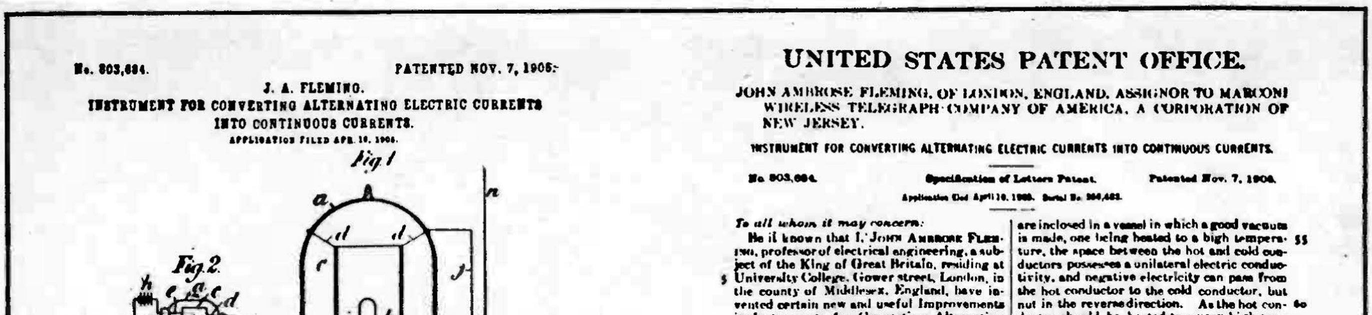
THE SAGA OF THE VACUUM TUBE

by GERALD F. J. TYNE
Research Engineer, N. Y.

Part 4 covering the development of communications for wireless telegraph, using thermionic tubes for the first time.

WHILE the work we have been describing was proceeding, the development of the then infant branch of the communications art, the wireless telegraph, was being carried on steadily. Since the earliest utilization of thermionic tubes was in wireless telegraphy, let us see how the two paths of thermionics and communication converged and formed the highway to the modern field of radio. The road thus formed led to the invention of communication systems on which, at the present time, the very security of the American way of life depends. All the knowledge of electromagnetism, heat, and vacua were brought together to solve the problems of converting the high frequency oscillations into sound.

In 1899, John Ambrose Fleming became a technical adviser to Marconi and in 1900 started assisting him in preparations for the experiments which were to lead to the establishment of transatlantic wireless telegraph communication, first in the matter of the transmitting apparatus and later as regards the receiving devices. In those days the only detector of wireless telegraph signals was of the contact type—coherers, microphones, and the like. The mechanical delicacy and erratic behavior of such devices led Marconi to develop the Magnetic Detector that proved to be reliable and stable and not to be thrown out of adjustment by the operation of nearby transmitters, but on the score of sensi-


No. 803,684. PATENTED NOV. 7, 1905.

J. A. FLEMING.

INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS.

APPLICATION FILED APR. 19, 1905.

UNITED STATES PATENT OFFICE.

JOHN AMBROSE FLEMING, OF LONDON, ENGLAND, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, A CORPORATION OF NEW JERSEY.

INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS.

No. 803,684. Specification of Letters Patent. Patented Nov. 7, 1905.

Application filed April 19, 1905. Serial No. [illegible].

To all whom it may concern:

Be it known that I, JOHN AMBROSE FLEMING, professor of electrical engineering, a subject of the King of Great Britain, residing at University College, Gower street, London, in the county of Middlesex, England, have invented certain new and useful Improvements in Instruments for Converting Alternating Electric Currents into Continuous Currents, of which the following is a specification.

This invention relates to certain new and useful devices for converting alternating electric currents, and especially high-frequency alternating electric currents or electric oscillations, into continuous electric currents for the purpose of making them detectable by and measurable with ordinary direct-current instruments, such as a "mirror-galvanometer" of the usual type or any ordinary direct-current ammeter. Such instruments as the latter are not affected by alternating electric currents either of high or low frequency, which can only be measured and detected by instruments called "alternating-current" instruments of special design. It is, however, of great practical importance to be able to detect feeble electric oscillations, such as are employed in Hertzian-wave telegraphy by an ordinary movable coil or movable needle mirror-galvanometer. This can be done if the alternating current can be "rectified"—that is, either suppressing all the constituent electric currents in one direction and preserving the others or else by changing the direction of one of the sets of currents which compose the alternating current so that the whole movement of electricity is in one direction. Many means have been devised and are in use for rectifying low-frequency alternating currents, such as are used in electric lighting. There are well-known forms of mechanical rectifier; also, there is a well-known form of electrochemical rectifier, depending on the fact that when a plate of carbon and aluminium is placed in any electrolyte which yields oxygen on electrolysis an electric current can only pass through this cell in one direction if below a certain voltage. Both these forms of rectifier are, however, inapplicable for high-frequency currents. I have found that the aluminium-carbon cell will not act with high-frequency currents.

I have discovered that if two conductors are inclosed in a vessel in which a good vacuum is made, one being heated to a high temperature, the space between the hot and cold conductors possesses a unilateral electric conductivity, and negative electricity can pass from the hot conductor to the cold conductor, but not in the reverse direction. As the hot conductor should be heated to a very high temperature—say near to the melting-point of platinum, (1,700° centigrade)—it should be of carbon, preferably in the form of a filament such as is used in any ordinary incandescent electric lamp. The cold conductor may be of many materials; but I prefer a bright metal, such as platinum or aluminium or else carbon. The two conductors are inclosed in a glass bulb similar to that of an incandescent lamp, and I generally heat the carbon filament to a high state of incandescence by a continuous electric current, the electrical connection to the filament and the cold conductor being made by platinum wires, sealed air-tight through the glass.

Figure 1 is a full-size sectional elevation of an instrument constructed according to this invention, the electrical connections being shown diagrammatically. This figure illustrates the application of the invention to wireless telegraphy. Figs. 2 and 3 show modifications to smaller scales.

In Fig. 1, *a* is a glass bulb, and *b* is a carbon filament like the carbon filament of an incandescent lamp, suitable, say, for taking a current of six to eight volts and two to four amperes. *c* is a cylinder of aluminium, open at the top and bottom, which surrounds but does not touch the filament. The cylinder *c* is suspended and steadied by platinum wires *d*, and the ends of the filament *b* are connected to platinum wires connected to the leads *e* and *f*. The platinum wires are sealed through the glass in the ordinary manner.

As a very high vacuum should be obtained in the bulb *a* and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted. The filament *b* can be conveniently heated by passing a current through it, while the cylinder *c* can be heated by surrounding the bulb *a* with a resistance-coil through which a current is passed, the whole being inclosed in a box lined with asbestos or the like. When, as hereinafter described, the cylinder *c* is re-

Fig. 15. One of the earliest patents of John Ambrose Fleming.

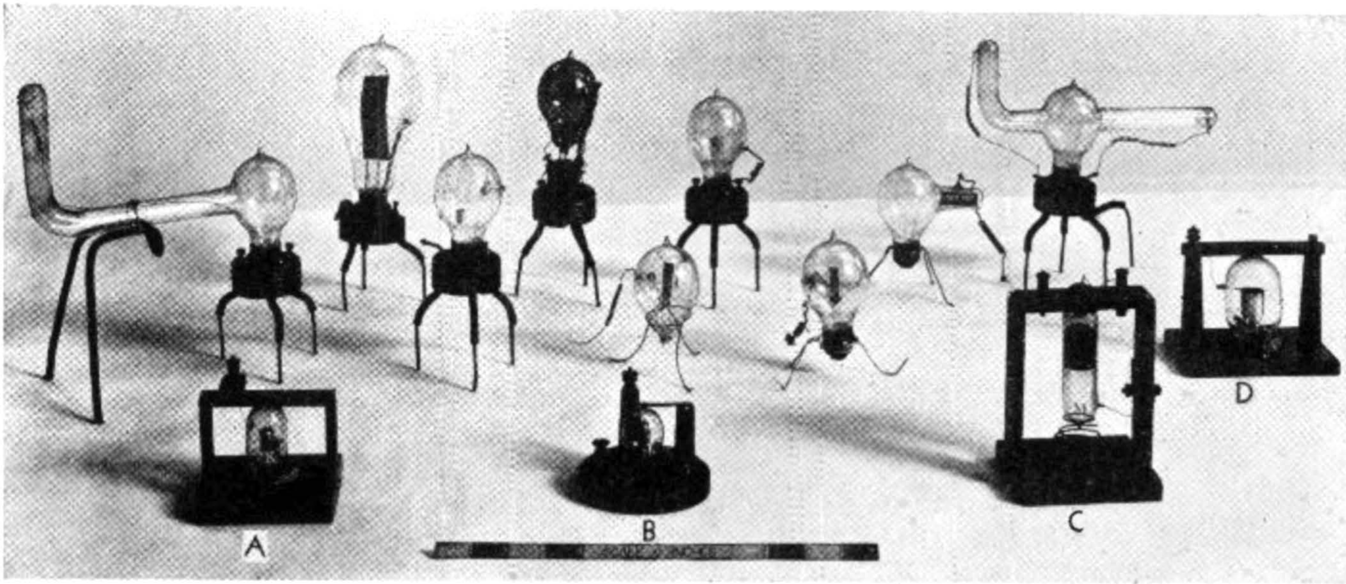


Fig. 16. Group of Fleming valves preserved in the Science Museum at South Kensington, England.

tivity it left much to be desired. In wireless the receiver continued to be a weak element of the system, so that one of the problems which Fleming set himself was that of developing a new type of detecting device. Since he was the victim of a progressive deafness he sought a device which would be capable of operating a recording mechanism, so that the signals might be fixed to be later translated by eye rather than by ear.

The most sensitive current indicating device in use at that time was the d'Arsonval type of mirror galvanometer, which operates only on unidirectional currents. Consequently, Fleming set about finding some means of utilizing this sensitivity, and realized that he needed some device which would act as a rectifier for the incoming high frequency oscillations, in order to have them actuate this type of galvanometer. At that time the available commercial rectifiers were of the electrolytic variety, such as the "Nodon" type. Fleming tried to use these arrangements for the rectification of high frequency oscillations but found them inoperative. This may have been due to the high capacitance of the electrolytic cells, or the fact that their chemical action was too slow. At any rate, he was unsuccessful in their use. Then Fleming did the thing which has so often produced revolutionary developments in many fields. He drew on the knowledge which he had gained by experiment in a totally different field, that of the incandescent lamp. He recalled to mind the work he had done many years before on the Edison effect, and decided to find out by experiment whether the known unidirectional conductivity of the vacuous space for direct current, and its rectifying action at low frequencies, would also exist at the high frequencies of the oscillations used in wireless telegraphy.

Accordingly, in October, 1904—but let us hear his own account of the discovery:[103]

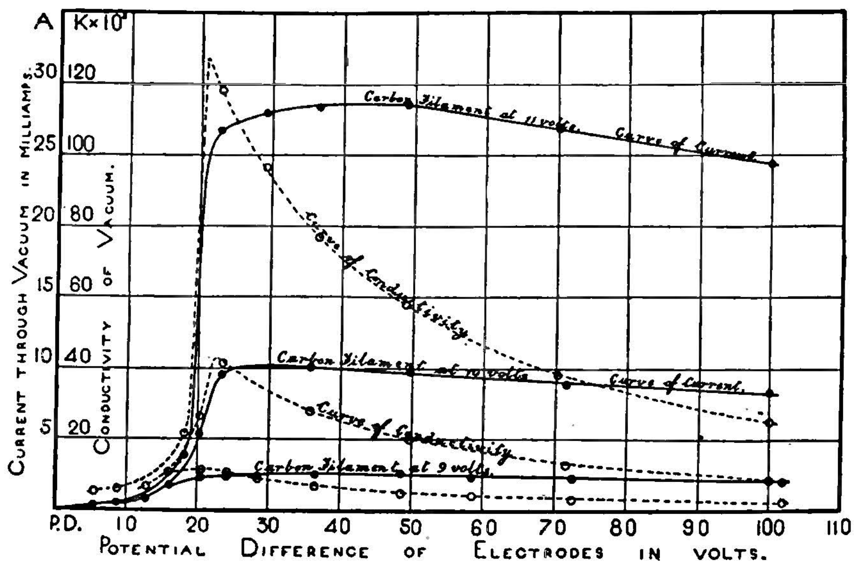


Fig. 17.

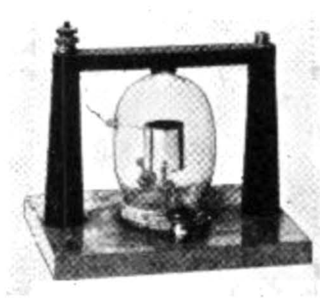


Fig. 18.

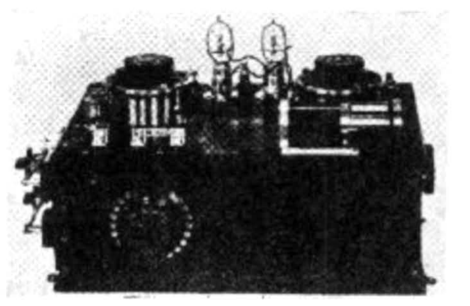


Fig. 19.

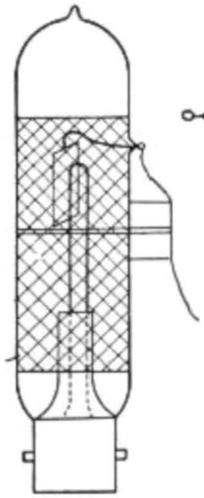


Fig. 20.

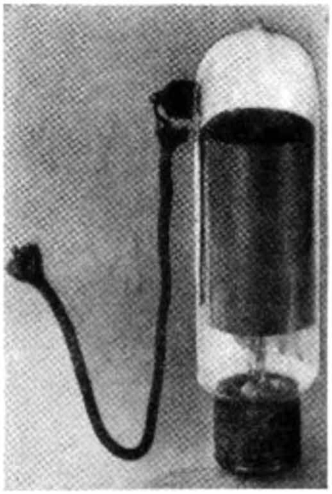


Fig. 21.

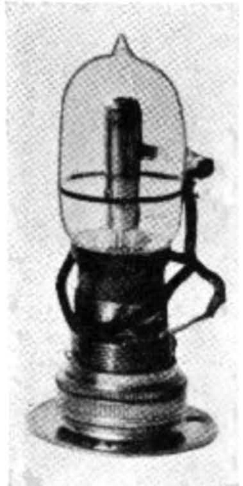


Fig. 22.

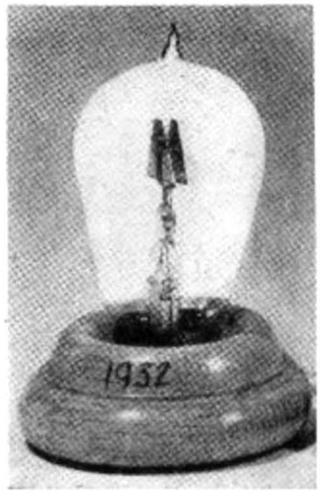


Fig. 23.

Fig. 24.

Fig. 25.

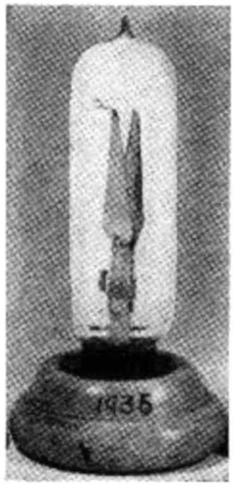


Fig. 26.

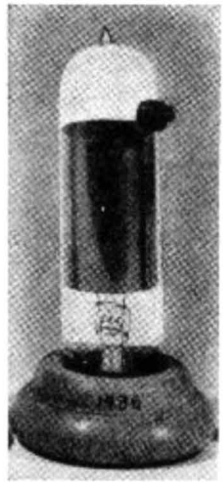


Fig. 27.

"—I was pondering on the difficulties of the problem when my thoughts recurred to my experiments in connection with the Edison effect.

"Why not try the lamps?" I thought.

Then and there I determined to see if they would serve the purpose. I went to a cabinet and brought out the same lamps I had used in my previous investigations. My assistant helped me to construct an oscillatory circuit with two Leyden jars, a wired wooden frame, and an induction coil. We then made another circuit, in which we inserted one of the lamps and a galvanometer, afterward tuning it to the same frequency as the first circuit.

It was about five o'clock in the evening when the apparatus was completed. I was, of course, most anxious to try the experiment without further loss of time. We set the two circuits some distance apart in the laboratory and I started the oscillations in the primary circuit.

To my delight I saw the needle of the galvanometer indicate a steady direct current passing through, and found that we had in this peculiar kind of electric lamp a solution of the problem of rectifying high frequency wireless currents. The missing link in wireless was found—and it was an electric lamp."

Fleming gave the name *"oscillation valve"* to the Edison effect lamp as thus utilized, and today in England all types of vacuum tubes are still known as *valves.* In fact, all such electron discharge devices are, in general, considered by the British as lineal descendents of the Fleming valve.

It cannot be emphasized too strongly, however, that Fleming did not invent the device to which he gave the name "oscillation valve." What he did was to apply the Edison effect lamp, a well known device, to the rectification of high frequency oscillations. His patent was not a patent on the device, *per se,* but on the combination of that known device, with minor modifications to suit the application, and a circuit in which it functioned as a rectifier of high frequency oscillations.

Actually Fleming was not the first to use a thermionic device as a rectifier, for just ahead of him was the pure thermionic device with the oxide-coated cathode devised and patented by Wehnelt, as we shall see. Also it is hardly fair today to read the term "valve" as taken from Fleming, on the three element and multi-element tubes used in today's amplifiers, since in this role the device cannot be classed as a rectifier.

In this connection the following passage, from a British text published in 1921, is of interest: [104]

"Fleming, in 1904, utilized the Edison effect, and Elster and Geitel's apparatus in a modified form, to produce a wireless detector, rectification being brought about owing to the unidirectional conduction already mentioned—.

(Continued on page 58)

Saga of Vacuum Tube

(Continued from page 32)

The Fleming valve was purely and simply a rectifier or detector. In no way was it an intensifying device, it did not use a very high vacuum, as is the case in the modern valves of Langmuir and Meissner, and it was not a means of generating oscillations like these later valves.

Whilst Fleming must be credited as being the first to apply thermionic phenomena to wireless detection, the claim that he is alone the originator of the present-day thermionic valve is rather exaggerated, since the intensifying properties of the present-day valve are far more important than its detecting properties—."

Fleming applied for patents on the use of the valve as a detector of oscillations in wireless telegraphy, which patents were granted in Great Britain, Germany, and the United States.[105] Fleming believed that to get complete rectification it was necessary to have the best possible vacuum in the valve. In his United States patent application (See Figure 15) he stated:

"As a very high vacuum should be obtained in the bulb a, *and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted. The filament can be conveniently heated by passing a current through it, while the cylinder* c *can be heated by surrounding the bulb* a *with a resistance coil through which a current is passed, the whole being inclosed in a box lined with asbestos or the like."*

This insistence by Fleming on the obtaining of the highest vacuum possible, and the use of only one battery, the filament battery (See Figure 15), should be carefully noted by the student, for comparison with the work of de Forest on the Audion.

Figure 16 shows a group of Fleming valves of great historic importance, all of which are preserved in the Science Museum at South Kensington, England.[106] Those marked A, B, C, and D are the later types as actually used in the detection of wireless signals.

Immediately after these first experiments, Fleming had made by the Edison and Swan United Electric Company some new lamps in which the filament was of treated carbon, and of such a size that it would be brought to the operating temperature by a battery of 12 volts. These were of the types marked A, B, C, and D (Figure 16) and had a plate in the form of a sheet metal cylinder, surrounding but not touching the filament. This cylinder was fixed to a platinum wire sealed through the glass. The vacuum was pushed to the highest possible point and during the exhaust the filament and the glass bulb were heated in the manner described in Fleming's patent.

Fleming, on February 8, 1905, read to the Royal Society of London a paper[107] wherein he described experiments to determine the apparent conductivity of the vacuous space. In this paper he describes one of the valves used in this experiment as follows:

"A bulb containing a 12 volt carbon filament rendered brightly incandescent by a current of 2.7 to 3.7 amperes was employed. The filament was surrounded by an aluminum cylinder. The length of the carbon filament was 4.5 cm., its diameter 0.5 mm., and surface 70 sq. mm. The aluminum cylinder had a diameter of 2 cm., a height of 2 cm., and surface of 12.5 sq. cm. The filament was shaped like a horseshoe, the distance between the legs being 5 mm."

In this paper Fleming described the use of a separate insulated battery for sending current across the vacuous space, the negative terminal of the battery being connected to the negative terminal of the filament. In this paper he gives data from which the curves shown in Figure 17 were plotted. He also describes experiments using an a.c. potential on the plate. He further showed how two valves might be used to rectify both halves of the oscillation in order to obtain greater output.

On March 23, 1906, Fleming presented another paper,[108] this time before the Physical Society of London. In this paper he presented a number of experiments using his oscillation valves, and showed that they were usable to make quantitative determinations of high frequency oscillations.

On June 15, 1905, or shortly after presenting the Royal Society paper previously mentioned, Fleming sent to Marconi at Poldhu, Cornwall, five of his oscillation valves for trial in service.[109] Marconi at once began to use these valves, a photograph of one of the earliest types of which is shown in Figure 18. Many more of these valves were supplied in 1905 and 1906. In 1907 the British Marconi Company began to manufacture these valves for themselves. These valves were made for use in combination with a special form of receiving circuit in a complete receiver, known as a "Marconi-Fleming Valve" Receiver. This receiver is shown in Figure 19.

Fleming describes the valves first used commercially as follows: [110]

"The valves first supplied were made with carbon filaments and with sheet nickel cylinders or collecting plates, the filament being of such size that it required about 12 volts to bring it to an incandescence corresponding to 3.0 watts per candle. —It was, in fact soon found that for radio telegraphic purposes a small four volt lamp made with a metal cylinder embracing, but not touching, the filament was as effective as a detector as a larger lamp, and required as a heating battery the use of only a couple of portable cells."

Because of the effects of nearby electrically charged bodies on the action of these valves, it was soon found necessary to shield them by means of a covering of copper gauze, which was grounded.

The practical pattern of the Fleming valve which then came into use is described as follows by Fleming: [111]

"The enclosing glass vessel consists of a tube of glass about 1 inch in diameter and 3.5 to 4 inches long. This was equipped at one end with a stem carrying a horseshoe filament of carbon, or later of tungsten wire. The filament was of such a length as to be brightly incandescent at some voltage between 10 and 12 volts. This cylinder is surrounded by a cylinder of copper or nickel sheet attached to a platinum wire sealed through the glass. In a type of valve once used by the Marconi Company, the collecting plate is a single flat plate of copper about 1 cm. square, held near to the carbon or tungsten loop which forms the filament of the valve with the flat surface of the collecting plate parallel to and a few millimeters from the plane of the horseshoe filament loop. The lamp is finished off with the usual bayonet or bottom contact pins so as to work in a standard electric lamp socket.

Figure 20, reproduced from Fleming's book, shows drawings of these valves. This is the first indication of the use of flat plates, or flat anodes, in Fleming valves. Figures 21 and 22 show two commercial valves of the cylindrical anode construction.

Later, in Marconi wireless telegraph receivers, other constructions of Fleming valves, with various types of trapezoidal plates were used. Some of these valves are shown in Figures 23, 24, 25, 26, and 27. Other types using cylindrical anodes were also used, as in Figure 26. Some of those with the trapezoidal plates had spring tension devices to maintain the filaments, which were of inverted "V" shape, type.

CAPTIONS FOR ILLUSTRATIONS

Figure 15. Fleming's United States Patent for the Utilization of the Edison Effect Lamp as a Rectifier of High Frequency Oscillations in Wireless Telegraphy.

Figure 16. Group of Fleming Valves Preserved in the Science Museum at South Kensington, England. Photograph Copyright by *H. M. Stationery Office.*

Figure 17. Characteristic Curves of Fleming Valves. Reproduced from *Proc. Roy. Soc. London.*

Figure 18. Early Type of Fleming Valve Using Cylindrical Plate. Photograph Courtesy *R. McV. Weston.*

Figure 19. Marconi-Fleming Valve Receiver. Two valves are used, with

changeover switch for quick transfer in case of burnout.

Figure 20. Drawings of Early Commercial Forms of Fleming Valve. Note bayonet base for mounting in Ediswan type lamp socket. Reproduced from J. A. Fleming's *The Thermionic Valve and Its Developments.*

Figure 21. Early Commercial Form of Fleming Valve, using Cylindrical Plate. Photograph Courtesy *Radio Corporation of America.*

Figure 22. Later Commercial Form of Fleming Valve, using Cylindrical Plate, and mounted in Ediswan Socket. Photograph Courtesy R. McV. Weston.

Figure 23. Commercial Form of Fleming Valve. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 24. Commercial Form of Fleming Valve. Later development showing improvement in mechanical design. The filament is supported by a tension spring. Commercial product—1913. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 25. Commercial Form of Fleming Valve. This valve has an improved filament support, and the plates are supported by a collar attached to the stem of the bulb. Commercial product—1913. Photo Courtesy *Bell Telephone Laboratories.*

Figure 26. Commercial form of Fleming Valve. Similar in construction to previously made tubes, except that the plate surface is increased and the filament lengthened. Commercial product—1913. Photograph Courtesy *Bell Telephone Laboratories.*

Figure 27. Commercial Form of Fleming Valve. This valve has cylindrical element, and filament is supported by glass arbor inside plate structure. The speciment shown has Ediswan bayonet base, but this valve was also made with Edison medium screw base. Photograph Courtesy *Bell Telephone Laboratories.*

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104. *Leggett, Bernard: "Wireless telegraphy with special reference to the quenched spark system." London*, 1921, *p.* 160.

105. *Fleming, J. A.: Patent No.* 24,850 *of November* 16, 1904, *in Great Britain. Patent No.* 803,684 *of April* 19, 1905, *in the United States. Patent No.* 186,084, *Klasse* 21*a, Gruppe* 68, *of April* 12, 1905, *in Germany.*

106. *Exhibit No.* 20: *Catalogue of the Science Museum at South Kensington—Electrical Communication II*, 1925, *p.* 21. *This catalogue entry describes these valves and tells the purposes for which they were used in Fleming's work.*

107. *Fleming, J. A.: "On the conversion of electrical oscillations into continuous currents by means of a vacuum valve." Proceedings of the Royal Society of London. Vol.* 74, 1905, *pp.* 476-487.

108. *Fleming, J. A.: "The construction and use of oscillation valves for rectifying high frequency electrical currents." Proceedings of the Physical Society of London, Vol.* 20, 1906, *pp.* 177-185. *See also Philosophical Magazine, 6th series, Vol. II, No.* 65, *May* 1906, *pp.* 659-665.

109. *Fleming, J. A.: Transcript of record of proceedings in the case of Marconi Wireless Telegraph Company of America vs. De Forest Radio Telephone and Telegraph Company. U. S. Circuit Court of Appeals. Second Circuit, Equity No.* 12/31. *Deposition of J. A. Fleming, p.* 128.

110. *Fleming, J. A.: "The thermionic valve and its developments in radiotelegraphy and telephony." London*, 1919, *p.* 62.

111. *Fleming, J. A.: See reference* 110, *pp.* 65-66.

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