeble direct or unidirectional currents are vastly more sensitive than any we have for detecting alternating currents. Hence it seems to me that we should gain a great advantage if we could convert the

feeble alternating currents in a wireless aerial into unidirectional currents which could then affect a mirror galvanometer, or the more sensitive Einthoven galvanometer. There were already in existence appliances for effecting this conversion when the alternations or frequency was low—namely, one hundred, or a few hundred per second.

For example, if a plate of aluminium and one of carbon are placed in a solution of sodic phosphate, this electrolytic cell [the Nodon rectifier] permits positive electricity to flow through it from the aluminium to the carbon, but not in the opposite direction. ... But such electrolytic rectifiers, as they are called, are not effective for high frequency current, because the chemical actions on which the rectification depends take time.

In spite of these difficulties, he eventually came to the ‘happy moment.’

After trying numerous devices my old experiments on the Edison effect came to mind, and the question arose whether a lamp with incandescent filament and metal collecting plate would not provide what was required even for extra high frequency currents, in virtue of the fact that the thermionic emission would discharge the collecting plate instantly when positively electrified, but not when negatively. ... I found to my delight that my anticipation were correct, and that electric oscillations created in the second coil by induction from the first were rectified or converted into unidirectional gushes of electricity which acted upon and deflected the galvanometer. I therefore named such a lamp with collecting metal plate used for the above purpose, an oscillation valve, because it acts towards electric currents as a valve in a water-pipe acts towards a current of water.<sup>3</sup>

The above recollection clearly shows three consecutive stages which Fleming went through in 1904: 1) the recognition of the trouble with the existing detectors, as well as of the need for a new detector; 2) the recognition of rectification as a new means to detect high-frequency oscillations; 3) finding a method of rectification in his prior research on the Edison effect in bulbs. These three stages provide compelling reasons for Fleming’s claim that it was only he who invented the valve. Since they are so convincing, few historians have doubted the story’s accuracy. On the demand for stable detectors around 1904, G. Shiers says that Marconi’s detectors ‘were not satisfactory for regular and dependable service; a new and better detecting device, or signal rectifier, was urgently needed.’ Concerning the importance of Fleming’s prior research on the Edison effect, Hugh Aitken asserts that ‘Fleming’s valve was a linear descendent of a device that had no connection with wireless telegraphy at all; this was the famous Edison Effect.’<sup>4</sup>

However, detailed examinations of the technical and corporate factors and contexts under which the valve was invented make some part of Fleming’s recollection disputable. First, his story about the existence of a compelling demand for a new detector around 1904 was not entirely convincing, because magnetic and electrolytic detectors, which were more stable and even more sensitive than coherers, were then widely used. Further, one could use a ordinary DC galvanometer with electrolytic detectors.<sup>5</sup> Second, Fleming’s research during 1903–1904 had apparently little to do with detectors in wireless telegraphy. His interest in this period largely lay in high-frequency measurement—the

measurement of inductance, capacitance, resistance, current, frequency, wavelength, and the number of sparks. Finally, Fleming never wanted to reveal the fact that he was being dismissed from the Marconi Company when he invented the valve in late 1904. In December 1903, his scientific advisorship to Marconi terminated in spite of his wish to retain it. His efforts to recover his connection to the Marconi Company changed Fleming's engineering style. Before 1903, he was distanced from inventing or patenting artifacts, but during the year 1904 he invented and patented the cymometer (a wave-measuring instrument) and the valve. As we will see, these two artifacts—the valve, in particular—helped him to resume his connection to the Marconi company in May 1905.

This paper will propose a different history of the valve. The central thread of my history is the interaction between Fleming and local resources—material, social, conceptual, and linguistic—available to him. These resources constrained and promoted his laboratory practice. Fleming's goal was shaped and materialized while mobilizing, changing, and combining these resources.<sup>6</sup> These resources, his laboratory practice, and his goal co-shaped each other. To show this, I will start with Fleming's work on high-frequency measurement in 1902–1904.

### **Measuring High-Frequency Alternating Current with Rectification**

At the turn of the century, there were two different methods for measuring high-frequency alternating current. The first method was to use the hot-wire amperemeter. It utilized the elongation of a metallic wire when heated by feeble high-frequency alternating current. The second method was to use sensitive AC dynamometers. Ordinary hot-wire amperemeters and dynamometers were not however sensitive enough to measure feeble high-frequency current that one had to measure in wireless telegraphy. Therefore, Fleming devised a third method, in which the effect of the magnetization of iron by electromagnetic waves was exploited.

The magnetization of a piece of demagnetized iron, as well as the demagnetization of a piece of magnetized iron, by electromagnetic waves was discovered by E. Rutherford in 1896. Based upon this, Marconi invented a practical magnetic detector in 1902. In designing his magnetic detector, Marconi used a telephone, not a galvanometer, because ordinary DC galvanometers could not detect high-frequency AC signals. In December 1902, Fleming and his assistant, A. Blok, decided to investigate how the Rutherford effect might be made to work with a galvanometer. The operational principle they tried to utilize was simple. Suppose, they thought, that electromagnetic waves were allowed only to demagnetize the iron, which was then magnetized again by some other means. Then, the effect of electromagnetic waves on the magnetic detector could be exhibited by an ordinary DC galvanometer. If electromagnetic waves were made to act only in one-way action (either to magnetize or to demagne-

tize), then this effect could be converted into electrical signals to be detected with a DC galvanometer. After much trial and error, Fleming and Blok constructed a workable device. Fleming described it before the Royal Society in March 1903.<sup>7</sup>

The measuring instrument is shown in Figure 3. In this,  $bb'$  is a large outer bobbin and inside it lie wire bundles upon which an ordinary magnetizing coil  $aa'$  and a demagnetizing coil  $cc'$  are wound (shown in the below). Magnetizing coil  $aa'$  is connected with battery  $P$  and demagnetizing coil  $cc'$  is connected with the receiving aerial and the earth. One end of outer bobbin  $bb'$  is connected with the galvanometer  $G$ . The commutator  $C$ , shafted to a 500 rpm motor, consists of five disks numbered 1, 2, 3, 4, and 5. Each disk has a fan-shaped sector made of brass, which occupies a certain angle. The angle of the brass sector of disk 1 is 95 degrees, 2 and 3 is 135 degrees, 4 is 140 degrees and 5 is 360 degrees. Disk 1 and 5 are connected to  $a$  and  $a'$ , 2 and 3 to  $b$  and  $b'$ , and 4 and 5 to the galvanometer  $G$ .

Commutator operation is as follows. When the commutator starts rotating, the battery magnetizes the iron bundle by the action of disk 1 and 5. This does not affect the galvanometer needle because during this time the galvanometer circuit is disconnected by disk 4. For a short time after the magnetizing current is stopped, the secondary bobbin is solely connected with the galvanometer circuit, because the brass sectors of disk 2 and 3 (135 degrees) are larger than that of disk 1 (95 degrees). After it was disconnected, a connection was made with the galvanometer circuit by disk 4 and 5. Suppose that electric waves strike the antenna and then oscillations pass

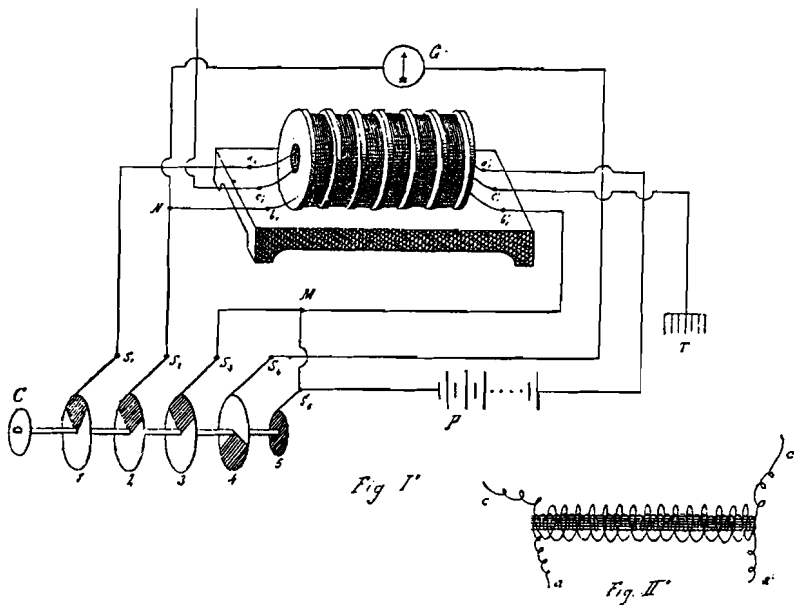


Figure 3. Fleming's 'Magnetic Detector for Hertzian Waves adapted for Quantitative Work.' Source: Nuovo Cimento 9 (1905), p. 108.

through  $cc'$  to the earth. This demagnetizes the iron bundle that has already been magnetized, which causes a change in the magnetic field in the interior of the bobbin, and produces an electric current in the bobbin wires  $bb'$ . The current is detected by the deflection of the galvanometer needle. Suppose that one rotation of the commutator occurs for a very short time (about 1/10 second), during which the galvanometer needle does not return to its normal place, then the effect accumulates and the deflection of the needle becomes steady until oscillation continues. This was what Fleming wanted:

Since the interrupter discs are rotating very rapidly, if the electrical oscillation continues, these intermittent electromotive impulses *produce the effect of a continuous current in the galvanometer circuit*, resulting in a steady deflection, which is proportional to the demagnetizing force being applied to the iron, other things remaining equal.<sup>8</sup> [emphasis added]

In short, the device showed an effect of rectifying high-frequency alternating current. The instrument 'converted' it into a direct current that was measured by an ordinary galvanometer.

What were the uses of this device? Fleming listed several primary uses:

By means of such an arrangement it is possible to verify the law according to which variation falls off with distance. *The instrument can be employed also as a telegraphic receiving instrument, but its chief use will be for comparing together the wave-making power of different radiators.* ... This detector serves, for instance, to show in a very marked manner the great effect of slight difference in the surface of the spark balls. ... Such an instrument will probably be found of great use in connection with the design of radiators and transmitters for Hertzian wave wireless telegraphy. ... Similarly, the instrument promises to be of considerable use in the investigation of the transparency or opacity of various substances to Hertzian waves, not merely qualitatively, but in the determination of a coefficient of absorption.<sup>9</sup> [emphasis added]

It is important to notice here that the device was not merely a detector in its usual sense; it was rather a laboratory instrument, a kind of high-frequency AC galvanometer. Used as a detector, it was very cumbersome and much less efficient than most detectors available at that time. A month after, Fleming again stressed the demanding need of a meter that could give a measure of the energy of waves quantitatively. 'It is only by the possession of such an instrument' he said, 'that we can hope to study properly the sending powers of various transmitters, or the efficiency of different forms of aerial, or devices by which the wave is produced.'<sup>10</sup> Remember that the measurement of the powers of transmitters was Fleming's primary goal.

However, the instrument was not widely used. Besides Fleming, as far as my knowledge goes, it was only used by an Italian scientist, V. Buscemi, in examining absorptions of electromagnetic waves in various dielectrics.<sup>11</sup> The reason for this neglect was due to its lack of stability. It turned out to

be very difficult to calibrate this device because of the complex commutator actions. After this failure, Fleming devised sensitive hot-wire amperemeters, but it was not sensitive enough to measure feeble current less than 5 milliamperes, a current which wireless engineers had to frequently measure in the laboratory and the field.<sup>12</sup>

In December 1903, when Fleming was still struggling with this measurement problem, he was informed that his scientific advisorship to the Marconi Company would not be renewed. Between 1899 and 1903, Marconi needed Fleming as an expert on patent and as a credible witness of Marconi's secret demonstration. Besides, Fleming played the role of a bridge between Marconi and the British scientific and engineering communities. Fleming also helped Marconi to design a high-power transmitting station at Poldhu for the first transatlantic experiment in 1901. The transatlantic transmission of wireless signals was a huge success, but Fleming was deeply hurt by Marconi's apparent attempt to monopolize credit for the success. Marconi was then much disturbed by Fleming's request to share it. After that, a subtle tension existed between them. The Maskelyne affair of June 1903, in which Nevil Maskelyne, Marconi's adversary, ruined Fleming's public demonstration of Marconi's new syntonic system by sending derogatory messages for interference, hurt much of Fleming's credibility.<sup>13</sup> His advisorship was scheduled to end in December of 1903. The Marconi Company did not renew it.

Fleming first approached to the Marconi Company with his new ball discharger, but it did not move Marconi who had already thought that Fleming's ball discharger was no more than a gadget. Fleming sensed the urgent need to invent something more useful. In the summer of 1904, he invented the cymometer (a convenient wave-length measuring instrument), and a few months later, the valve. These two artifacts provided Fleming with what he wanted: a revival of the connection to the Marconi Company.

### **The Invention of the Valve**

Fleming invented and applied for a patent on the cymometer in June 1904.<sup>14</sup> After this he returned to the measurement of current. Since specially constructed AC amperemeters and dynamometers proved to have been unreliable for high-frequency alternating current, he returned to the original method of effectively rectifying it. As before, he borrowed technologies from power engineering. Converting AC into DC was an important subject in power engineering. Several rectifiers such as rotary converters and electrolytic cells had been widely used. Obviously, the rotary converter, a huge machinery used in power engineering to convert between AC and DC, was not a candidate.<sup>15</sup> The second candidate, some electrolytic cells, looked more promising. Fortunately for Fleming—and this is what I want to argue—he found what he had been looking for. The *Electrician* of 14 October (1904) published a paper by A. Nodon, a French electrician,



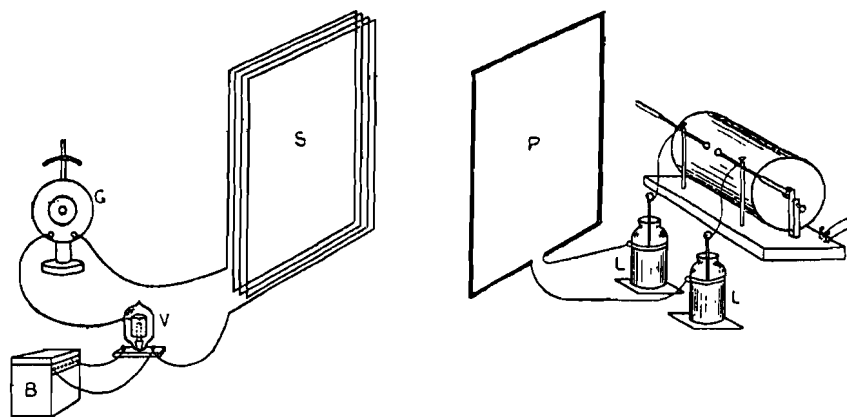
entitled 'Electrolytic Rectifier: An Experimental Research.' This article described the characteristics and the efficiency of Nodon's aluminium cell rectifiers, which consisted of two metals (one usually aluminium) dipped in an electrolyte (carbonate of ammonium, for example). With AC of 42–82 Hz, Nodon obtained 65–75% rectification. In this article, Nodon described his rectifier as electrolytic 'valve'—which suggests the origin of the name of Fleming's valve—and used the term 'valve effect' and the 'action of the valve.' Fleming constructed Nodon's valve to replicate the rectifying effect with high frequency oscillations, but after many experiments he eventually found that the Nodon valve was not effective for high-frequency alternating current.<sup>16</sup>

The Nodon valve illuminates some interesting points. First, we can understand why Fleming later repeated that 'electrolytic rectifiers' were inefficient for the rectification of high-frequency oscillations. Lee de Forest once criticized Fleming over this point, because most electrolytic detectors in fact rectified high-frequency oscillations. But what Fleming meant by the electrolytic rectifier was not ordinary electrolytic detectors used in wireless telegraphy, but the Nodon electrolytic rectifier designed for power engineering. Secondly, Fleming's attention to the Nodon valve supports my argument that Fleming was less concerned with the new detectors than with a metrical instrument for high-frequency current measurement. If Fleming had been really interested in detectors, he would have experimented on existing electrolytic detectors, rather than Nodon rectifiers which had nothing to do with wireless telegraphy. Finally, although Fleming later mentioned that he invented the valve in October 1904, the Nodon rectifier, noticed by Fleming in mid-October, suggests that the discovery might have been later. In fact, in a short letter to the *Electrician* in 1906, Fleming said that 'in November, 1904, [I] discovered that this unilateral conductivity [in the lamp] held good for high frequency current, which is not the case for electrolytic rectifiers.'<sup>17</sup> [emphasis added]

After his failure with the Nodon valve, Fleming pondered other means to create the valve effect (rectification) for high-frequency oscillations. What he needed was a device that allowed only one-way flow of currents. This reminded him of the unilateral conductivity in the small space inside the bulb, a phenomenon which he had investigated a few times in the 1880s and 1890s. He asked his assistant, G. B. Dyke, to connect a circuit as instructed, and 'took out of a cupboard one of [his] old experimental bulbs.' It immediately proved workable (see Figure 4 and Figure 5).<sup>18</sup>

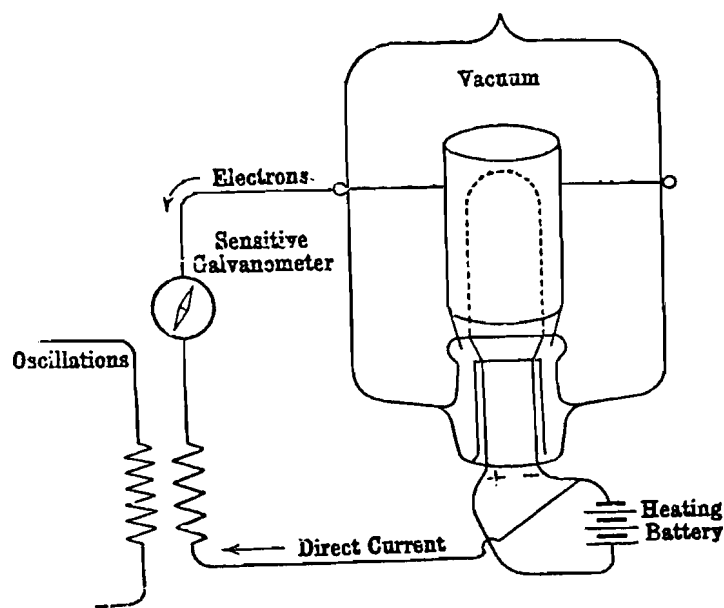
Why at this moment did Fleming come up with the idea of using the lamp for rectification? I have suggested that an 'invention imperative' pressed Fleming to design something useful. Nodon's paper on electrolytic 'valve' was published in October 1904, which provided Fleming with conceptual and linguistic resources such as the term valve and the idea of the valve effect. In addition to these, the electron theory that Fleming adopted around 1900

Figure 4. Fleming's First Test on Rectifying Characteristic of the Valve.  
 Source: Proceedings of the Physical Society 20 (1906), p. 179.



enabled Fleming to reinterpret the mechanism of the Edison effect. In the 1880s and 1890s, unilateral conductivity in the Edison effect was explained by Fleming in terms of the emission of negatively charged carbon molecules from the filament of a lamp to an inserted third electrode. A battery attached to the third electrode functioned as a discharger of negative charges accumulated on it, and a galvanometer measured the rate of this discharge. In 1904, Fleming was able to reinterpret the mechanism of the Edison effect in a radically different way. The battery attached to the third circuit functioned as a

Figure 5. Rectification by the Valve.  
 This is one of the earliest printed circuits on the valve. Source: Electrician 54 (31 March 1905), p. 967.



source of electrons which were pushed into the vacuum, and the galvanometer measured the rate of this current of electrons. Unilateral conductivity was transformed into a valve action.<sup>19</sup>

### **Constructing the Uses of the Valve**

After his first successful experiment, Fleming filed a provisional specification of the British patent, No. 24,850, on 16 November 1904. The title of the patent was 'Improvements in Instruments for Detecting and Measuring Alternating Electric Currents.' We can confirm the purpose of his invention in this provisional specification. Nowhere did he mention troubles in existing detectors, nor did he allude to putative demand for new ones. All that he mentioned was his former research on the measurement of high frequency alternating current. After this, he explained his purpose: 'The object of my invention is to provide a means by which an ordinary galvanometer can be used to detect and measure alternating electric currents and especially high frequency currents commonly known as electric oscillation.' Then, he mentioned two uses of the valve: 1) 'the device is especially applicable to the detection and measurement by an ordinary galvanometer of high frequency current or electric oscillations, where any form of mechanical or electrolytic rectifier is useless'; 2) the device 'and a galvanometer *may be used* as a receiving instrument in wireless telegraphy.' The first objective stressed its use (with an ordinary galvanometer) as a current measurer in the laboratory, and the second one indicated its possible use as a receiver in wireless telegraphy.<sup>20</sup>

Between December 1904 and January 1905, Fleming conducted a series of experiments with his single valve—the only valve working satisfactorily—to determine its conductivity at different electrode voltages. The experiments showed that the current-voltage (I-V) characteristics of the valve were neither linear nor regular. This made its rectifying power highly unpredictable. It undermined Fleming's initial hope to have produced a metering device. What about the valve as a detector, then? As a detector, 'the arrangement [a valve with a galvanometer in Figure 4], although not as sensitive as a coherer or magnetic detector, is much more simple to use.' Manageability was a merit and bad sensitivity was a weakness. But another merit, such as detecting 'a change in the wave-making power or uniformity of operation of transmitting arrangement,' would make up for this disadvantage.<sup>21</sup> Though not entirely linear, the valve had an instrumental or a metrical character that was lacking in other detectors. In sum, the valve had *potential* merit as a '*metrical detector*,' not simply as a metre or a detector.

But its obvious and immediate use lay elsewhere. The valve seemed useful in rebuilding his connection to Marconi and the Marconi Company. Having filed a patent for his valve, Fleming wrote to Marconi. In this undated letter (written in late November), he first mentioned his

invention of the wavelength measuring instrument (the cymometer), and then remarked:

I have found a method of rectifying electrical oscillation, 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 mirror galvanometer and my device, but at present only on a laboratory scale. This opens up a wide field for work, as I can now measure exactly the effect of the transmitter.

Then, Fleming assured Marconi that 'I have not mentioned this to anyone yet as it may become very useful.'<sup>22</sup>

Fleming's new inventions impressed Marconi who expressed his wish to perform some experiments with Fleming's 'electrical oscillation current rectifier.' Fleming proposed setting up his apparatus at Marconi's factory at Chelmsford, where Marconi 'might come to see it at some convenient time.' In his Friday Lecture on 3 March 1905, Marconi exhibited the cymometer and the valve. After the lecture, Marconi asked Fleming if he could borrow the valve for more experiments.<sup>23</sup> This was an opportunity for Fleming to firmly re-establish his connection with Marconi, one that Fleming took care not to miss. He immediately replied to Marconi:

The only valve I have in my possession which works well is the one I lent you for your lecture, and with which all the work for my Royal Society paper was done. I do not wish to part with this valve as I shall have then no means of making comparison measurements. I will endeavour to get a couple of good valves made as soon as possible and sent over to you. Meanwhile I should like to draw your attention to the matter of my agreement with the Company about which I spoke to you when we last meet. In your absence I trust the matter will not be prolonged as it will be to the interest of the Company that it should be reestablished.<sup>24</sup>

A few months later, in May 1905, the Marconi Company re-appointed Fleming as scientific advisor starting on the first of that same month. A Memorandum of Agreement was signed between the two directors of the Company and Fleming. The agreement contained four terms, the third of which specified that Fleming's inventions made between 1 December 1903 and 1 May 1905 would be put under the same agreement as if he had been a scientific advisor during that time.

In particular the said John Ambrose Fleming shall from time to time and at all times during the said period [1 May 1905–30 April 1908] communicate to the Company free of all charge and expense all improvements discoveries and inventions which he may hereafter make or become acquainted with in connection with the Company's business or any part thereof and shall also at the request and cost of the Company but free of charge use his best endeavour to obtain letters patent and/or the foreign equivalents thereof in such countries as the Company may desire in respect of any such improvements discoveries and inventions (*whether the same may have been made or brought to his knowledge heretofore since the expiration of the first above mentioned period of three years from the first day of 1 December, 1900, or may be made or brought to his knowledge hereafter during the period of this agreement*) ...<sup>25</sup>

Though the patent on the valve was issued in the single name of Fleming, the Marconi Company now had rights to it.

For the following few years until around 1907, Fleming, not Marconi, ordered the fabrication of the valve at the workshop of the Ediswan Company in Ponders End. Charles Gimingham of the Ediswan Company, a skilled artisan of lamp construction and Fleming's life-long friend, made them under Fleming's instruction. Whenever Marconi and the Marconi Company asked Fleming for valves, Fleming ordered them and Fleming's assistant, G. B. Dyke, took them to the Marconi Company. But, even during this early period, the *use* of the valve was not under Fleming's control. In late 1906, one Italian professor asked Fleming whether he could obtain the valve for scientific experiments. Thinking it possible, Fleming told Marconi about this, saying that 'even if you wish to keep the exclusive use of the valve for wireless telegraphy, it might still be possible to supply it for such other scientific uses as do not conflict with your work.'<sup>26</sup> Marconi, however, refused to hand over the valves to others, on the basis of his current experiments on the valve as a long-distance wireless detector. In 1907, however, Marconi decided to hand over several valves to the Italian Government, and Fleming was asked to give instruction to the Italians.

Marconi's experiment, not Fleming's, transformed the valve into a sensitive detector for wireless telegraphy. In mid-1905, while experimenting with the device, Marconi found that it became much more sensitive when he replaced the galvanometer with a telephone. In 1906–1907, Marconi increased its sensitivity by connecting a telephone inductively to the valve circuit using his oscillation transformer or 'jigger.' Only with this modification did the valve become 'one of the best long distance receiver yet made, under some conditions better even than the magnetic detector.' But it was still far from a manageable device. It developed problems when used with Marconi's new 'continuous waves' (which were actually quasi-continuous waves with reduced damping). In his station at Poole, Marconi could receive clear signals sent from Poldhu with other receivers, but not with the valve, when the continuous wave was used.<sup>27</sup>

In 1908, Fleming devised a tungsten valve and a new circuit for connecting the valve to the receiver. As in November of 1904, Fleming wrote a letter to Marconi, saying that 'I am anxious this should not be yet known to anybody but yourself.' Marconi, however, did not welcome the new modifications. After some experiments, he informed Fleming that 'Tungsten valves are not more sensitive than the best carbon valves ... [and] that your new arrangement of circuit does not give as good results as the standard circuit which ... is strictly in accordance with the description given in my [Marconi's] patent for the mode of using your valve as a receiver.' After that time, Fleming made no further important contribution to the development of the valve.<sup>28</sup>

During this early period, Fleming apparently was not concerned with the use of his valve by others. In October, 1906, Fleming told Marconi:

[The patent on the valve] is not by any means a strong patent and if we refuse to supply the valve for all purposes, people may import the similar device of Wehnelt from Germany or perhaps make it for themselves. I can hardly believe that the patent is worth fighting. ... Personally I have no interest in the matter; I have already any little scientific credit there may be for the invention.<sup>29</sup>

Just after this, however, the development of the valve took an unforeseen direction. Lee de Forest in America announced his invention of the audion in October 1906. Basically, de Forest inserted a grid (applied to a separate potential difference) in the vacuous space between the plate and the filament, by means of which the current flow in the space was controlled. With this improvement, de Forest argued that the audion showed not only rectification, but also amplification, of received signals. He tried to undermine Fleming's earlier contribution as much as he could. As to its scientific side, de Forest stressed that Fleming's work on unilateral conductivity in the Edison effect had already been anticipated by Elster and Geitel. De Forest argued that the use of Fleming's valve was confined to 'quantitative measurements over short distances.' He even remarked:

The value of such a device [Fleming's valve] as a wireless telegraph receiver is nil. Exceedingly powerful signals are required to affect this galvanometer at all. Put a telephone in the circuit, and if the signals are sufficiently intense you can detect the pulsating currents in the telephone. But it is not practicable in commercial wireless telegraphy.<sup>30</sup>

Even though Fleming did not read de Forest's paper in full, the abstract published in the *Electrician* was enough to infuriate him. Fleming immediately countered that 'the actual construction of the apparatus [the Audion] is the same [as mine]' and that his valve had been actually used as a sensitive receiver in wireless telegraphy. In his reply, de Forest again argued that the real genesis of his audion, as well as Fleming's valve, was Elster and Geitel's research in the 1880s. He then compared the valve to 'a laboratory curiosity' and the audion to 'an astonishingly efficient wireless receiver employing the same medium, but operating on a principle different in kind.'<sup>31</sup> Fleming's credibility was threatened, which was unbearable to him. This brought him into an alliance of mutual interest with Marconi, since de Forest was one of Marconi's chief competitors. Fleming thus urged Marconi:

It is extremely important that de Forest in America should not be allowed to appropriate all methods of using the glow lamp detector ... I want our Company to have all the

commercial advantage possible but I am anxious that de Forest shall not deprive me of the scientific credit of the valve invention as he is anxious to do ...<sup>32</sup>

This was the beginning of Fleming's life-long animosity against de Forest. They again crossed swords in 1913 through the column of the *Electrician*. But the controversy was not to be resolved in engineering journals; it was resolved in court. In 1917, Fleming began his legal battle with de Forest in the court of United States of America. Four years later, in 1921, Fleming's priority in the utilization of the two electrode lamps in wireless telegraphy was supported by the U. S. court.<sup>33</sup>

De Forest's audion apparently forced Fleming to ponder the originality of his invention. Fleming knew that originality did not lie in the device itself—a lamp with one more electrode—because it had been made by Edison, as well as by Elster and Geitel. Rectification of high-frequency alternating current was insufficient, because it could be regarded as 'a laboratory curiosity.' De Forest persistently argued that only his audion suited to practical detection. Fleming for his part repeatedly emphasized that what he had invented was a new detector for wireless telegraphy, whereas what de Forest had done was simply to add one more plate to his valve. This way of thinking seemed to be firmly implanted in his mind after the patent litigation against de Forest. Fleming first recalled how he invented his valve in 1920, when he was in the middle of the battle with de Forest. The same story was then repeatedly told. It was reiterated by engineers and historians of later generations.

### **Conclusion**

Fleming's valve became more famous after the 'triode revolution' in the mid-1910s.<sup>34</sup> The triode, or the audion, began to be used not only as an amplifier but also as an oscillator for continuous waves. As the audion became more essential to radio engineering, the valve—as audion's predecessor—was increasingly highlighted. However, Fleming was not always happy with the changed situation. In a sense, Fleming became increasingly frustrated. In 1918, the Marconi Company applied for an extension of Fleming's patent, but it was dismissed on the grounds that the Company had earned sufficient profit by the sale of Fleming's valve. However, 'as the original inventor of it,' Fleming later complained 'I have never received a single penny of reward for it.' In addition, in Fleming's view, the Company hurt Fleming's credibility by dissociating Fleming's name from his invention. Only after he resigned the scientific advisorship to the Marconi Company, he confessed that 'one firm has sold valves for many years made exactly in accordance with my patent specification, but which they advertise and mark "Marconi Valves."<sup>35</sup> This 'injustice of some present-day commercial practice' that he lamented was the price he paid for resuming his connection with the Marconi Company in 1905.

Fleming's recollection of the invention of the valve can be characterized by the continuity of the device to his previous work (the Edison effect), as well as by the radical discontinuity between his and others' work. He stressed his 'scientific' research on the Edison effect that he had conducted in the 1880s and 1890s, the importance of his role as scientific advisor to Marconi, and the demand for new detectors around 1904, as well as the valve's straightforward use as a sensitive detector when it was invented. However, I have revealed complexities and contingencies behind this neat story of Fleming. The invention turns out to have more to do with local and temporal resources specifically available to Fleming in the fall of 1904, than his long-term research on the Edison effect or the putative high demand for new detectors for wireless telegraphy. I argued that the combination of heterogeneous factors such as Fleming's previous research on the measurement of high-frequency alternating current by rectification, Fleming's dismissal from the Marconi Company at the end of 1903, Nodon's electrolytic valve publicized by the *Electrician* in October 1904, and the electron theory formed technical, material, conceptual, and linguistic resources that Fleming mobilized in a timely manner.

I also tried to show that the use of the valve was not clearly defined in 1904. Fleming intended it to be a measuring instrument, a meter. Its irregular and nonlinear current-voltage characteristics made it very difficult to use the device as a meter. As a detector, it was less sensitive than other detectors. But it had a social use. It was successfully exploited to revive Fleming's severed connection to the Marconi Company. As a detector, it remained auxiliary until Marconi connected a telephone and a jigger to the valve circuit. I have also shown that Fleming became much concerned about his credit as the inventor of the valve when de Forest depreciated Fleming's originality. The 'canonical' story about the invention of the valve was first remembered by Fleming when he was deeply engaged in a lawsuit with de Forest.

I have tried to criticize this 'canonical' story by discovering various factors which I believe shape a more appropriate and compelling context for Fleming's invention. I have also located Fleming's canonical story in its own context—the context of his battle with de Forest and the subsequent patent litigation. The usefulness of the device and its history have been constructed and consolidated into the form that we now know today in a very similar fashion. Inventors not only invent a novel artifact; they also invent a novel history for it.

#### *Acknowledgements*

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## Notes

1. For the interrelatedness between recalled narratives of an invention and patent litigation, see Sungook Hong, 'Marconi and the Maxwellians: the Origins of Wireless Telegraphy Revisited,' *Technology and Culture* 35 (1994), 717–749. The constructed nature of the history of scientific discoveries written by the actors involved in them is well discussed by Simon Schaffer, 'Scientific Discoveries and the End of Natural Philosophy,' *Social Studies of Science* 16 (1986), 387–420. The role of a collective memory for the scientific community is examined by Pnina Abir-Am, 'A Historical Ethnography of a Scientific Anniversary in Molecular Biology: The First Protein X-ray Photograph,' *Social Epistemology* 6 (1992), 323–354.
2. Another paper of mine focuses on the transformation from the Edison effect to the valve. See Sungook Hong, 'From Effect to Artifact (II): The Case of the Thermionic Valve,' *Physis* 33 (1996), 85–124.
3. J. A. Fleming, 'The Thermionic Valve in Wireless Telegraphy and Telephony' (Friday Evening Lecture on 21 May 1920), *Proceedings of the Royal Institution* 23 (1920), 167–168. See also J. A. Fleming, 'How I Put Electrons to Work in the Radio Bottle,' *Popular Radio* 3 (1923), 175–182.
4. G. Shiers, 'The First Electron Tube,' *Scientific American* 220 (March 1969), 109; Hugh G. J. Aitken, *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton, 1985), p. 205.
5. For magnetic and electrolytic detectors, see, respectively, T. H. O'Dell, 'Marconi's Magnetic Detector: Twentieth Century Technique Despite Nineteenth Century Normal Science?' *Physis* 25 (1983), 525–548 and V. J. Phillips, *Early Radio Wave Detectors* (London, 1980), pp. 65–84.
6. For some general considerations of experimental culture in the laboratory, see Jed Buchwald, *The Creation of Scientific Effects: Heinrich Hertz and Electric Waves* (Chicago, 1994); Ian Hacking, 'The Self-Vindication of the Laboratory Science,' in Andy Pickering (ed.), *Science as Practice and Culture*, (Chicago, 1992), pp. 29–64; Andy Pickering, 'The Mangle of Practice: Agency and Emergence in the Sociology of Science,' *American Journal of Sociology* 99 (1993), 559–589.
7. J. A. Fleming, 'A Note on a Form of Magnetic Detector for Hertzian Waves adapted for Quantitative Work,' *Proceedings of the Royal Society* 71 (1903), 398–401.
8. J. A. Fleming, 'A Note on a Form of Magnetic Detector,' p. 400. Twelve years later, Fleming modified it as follows:

Since the interrupter discs are rotated very rapidly, if the oscillations continue, this intermittent electromotive force produce a *practically steady current* through the galvanometer which is proportional to the demagnetizing force being applied to them.

J. A. Fleming, *An Elementary Manual of Radiotelegraphy and Radiotelephony* (London, 1916), p. 205.
9. J. A. Fleming, 'A Note on a Form of Magnetic Detector,' pp. 400–401.
10. J. A. Fleming, 'Hertzian Wave Telegraphy' (Cantor Lecture given on 16 March 1903), *Journal of the Society of Arts* 51 (1902–03), 762.
11. V. Buscemi, 'Trasparenza dei Liquidi per le onde Hertziane,' *Nuovo Cimento* 9 (1905), 105–112. Figure 3 comes from this paper.
12. Fleming's hot-wire ammeter was able to measure 10 milliamperes within an accuracy of 2–3 percent and it could detect 5 milliamperes, but did not measure below 5 milliamperes, which was its serious weakness. See J. A. Fleming, 'On a Hot-Wire Ammeter for the Measurement of Very Small Alternating Currents' (read at the Physical Society on 25 March 1904), *Proceedings of the Physical Society* 19 (1904), 173–184.
13. For this, see Sungook Hong, 'Styles and Credit in Early Radio Engineering: Fleming and Marconi on the First Transatlantic Wireless Telegraphy,' *Annals of Science* 53 (1996): 431–465; 'Syntony and Credibility: John Ambrose Fleming, Guglielmo Marconi, and the Maskelyne Affair,' *Archimedes* 1 (1996), 157–176.
14. For a useful description of various rectifiers, see P. Rosling, 'The Rectification of Alternating Currents,' *Electrician* 58 (1906), 677–679. The rotary converter was a 'gateway technology' which enabled the coupling of different networks of AC and DC systems. For this, see Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore and London, 1983), pp. 120–121.
15. For a useful description of the rectifiers, see P. Rosling, 'The Rectification of Alternating Currents,' *Electrician* 58 (1906), 677–679.
16. A. Nodon, 'Electrolytic Rectifier: An Experimental Research' (read at the St. Louis International Congress), *Electrician* 53 (14 October 1904), 1037–1039. On the description of Fleming's trial with the Nodon valve, see J. A. Fleming, 'On the Conversion of Electric Oscillation into Continuous Currents by means of Vacuum Valve,' *Proceedings of the Royal Society* 74 (1905), 476.

17. For the dispute between Fleming and de Forest over electrolytic detectors, see Fleming's and de Forest's letters to the Editor of the *Electrician* in 1906. J. A. Fleming, 'Oscillation Valve or Audion,' *Electrician* 58 (30 November 1906), 263; L. de Forest, 'Oscillation Valve or Audion,' *Electrician* 58 (29 December 1906), 425; J. A. Fleming, 'Oscillation Valve or Audion,' *Electrician* 58 (4 January 1907), 464. The quotation is from Fleming's 26 November letter. It was the first published identification of the date, but after 1920 he said that he had invented it someday in October 1904. For this 'October-invention' story, see J. A. Fleming, *Memories of a Scientific Life* (London, 1934), p. 141.
18. J. A. Fleming, *Memories*, p. 141. The first circuit is described in J. A. Fleming, 'The Construction and Use of Oscillation Valves for Rectifying High-Frequency Electric Currents,' *Proceedings of the Physical Society* 20 (1906), 177–185.
19. The role of the electron theory for the invention of the valve is described in detail in Sungook Hong, 'The Electron Theory and Wireless Telegraphy,' a paper read at the workshop on the 'Electron and the Birth of Microphysics' (Dibner Institute, MIT, 10 May 1997). For Fleming, as for J. Larmor, the electron was not a solid particle like a billiard ball. It was instead a kink, or knot, of the ether strain. Fleming detailed his electron theory in his Friday Lecture, 'The Electronic Theory of Electricity' (Friday Lecture given on 30 May 1902), *Proceedings of the Royal Institution* 17 (1902), 163–181.
20. J. A. Fleming, 'Improvements in Instruments for Detecting and Measuring Alternating Electric Currents,' Provisional specification, British patent No. 24,850, 16 November 1904.
21. Fleming, 'On the Conversion of Electric Oscillation,' p. 480.
22. Fleming to Marconi, n.d., (circa 30 Nov. 1904), Marconi Company Archives [hereafter abbreviated MCA], Chelmsford. G. Shiers, who argues that Fleming invented his valve because of the urgent need for new detectors, presented this letter of Fleming's to Marconi as a piece of supporting evidence. However, nowhere in this letter did Fleming mention that he had found a new detector. The phrase that 'I can now measure exactly the effect of the transmitter,' in fact, supports my point. See Shiers, footnote 4, p. 111. Aitken, footnote 4, p. 211, also quotes this letter from Shiers, but Aitken seems to have noticed that Fleming invented it as a meter, not as a detector (on p. 212).
23. Marconi to Fleming, 14 Feb. 1905, University College London [hereafter abbreviated UCL] MS Add 122/1, Fleming Collection. Fleming to Marconi, 15 Feb. 1905, MCA, Chelmsford. G. Marconi, 'Recent Advances in Wireless Telegraphy' (Friday Lecture on 3 March 1905), *Proceedings of the Royal Institution* 18 (1905), 31–45.
24. Fleming to Marconi, 24 March 1905, MCA, Chelmsford.
25. 'Memorandum of Agreement between the Marconi Company and Fleming' 26 May 1905, MCA, Chelmsford.
26. Fleming to Marconi, 9 Oct. 1906, MCA, Chelmsford.
27. (A copy of) Fleming to A. R. M. Simkins (Work Manager of Marconi Company), 17 Jan. 1907, UCL MS Add 122/48, Fleming Collection; Marconi to Fleming, 14 April 1907, UCL MS Add 122/48, Fleming Collection; (A copy of) Fleming to Marconi, 15 April 1907, UCL MS Add 122/48, Fleming Collection.
28. (A copy of) Fleming to Marconi, 8 Sep. 1908, UCL MS Add 122/48, Fleming Collection; Marconi to Fleming, 8 Jan. 1909, UCL MS Add 122/48, Fleming Collection.
29. Fleming to Marconi, 9 Oct. 1906, MCA, Chelmsford.
30. Lee de Forest, 'The Audion: A New Receiver for Wireless Telegraphy,' *Transactions of the American Institute of Electrical Engineers* 25 (1906), 748, 775. Its abstract was published in *Electrician* 56 (1906), 216–218.
31. See the exchanges between Fleming and de Forest cited in note 17.
32. (A copy of) Fleming to Marconi, 14 Jan. 1907, UCL MS Add 122/48, Fleming Collection.
33. For the story of the patent litigation over the vacuum tube see G. W. O. Howe, *The Genesis of the Thermionic Valve in Thermionic Valves 1904–1954: The First Fifty Years* (London, 1955), pp. 15–16.
34. For the 'triode revolution' refer to Sungook Hong, 'The Triode Revolution: A New Interpretation' (Colloquium at the Institute for the History and Philosophy of Science and Technology, University of Toronto, 25 November 1998).
35. Fleming, *Memories*, p. 147.