THE SAGA OF THE VACUUM TUBE

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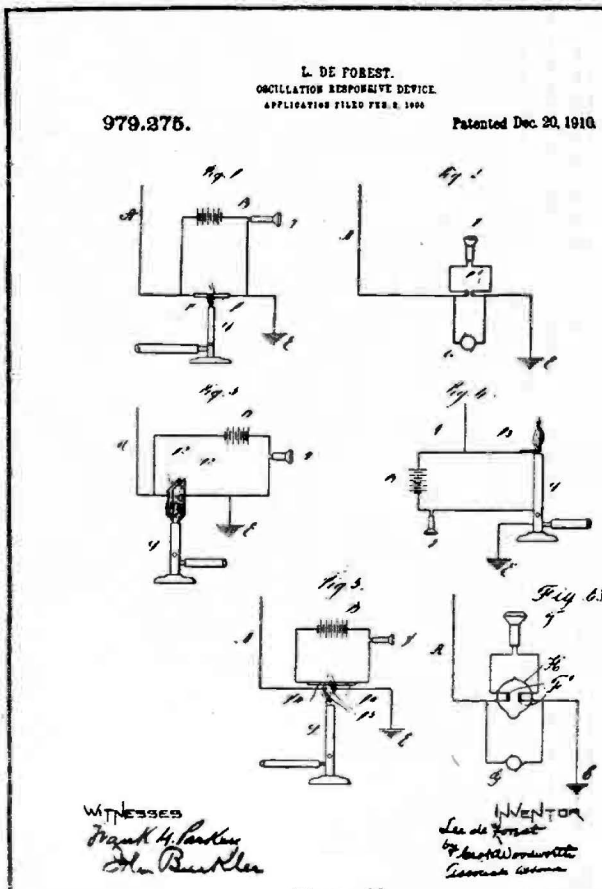
Part 6. Covering the period during which Dr. Lee de Forest was at the height of his inventive career. Many of his tube patents are discussed.

IN THE evolution of the vacuum tube the scene shifts back to America, and to Lee de Forest. De Forest had become very much interested in wireless telegraphy while in his senior year at Yale. Some time after leaving Yale he went to work for the Western Electric Company in Chicago, and later for the magazine "Western Electrician." While there he entered into active partnership with E. H. Smythe of the Western Electric Company. Mr. Smythe was a telephone engineer and had several inventions to his credit at that time. The purpose of the partners was to develop a new system of wireless telegraphy. They first devised a new type of detector, which they called a "Responder." In September, 1900, while conducting tests of the new detector, de Forest noted that when the induction coil used in the experiments was in operation, the gas light in the room, which was of the Welsbach burner type, dimmed. When the coil operation ceased, the light returned. Further experiments made it obvious that the variations in the air pressure caused by the sound waves from the spark gap of the induction coil were what caused the dimming of the light. But in the meantime de Forest and Smythe were imbued with an idea that influenced their thoughts ever after.

Smythe made a note of one of their discussions of this phenomenon on September 20, 1900 as follows:

In developing a hypothesis to fit the observed effect of the inductance coil discharge on the Welsbach light it was suggested that the action was due to an electrification and consequent expansion of the gases of the flame.

De Forest suggested an analogy between sun-spots and their accompanying magnetic disturbances and the miniature magnetic storm in the induc-

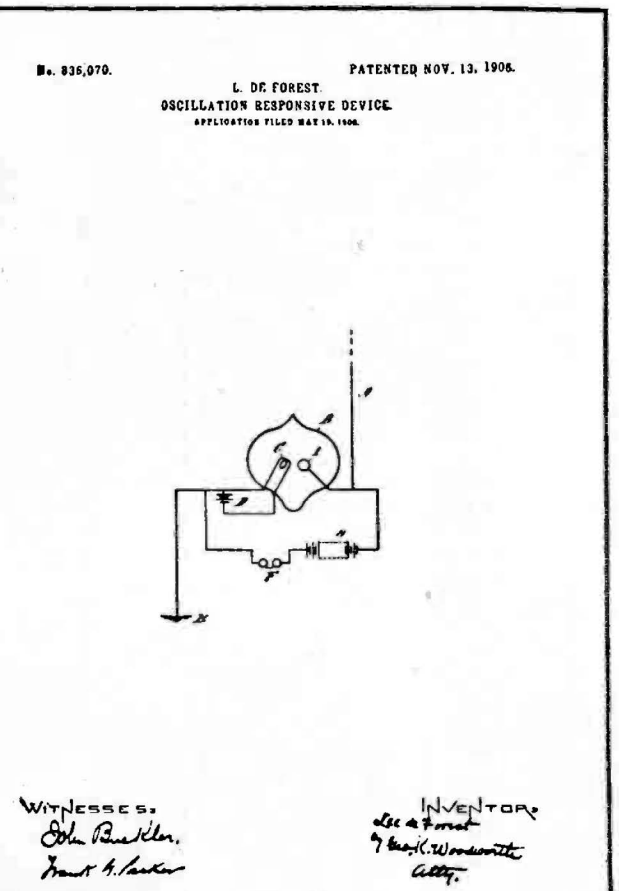

L. DE FOREST.
OSCILLATION RESPONSIVE DEVICE.
APPLICATION FILED FEB. 8, 1906.

979,275. Patented Dec. 20, 1910.

WITNESSES
Frank L. Barker
John Buckler

INVENTOR
Lee de Forest
by Chas. J. Woodworth
Counsel

Figure 36.


No. 836,070. PATENTED NOV. 13, 1906.

L. DE FOREST.
OSCILLATION RESPONSIVE DEVICE.
APPLICATION FILED MAY 19, 1906.

WITNESSES:
John Buckler.
Frank L. Barker

INVENTOR:
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by Chas. J. Woodworth
Atty.

Figure 37.

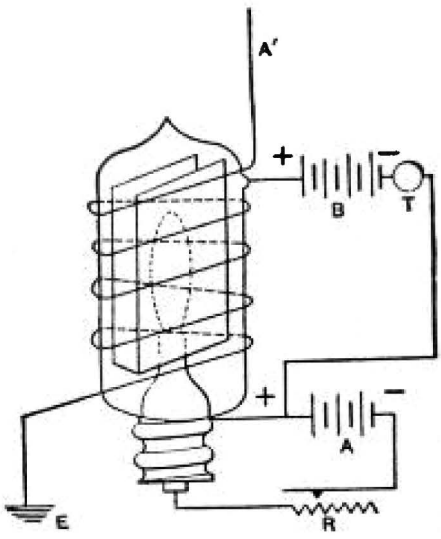


Figure 38.

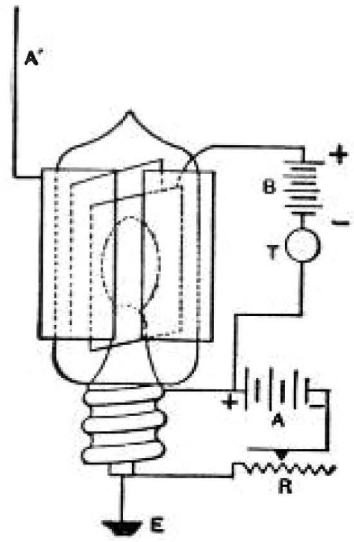


Figure 39.

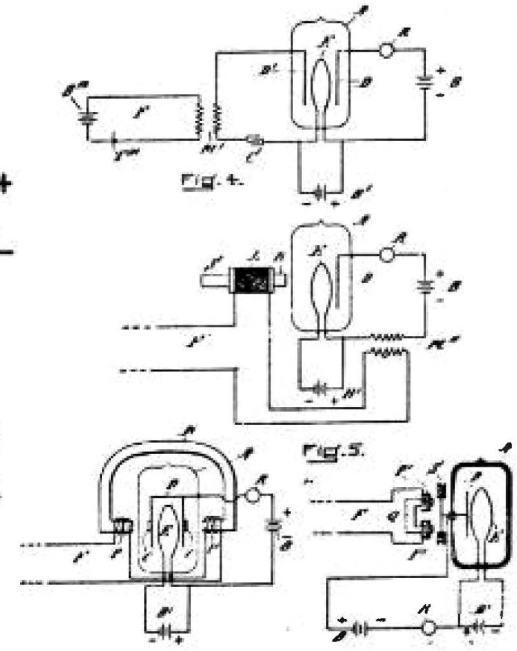


Figure 40.

tance coil and its effect upon the flame. If it should be found true that an electrification of a volume of gas causes expansion, a detector for transmitted impulses might consist of a volume of gas confined and provided with a sensitive instrument adapted to indicating slight changes in pressure. The impulses might be made to affect the gas directly (by confining it in a high upright tube) or indirectly by means of an aerial upright conductor terminating in the receptacle. Possibly the gas could be made more sensitive to the impulses by being rarefied or heated.

While the suggested method of utilization was never realized, the records are of academic interest, and the idea so expressed may well have been the foundation of the later work, by de Forest alone, on the Bunsen burner and rarefied gas tube, both of which were steps in the evolution of the Audion.

A student of the history of the development of wireless during the first decade of this century will find the study of pertinent patent specifications of that period most absorbing. For our purposes at this time we shall examine only those patents forming a definite sequence of steps from the germ of the idea of the heated gas detector to the accomplished fact of the three-electrode grid-type Audion. Some of these devices were found impracticable. The three which are significant are: Patent 979,275 (application date February 2, 1905), which is the parent Bunsen burner patent and is important because it is the first embodiment of the heated gas detector; 836,070 which covers the two-element Audion; and 879,532 (application date January 29, 1907) which covers the three-element grid-type Audion.

We describe briefly twelve patents granted to de Forest, as showing the continuity of development of the Audion. For the convenience of the reader we have starred the significant patents noted above.

About 1903 de Forest, having broken with Smythe, began to search for genuine response to electrical vibrations in the gas flame. He found that the conductivity of the Welsbach burner flame was very small for the range of voltages at which a wireless telegraph detector would be required to operate. Experiments with the flame of the Bunsen burner followed, with the conductivity of the flame increased by the introduction of salts of the alkaline metals. This was actually the first form of Audion. It was not a very practical device, and de Forest thought of it only in connection with wireless telegraphy.

De Forest applied, on February 2, 1905, for a patent ★(U. S. Patent No. 979,275)[125] on such a device and for associated devices shown in Figure 36, among which was one consisting of a bulb filled with a gas (which might be air), in which were two electrodes intended to be heated by a dynamo, although from the diagram given in the patent it would seem difficult of accomplishment. The specification contained numerous claims, and in some cases used such vague phrases as "a self-restoring constantly receptive oscillation responsive device comprising in its construction a sensitive gaseous medium." The various items in this specification were subsequently divided into separate applications which issued as patents as follows: 867,876, issued October 8, 1907; 867,877, issued October 8, 1907; and 867,878, issued February 11, 1908. This last specification claims asymmetric conductivity in the Bunsen burner type detector.

His next patent specification (U. S. Patent No. 823,402),[126] which is for a static valve, discloses another Bunsen burner device, the flame of which is rendered more conductive by the use of salts, and this flame is also described as having asymmetrical conductivity. In this patent he states that positive electricity passes more readily in one direction through the flame than in the other. That is, the Bunsen burner flame acts as a rectifier, and is described as a valve in this specification. This specification also refers to an incandescent lamp type valve which could be used for a similar purpose (as a static valve, and refers to Fleming's paper in the Proceedings of the Royal Society of London[127] for a full description of the physical embodiment of the device.

De Forest's next patent specification (U. S. Patent No. 824,637)[128] was for an oscillation detector "of great simplicity and sensitiveness." This specification covered an invention comprising a receptacle which incloses a gaseous medium put into a condition of molecular activity, so that it is highly sensitive to electrical oscillations when two highly resistant electrodes are heated by an electric current. In the specification, however, it was stated that heating the electrodes was not even necessary, and that the gas might be made responsive to electrical oscillations by heating or by any other suitable means, such as covering the elec-

trodes with a radioactive substance. This specification shows two batteries, one to heat one electrode, the other connected between the electrodes and in series with a telephone receiver.

The original application was subdivided into two others, which issued as patents nos. ★836,070[129] and 836,071[130]. The first of these covers a partially exhausted receptacle into which are sealed two electrodes, one of which may be an ordinary incandescent lamp carbon filament, the other a disc of platinum or other material. Two batteries were shown, as in the original application. The gaseous medium was to be rendered sensitive to electrical oscillations by radiation of heat from the incandescent electrode. (See Figure 37.) *This was the two-element Audion.*

The next specification (U. S. Patent No. 824.638)[131] discloses another type of Bunsen burner detector, in which electrodes of platinum or carbon are placed in the flame. It was claimed that the passage of electrical oscillations through the gaseous medium altered its conductivity.

The next patent specification (U. S. Patent No. 837,901)[132] shows an incandescent lamp detector having a mercury-filled projection on the bulb, which acts as a cold electrode.

This was followed by another specification (U. S. Patent No. 841,386)[133] in which an oscillation detector is described. This consisted of an evacuated vessel having two separated electrodes between which intervened a gaseous medium which formed the sensitive element upon being heated or otherwise rendered highly conducting.

The hybrid name "Audion" was given to this device by C. D. Babcock, one of de Forest's technical aids. The name was derived from the Latin verb *audire* meaning *to hear*, and the Greek derivative *ion*. *Ion* comes from the Greek verb *ienai* meaning *to go*, and the word "ion" had been previously used in connection with electrolytic phenomena to designate an atom carrying a charge and in motion. Hence, "Audion," a device to enable us to hear electricity in motion.

The first public announcement of the invention of the Audion was given by de Forest at the October 26, 1906 meeting of the American Institute of Electrical Engineers in New York, in his paper entitled "The Audion, A New Receiver for Wireless Telegraphy"[134]. This paper was discussed both at this meeting, and at a meeting in Philadelphia which took place two weeks later.

De Forest's paper began by giving an account of the Bunsen burner and electric arc experiments as the foundation of all his work. He described his new invention as a detector for use in wireless telegraphy. It consisted of a partially evacuated glass bulb containing an incandescent lamp filament, the filament being flanked by two platinum "wings" parallel to the plane thereof and about 2 mm. away from it on either side. In the paper de Forest referred to three types of filaments; platinum, tantalum, and carbon.

At the Philadelphia discussion, in response to a question from H. C. Snook, one of the members present, de Forest stated that he was using tantalum filaments entirely, that he had never been able to use the tungsten filament, but that he thought that it (tungsten) might give better results than tantalum. He also said that some work had been done with filaments of the Wehnelt type, coated with alkali salts of potassium and sodium, and that although their life had been short they might yet be produced so as to be better than the tantalum filament.

In his paper de Forest made reference to the work of Elster and Geitel as follows:

"Elster and Geitel, beginning in 1882 a systematic investigation of the ionization produced by incandescent metals, frequently employed an exhausted glass vessel containing an insulated platinum plate, stretched close to which passed a fine metallic filament brought to incandescence by an electric current."

One of Elser and Geitel's earlier papers "Ueber die Electricitat der Flamme" is cited as the foundation of their work, and de Forest then gives a diagram of their later apparatus as described above, taken from a subsequent paper published in 1887.

De Forest also made reference to the work of Fleming with an "Elster and Geitel" tube but stated that the action of the Audion was quite different from that of such a device, and that the Audion acted as a relay rather than as a rectifier. That this was his sincere belief may be adduced from the statements and diagrams of variations in methods of operation, such as the use of an external electrode connected to the antenna (See Figure 38), and the use of what we now know as magnetic control, by passing the high-frequency current through a helix of wire around the Audion bulb (See Figure 39), or through a flat coil brought close to the tube with its axis perpendicular to the tube. These arrangements involved no metallic connections between the oscillatory circuit and the "wings" and hence could not be considered as rectifiers. De Forest attributed the action to the influence of the electrostatic field in the case of the external electrode, and to the electromagnetic field in the case of the coils, on the motion of the ions within the bulb. He also attempted to explain the action of an external permanent magnet on the "flux" (space current) within the bulb.

The discussions which followed the paper showed that the exact principle of operation of the device was not clear, even to de Forest. In response to a question from Percy Thomas at the New York discussion, as to whether the action depended on the ionization of the residual gases or the particles coming from the electrodes themselves, de Forest replied:

"I think that it is due to the ionization of the residual gases; the gases still exist in the lamp, because the vacuum is only that which obtains in all incandescent lamps."

In response to another question from H. C. Snook at the Philadelphia discussion de Forest stated:

"If the exhausting process is carried too far, the Audion loses its sensitive ness. The gas particles rather than the particles of the metal dust are the carriers. I do not believe the dust particles are controlling at all."

Only the day before presenting this

(*Continued on page* 91)

Figure 41.

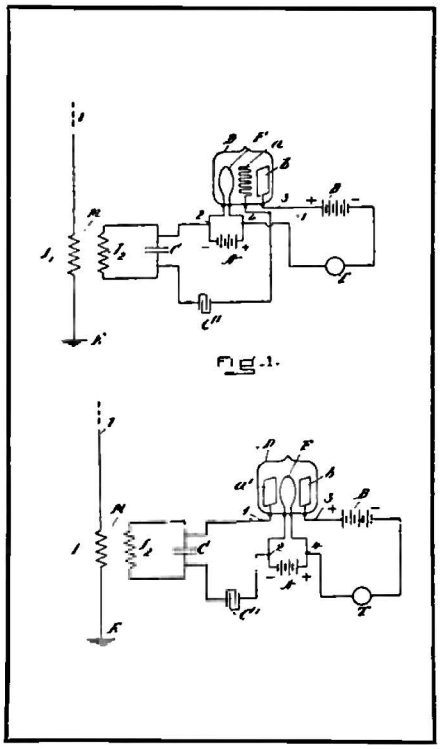
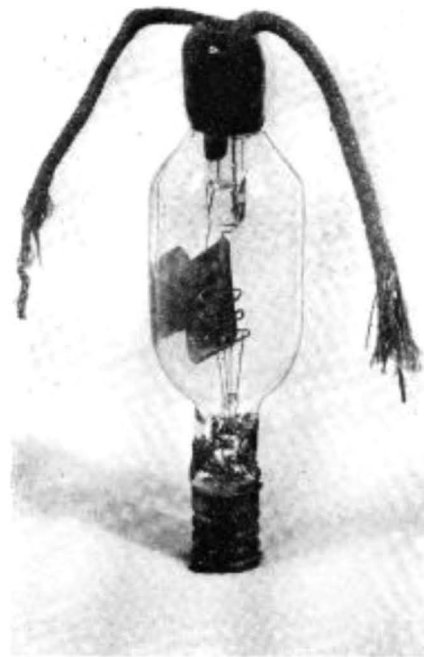


Figure 42.



ESCS Training

(*Continued from page* 25)

The first installation was bi-dimensional. Its flat surface was unable to provide an impression of depth and perspective. With assistance from the Officers Candidate School drafting and visual aids department, an improvement upon the basic idea has been designed, and is nearing completion. This structure, measuring twelve feet in length, five in height and three in depth was planned and executed by S/Sgt. Ralph A. Vernacchia and T/5 Stanley Elkman upon an original suggestion from Captain Abramowitz.

Its tri-dimensional reproduction of geographical contours, foliage, vehicles, human figures and an airplane offer emphatic visual impact. Simulated blinker lights are set on a hilltop, in the plane itself and in the immediate foreground. It is expected that installation of this display at the new and greatly expanded code and traffic section will mark another significant achievement in the rapid training of Signal Corps Radio Operators by means of dramatic visual facilities.

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Saga of Vacuum Tube

(*Continued from page* 28)

paper de Forest filed another patent application (U.S. Patent No. 841,387)[135] on an arrangement entitled "Device for Amplifying Feeble Electrical Currents." This application disclosed an incandescent lamp having, in addition to the carbon or metal filament, two metal plates sealed into the bulb. (See Figure 40.) This was not new but the external connections and method of use disclosed were new. The arrangement was said to depend on the electrostatic attraction between the plate connected to the antenna and the filament for its operation. This application contains the first mention of what Fleming later termed a "split cold electrode" and was the first form of the three-electrode Audion.

The next patent application by de Forest was for an "Improvement in Oscillation Detectors" of the type described in U. S. Patents Nos. 824,637 and 836,070. This application, which issued as U. S. Patent No. ★879,532,[136] disclosed a second cold electrode in the form of a grid placed *between* the incandescent electrode (filament) and the other cold electrode (plate). (See Figure 41.) This third electrode had actually been added to the assembly in a laboratory test on December 31, 1906.[137] This was the three-electrode grid type Audion, although de Forest originally applied the term to the two-electrode arrangement.

The first public disclosure of the grid type Audion by de Forest was made at the Brooklyn Institute of Arts and Sciences on March 14, 1907 in connection with a paper on "The Wireless Transmission of Intelligence."

It is perhaps well that no scientist has developed a mechanism whereby we can see into the future. All parents know that the first seven years of a child's life are serious years; years demanding study of this new being, noting its characteristics, guiding it through hazardous days, observing and developing its potentialities. Yet could de Forest have foreseen the turbulent days ahead in the seven years following the first disclosure of his brain-child, the grid type Audion, he might not have taken the trip to Brooklyn on March 14, 1907. De Forest never lacked courage, but the time consumed in tireless efforts to make his contemporaries understand his brain-child, his corporate troubles and desperate attempts to obtain financial backing, the endless litigation into which he was plunged, all were a tragic waste to the man interested primarily in the furtherance of wireless communication. While other men might have cracked under the strain of those years and been lost in the depths of despair, to de Forest had been given the strength and buoyance to lose himself in his work in moments of distress. Trouble produced in him mental stimulation. His brain was most productive when his back was against the wall.

About the time of this first public disclosure of the grid type Audion de Forest was organizing the "De Forest Radio Telephone Company" to develop and market the de Forest wireless telephone system. Funds for this purpose were insufficient and hence a subsidiary company, the "Radio Telephone Company" was formed late in the same year to manufacture and market wireless apparatus on which de Forest owned or controlled patents.

De Forest used the Audion as a detector for both wireless telegraphy and wireless telephony. Only two of the two-element Audions were ever sold, and these to the U. S. Navy for use at the Brooklyn Navy Yard.[138]

Grid type Audions for use as detectors were incorporated in a number of sets of radio-telephone apparatus sold to the U. S. Navy in 1907. When the U. S. Fleet of "Fighting Bob Evans" made its memorable cruise around the world in 1907-1908 over

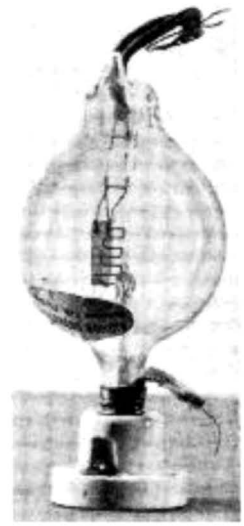
twenty vessels were equipped with such de Forest apparatus. However, radio telephony was so very experimental at the time that a few years thereafter a Naval representative reported, as if with relief, that "all wireless telephone sets thus far supplied, having proved unreliable in action, have been withdrawn from service." [139]

Since from this time on only the grid type Audion was in commercial use, future use of the word Audion, unless otherwise stated, will apply to this type bulb.

The first commercial Audions, a photograph of one of which is shown in Figure 42, were made with a narrow flat plate of platinum or other metal placed near a carbon or metal filament in a more or less cylindrical bulb. Between the plate and filament was fixed a grid or simple zig-zag of wire. The plate and grid were supported on wires sealed through the glass. These were made for de Forest by H. W. McCandless & Company, 67-69 Park Place, New York City, who were manufacturers of Christmas-tree type incandescent lamps.

About 1908 the filament structure was changed to the two-filament type, as shown in Figure 42, the filaments to be used consecutively, in order to increase the useful life of the device. About the same time the bulb shape was changed from cylindrical to spherical.[140] This was done at the suggestion of McCandless, who felt that the spherical bulb would permit of easier assembly. A photograph of one of the earlier spherical types is shown in Figure 43. This tube was made with a candelabra type base which was not changed till some time later.

Figure 43.



References

125. *de Forest, Lee: "Oscillation Responsive Device." U. S. Patent No. 979,275, application date February 2, 1905, issued December 20, 1910.*

126. *de Forest, Lee: "Static Valve for Wireless Telegraph Systems." U. S. Patent No. 823,402, application date December 9, 1905, issued June 12, 1906.*

127. *Fleming, J. A.: See Reference 107.*

128. *de Forest, Lee: "Oscillation Responsive Device." U. S. Patent No. 824,637, application date January 18, 1906, issued June 26, 1906.*

129. *de Forest, Lee: "Oscillation Reponsive Device." U. S. Patent No. 836,070, original application date January 18, 1906, divided application filed May 19, 1906, issued November 13, 1906.*

130. *de Forest Lee: "Oscillation Responsive Device." U. S. Patent No. 836,071, original application date January 18, 1906, divided application filed May 19, 1906, issued November 13, 1906.*

131. *de Forest, Lee: "Oscillation Responsive Device," U. S. Patent No. 824,638, application date January 20, 1906, issued June 26, 1906.*

132. *de Forest, Lee: "Wireless Telegraphy." U. S. Patent No. 837,901, application date February 11, 1906, issued December 4, 1906.*

133. *de Forest, Lee: "Wireless Telegraphy." U. S. Patent No. 841,386, application date August 27, 1906, issued January 15, 1907.*

134. *de Forest, Lee: "The Audion—A New Receiver for Wireless Telegraphy." Proceedings A.I.E.E., Vol. 25, 1906, pp. 735-763. Discussion on pp. 761-779.*

135. *de Forest, Lee: "Device for Amplifying Feeble Electrical Currents." U. S. Patent No. 841,387, application date October 25, 1906, issued January 15, 1907.*

136. *de Forest, Lee: "Improvement in Oscillation Detectors." U. S. Patent No. 879,532, application date January 29, 1907, issued February 18, 1908.*

137. *Archer, G. L.: "History of Radio." American Historical Society, 1938, p. 92.*

See Also Carneal, Georgette, "The Conqueror of Space." Horace Liveright, 1930, pp. 195-196.

138. *Arvin, W. R.: "The Life and Work of Lee de Forest—Part VIII." Radio News, Vol. 6, No. 11, May 1925, p. 2066.*

139. *Robison, (Commander) S. S.: "Manual of Wireless Telegraphy for Use of Naval Electricians," 2nd edition, 1911, p. 169.*

140. *de Forest, Lee: "The History of the Radio Tube, 1900-1916." Radio News, Vol. 24, No. 6, December 1940, p. 8.*

Figure Captions

Figure 36. The Bunsen burner patent. This was the fundamental de Forest heated gas patent.

Figure 37. The two-electrode Audion patent. Note the use of two batteries, one for heating the filament, the other for applying positive potential to the plate.

Figure 38. The Audion with external electrostatic control. An antenna and ground connection is made externally to a wire wrapped around the glass envelope of the tube. Reproduced from *Proceedings A.I.E.E., 1906.*

Figure 39. The Audion with electromagnetic control. Reproduced from *Proceedings A.I.E.E., 1906.*

Figure 40. The first three-electrode Audion patent. Note the external connections.

Figure 41. The grid-type Audion patent. Note the use of the condenser in series with the grid.

Figure 42. Early cylindrical candelabra-base Audion. This specimen was probably made in 1908, since it has a double filament. Photograph courtesy *Radio Corporation of America.*

Figure 43. Early spherical bulb single-grid, single-plate Audion. Both filaments of this Audion are still good, hence the projecting wire has not been connected to the base shell which is of the candelabra type.

(To be continued)

R-F Converter

(Continued from page 29)

The builder who possesses a broadcast receiver of good quality, will have with the addition of this converter, a short wave combination capable of giving remarkable performance. Most radio parts jobbers are still able to supply most of the items needed. Furthermore, inasmuch as standard parts are used many of them will be found in the average service shop or experimenters, laboratory. The use of an efficient all-wave antenna is highly recommended. No converter can work at its best unless it terminates at a proper receiving system.

Inasmuch as standard tubes are used it is possible to use substitutes simply by changing supply voltages.

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