

The Story of How Lee De Forest Developed the Audion

Part I. The History of De Forest's Published Accounts

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Lee De Forest's many accounts of how he invented this three-electrode audion invariably began with an account of how he developed his two-electrode audion, a development that he claimed was an integral step in the development of the three-electrode audion. De Forest also claimed that he developed his two-electrode audion without any knowledge of John Ambrose Fleming's very similar oscillation valve. De Forest published two extensive but conflicting accounts about how he developed his two-electrode audion, one at a lecture to the American Institute for Electrical Engineers in October 1906, and the other at a lecture to an audience of his peers at the Franklin Institute in January 1920. The differences between these two accounts are dramatic and cast doubt on the credibility of both. It turns out that De Forest provided a third and very different account of how he developed the two-electrode audion during a lawsuit filed by American Marconi in 1914 alleging that De Forest's audions infringed Fleming's valve patent. The testimony and exhibits from the trial were documented in five volumes for the participants in the lawsuits and court records, but they were never made public. The five volumes prepared for the plaintiff's attorney became available recently, so a very different version of how De Forest developed his two-electrode audion can now be told—a story that is based to a large degree on De Forest's sworn testimony and unpublished documents that he submitted as exhibits.

Historical Perspective

The two-electrode thermionic vacuum tube was important for several reasons. It was the first thermionic vacuum tube detector to be widely used in commercial communication systems, namely in the communication systems of the British and American Marconi companies. Both the British and American Marconi Companies used two-electrode valves in the Fleming Valve Receiver beginning in 1910 and ending in early 1917

when commercial message transmissions were banned during WWI.¹ The two-electrode thermionic detector was also the forerunner of De Forest's three-electrode vacuum tube,² which replaced the two-electrode valve in virtually all radiotelephone and radiotelegraph systems after WWI. Consequently, whoever invented the two-electrode tube could claim credit and honors for an important seminal invention that led to a revolution in communication systems

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and was also used in many applications other than communication systems. It also turned out that the inventor of the two-electrode thermionic vacuum tube had a valid legal claim to royalties from revenues that accrued from the use or sale of the three-electrode tube.

Both John Ambrose Fleming and Lee De Forest laid claim to having priority in the invention of the two-electrode thermionic vacuum tube, which Fleming called a valve and De Forest called an audion. Fleming filed the first patent application for his valve in the United Kingdom on November 16, 1904, and he also filed a U.S. patent application on the same device on April 19, 1905. According to U.S. patent law, his U.S. patent was accorded the same priority date as the filing date for his UK patent, namely November 16, 1904. De Forest filed the first patent application for his audion on January 18, 1906, almost two years later. However, the United States Patent Office (USPO) at that time awarded patents to the first to invent, not the first to file a patent, so if De Forest could prove he had invented a flame detector that operated on the audion principle before Fleming filed the patent application for his valve, he could present a legal argument for being awarded precedence in the invention of the thermionic valve in any litigation over priority.

The matter of priority was settled in a lawsuit that Marconi Wireless Telegraph Company of America (a.k.a., American Marconi) filed in October 1914 against the De Forest Radio Telephone & Telegraph Company, Abraham White as its president, and Lee De Forest as

an individual. The lawsuit alleged that De Forest's two- and three-electrode audions infringed the Fleming valve patent. The De Forest Company countersued by claiming that the Fleming patent was not valid because Fleming had not invented anything new; they claimed he merely used an existing device in the form of an Edison effect incandescent light bulb. The De Forest Company also asserted that the Fleming valve infringed De Forest's flame detector patent because De Forest had discovered the audion principle in the form of a flame detector using a Bunsen burner before the priority date of Fleming's valve patent. They also asserted that De Forest had perfected it soon thereafter in the form of an evacuated audion bulb detector. Before the trial began, American Marconi confessed judgment in court, admitting it had infringed the De Forest three-electrode patents by using them in its commercial stations. Consequently, that issue was not before the court in the trial that took place in September 1916.

Julius Mayer issued his opinion in September 1916 by finding that the Fleming valve patent was valid and did not infringe De Forest's two-electrode audion patents. The judge found that De Forest's two-electrode audions infringed the Fleming patent, but he stopped short of invalidating De Forest's patents. He then found that De Forest's three-electrode audion patents were valid and a valuable contribution to the technology, but he also ruled that the three-electrode audions infringed Fleming's two-electrode valve patent. Judge Mayer's opinion was published in volume 236 of

Federal Reporter.³ De Forest appealed the judge's decision, but the appellate court agreed with Judge Mayer's ruling.

While the matter was settled from the legal point of view, De Forest never accepted Judge Mayer's decision. Furthermore, it does not necessarily follow that the party who wins a priority suit in a court of law is the actual inventor. There was one noted historian in particular who believed that De Forest may have had priority in the invention of the two-electrode audion. Hugh Aitken in his well-received 1985 book, *The Continuous Wave*, gave a very detailed and balanced treatment of the events leading to the respective discoveries of the two-electrode vacuum tubes by both Fleming and De Forest. He pointed out that while Fleming filed his patent on the thermionic valve well before De Forest filed his patent on the thermionic vacuum audion, De Forest claimed that he began his search for a more sensitive detector long before Fleming discovered the Edison effect bulb was a detector. Aitken also pointed out that De Forest claimed that his detector was different from that of Fleming. Aitken speculated that it was possible De Forest conceived of the essential elements of his two-electrode audion prior to Fleming's discovery in October 1904, a discovery that may have forestalled (anticipated) Fleming's patent, and the issue became the interpretation of the existing evidence supporting De Forest's version of events. Aitken says that a dispute over which interpretation of events was correct started almost as soon as the three-element audion was announced, and the debate has been

ongoing ever since. At the time Aitken wrote his book in 1985, he concluded: "It is highly unlikely that any new evidence will be uncovered to settle this issue."⁴

Indeed, Aitken provides a very impressive list of source material, but absent from his list are transcripts of the 1916 trial testimony and the associated exhibits produced in the Marconi vs. De Forest litigation. These documents, which amount to more than a foot of shelf space, surfaced a few years ago. The five volumes prepared for L.F.H. Betts of the Sheffield and Betts law firm (see Fig. 1) were passed on to Gerald Tyne and then to Jerry Vanicek. With a few exceptions, neither the testimony nor the exhibits were disclosed by either one. This author came into possession of these five volumes and studied them for several years before preparing this manuscript. The account that will be



Fig. 1. Five unpublished volumes of sworn testimony, exhibits, and summations prepared after the 1916 trial in the lawsuit of Marconi v. De Forest present an entirely different account of how De Forest developed his audions than the ones he published during his lifetime. (Author's photograph)

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presented in Part II of this article, which is based on these five volumes, is believed to be the most accurate account of how De Forest invented his two-electrode audion because it is based on the sworn testimony and exhibits of the following key witnesses: Lee De Forest; George Woodworth, De Forest's attorney; John Ambrose Fleming; Henry McCandless, president of the H. W. McCandless & Company; Jacob Grogan, the McCandless Company foreman; and Roy Weagant, chief engineer for American Marconi.

Aiken also said this about De Forest's accounts: "Lee De Forest himself provided a highly plausible and internally consistent account of how the invention was made. In fact, every time he told the story it became more 'rational,' in the sense that each step in the process of invention was presented as following reasonably and naturally from what had gone on before." It is certainly true that every time De Forest recounted the story it became more rational—not because it was rational at the outset, but because he altered his account on occasion to make it seem more rational as he retold his story time and again. The claims De Forest made for events and dates in his many accounts are sketchy, contradictory, and unsupported by any documentary evidence. De Forest did not create a single document describing how he discovered the two-electrode audion before his lecture to the AIEE on October 26, 1906, which provided the most detailed account of how it was developed. If the story seemed to flow "reasonably and naturally," it was because De Forest often

skipped pertinent information, such as the dates and sequences of various events. In many of his accounts, several intervening months or years often go by from one paragraph to the next—without alerting the reader to significant gaps in the time between events.

The account of how De Forest invented his two-electrode audion based on trial testimony and exhibits is significantly different from all other accounts that De Forest published throughout his life. The differences in these accounts can be discerned and appreciated only by those who have a basic understanding of De Forest's published accounts. To that end, a rather comprehensive history of the principal accounts that De Forest published is presented in this issue of the *AWA Review* as a prelude to Part II of this paper planned for the next issue of the *AWA Review*, which will present the trial account. This review of De Forest's accounts is accompanied by a critical analysis that identifies discrepancies, misrepresentations, and deceptions in De Forest's very different published accounts. This review will also provide some technical details that are particularly important for understanding the similarities and differences between Fleming's valve and De Forest's audion.

An Inventory of De Forest's Published Accounts

De Forest published any number of accounts of how he invented his two-electrode audion detector throughout his life beginning with the first account he gave at a lecture to the American Institute of Electrical Engineers (AIEE) on

October 26, 1906. That lecture was given shortly after his first U.S. Patent 824,637 for a two-electrode audion detector was issued by the United States Patent Office (USPO) on June 26, 1906. The accounts he published can be conveniently divided into six categories:

1. Lectures to his peers that were subsequently published in science and engineering journals (*Proceedings of the AIEE*,⁵ *Journal of the Franklin Institute*),⁶
2. Articles and letters to the editor published in electrical journals intended for the trade (*The Electrician* and *Electrical World*),
3. Testimony that De Forest gave in the 1916 trial, a brief synopsis of which was documented by the trial judge, Julius Mayer, in his findings published in the *Federal Reporter* in 1916,⁷
4. Articles in magazines intended for radio amateurs and electrical experimenters (e.g., *Radio News* and *Radio-Craft*),
5. Articles appearing in magazines intended for the layperson (e.g., *Scientific American* and *Popular Science*), and
6. De Forest's autobiography, *Father of Radio*, published in 1950.⁸

Principal Documents

The most important and detailed accounts are the four that have citations to specific references in the above list. The two lectures he gave to his peers at the AIEE in 1906 and 1920 provided the most important accounts of his two-electrode audions because they had more

historical and technical information than any other of his many accounts. Also, the lecture to the AIEE in 1906 was followed by two discussion sessions that provided critical comments and observations that clarified many points De Forest raised in the lecture. While the accounts in these two lectures were significantly different, the many accounts that followed the second lecture at the Franklin Institute in 1920 did not change significantly. The account De Forest gave in his autobiography published in 1950, *Father of Radio*, was copied verbatim from paragraphs that appeared in his 1920 lecture.

De Forest never explained the many significant differences in his two lecture accounts, but it will become clear in due course that the significant differences resulted from the proceedings of the trial in 1916. A few details of the account that De Forest gave at the trial were revealed in Judge Mayer's findings published in the *Federal Reporter* in 1916. However, the transcripts, documents, and other exhibits from the trial that documented how De Forest invented his two-electrode audion were never published. The most important accounts, with references, are listed in Table 1 and Table 2. These are the accounts that are addressed in this paper.

There were two discussion sessions by attendees of the 1906 AIEE lecture that provided additional and important information. One of these sessions took place in New York immediately after the meeting on October 26, 1906, and a transcript of this discussion appeared in the October issue of the *Proceedings of the AIEE* that documented his lecture.

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Table 1. The most relevant accounts of how De Forest developed his two-electrode Audion.

Year	Author	Venue	Audience	References
1906	De Forest	AIEE lecture	AIEE	<i>Proc. AIEE</i> , Vol. 25, p. 719
1906	De Forest	Discussion sessions (2)	AIEE	<i>Proc. AIEE</i> , Vol. 25, p. 863 <i>Trans. AIEE</i> , Vol. 25, p. 735
1906-1914	De Forest and Fleming	Letters to editors (12)	Electrical journals	See Table 2
1916	Judge Mayer	1916 Trial	Court	<i>Federal Reporter</i> , 236 F 942
1920	De Forest	Franklin Inst. lecture	AIEE	<i>J. Franklin Inst.</i> , Vol. 190, p.1

Table 2. Acrimonious letters to the editors of two journals in which Fleming and De Forest contested priority and other facts associated with the development of their respective two-electrode vacuum tubes.

Pub. Date	Author	Journal	Vol. and Page
Nov. 30, 1906	Fleming	<i>Electrician</i>	Vol. 58, p. 263
Dec. 08, 1906	Fleming	<i>Electrical World</i>	Vol. 48, p. 1117
Dec. 15, 1906	De Forest	<i>Electrical World</i>	Vol. 48, p. 1205
Dec. 28, 1906	De Forest	<i>Electrician</i>	Vol. 58, p. 425
Jan. 04, 1907	Fleming	<i>Electrician</i>	Vol. 58, p. 464
Sept. 04, 1908	De Forest	<i>Electrician</i>	Vol. 61, p. 804
Sept. 11, 1908	Fleming	<i>Electrician</i>	Vol. 61, p. 843
Oct. 09, 1908	De Forest	<i>Electrician</i>	Vol. 61, p. 1006
Nov. 21, 1913	De Forest	<i>Electrician</i>	Vol. 72, p. 285
Dec. 05, 1913	Fleming	<i>Electrician</i>	Vol. 72, p. 377
Jan. 23, 1914	De Forest	<i>Electrician</i>	Vol. 72, p. 659
Jan. 23, 1914	Fleming	<i>Electrician</i>	Vol. 72, p. 659

A second discussion session took place at the next meeting of the AIEE that took place in Philadelphia on November 12, 1906. A transcript of this discussion appeared in the *Transactions of the AIEE*, which was published in early 1907.⁹

The account De Forest gave in his 1906 AIEE lecture would not be complete without considering the numerous

letters to the editors of *The Electrician* (London) and *Electrical World* (New York) that resulted from their publication of portions of De Forest's lecture. News of De Forest's AIEE lecture was published the day after the lecture in the *New York Times* on October 27, 1906, under the headline "The Audion Described" (see Fig. 2).¹⁰ Extensive

THE AUDION DESCRIBED.

Lee De Forest Tells Electrical Engineers of His New Invention.

At the monthly meeting of the American Institute of Electrical Engineers in the assembly room of the New York Edison Company's building, at 44 West Twenty-seventh Street, last night Lee De Forest, Vice President of the De Forest Wireless Telegraph Company, read a paper on "The Audion, a New Receiver for Wireless Telegraphy." The audion is one of Mr. De Forest's own inventions on which he has been working for years, and he is now installing it in his plants as a substitute for the receivers formerly used by his company.

The inventor of the Audion says it possesses greater accuracy and a more delicate attunement for the detection of Hertzian waves than any other wave detector. The principle of the construction of the Audion differs from that employed in other wireless telegraph receivers in that, instead of the nickel and silver filings of the Marconi receiver, or the liquids found in later types, Mr. De Forest makes use of a vacuum similar to that of an ordinary incandescent lamp, sensitized by the passage of an electric current.

The paper was received with great interest by the members of the Institute. Prof. Michael I. Pupin of Columbia was among those who took part in the discussion that followed the reading. He admitted the highly interesting features of the new invention, but he questioned the legitimacy of the name given to it. He said that "audion" was of composite Greek and Latin origin and was therefore a "mongrel." Mr. De Forest replied that the same objection could be urged against "centimeter," and that the coinage of the word "hectometer" purposely created it of mixed parentage.

Fig. 2. News of De Forest's AIEE lecture was published with the headline "The Audion Described" on the day after the lecture in the *New York Times* on October 27, 1906. (*New York Times*, Oct. 27, 1906, p. 9)

excerpts of this lecture were published within weeks of the lecture in prominent electrical journals in the United States and England. No sooner were the accounts of De Forest's lecture

published than Fleming wrote scathing letters to several editors complaining about De Forest's articles. Fleming was incensed by De Forest's account because he marginalized the Fleming valve as being useful only for laboratory work, and he failed to mention that Fleming had received a patent on the device for use as a detector in wireless systems. The exchange of letters clarified several important points that De Forest made in his lecture—in particular the source of inspiration for his audion invention. These acrimonious letters appeared on and off in several publications for the next seven years.

Other Relevant Documents

De Forest's patent applications for his two-electrode flame and evacuated bulb detectors are relevant to his accounts because they provide the only documentary evidence of what he developed and when he developed it. There were four patent applications for a Hertzian wave detector that he filed before the account he gave at his lecture to the AIEE in October 1906. Two of these patents were for flame detectors, which he later claimed were "flame audions," and two were for evacuated bulb audion detectors (see Table 3). Notably, De Forest did not

Table 3. De Forest's flame and audion patents relevant to his accounts of how he developed his two-electrode vacuum audions.

Descriptor	Patent No.	Date Filed	Date issued
1 st Flame patent	979,275	Feb. 2, 1905	Dec. 20, 1910
2 nd Flame patent	824,638	Jan. 20, 1906	Jun. 26, 1906
1 st Audion patent	824,637	Jan. 18, 1906	Jun. 26, 1906
2 nd Audion patent	841,386	Aug. 27, 1906	Jan. 15, 1907

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mention in his 1906 lecture that he had filed patent applications for any of these four detectors.

Several other important documents were the writings of J. J. Thomson on the subject of currents flowing through gases. De Forest would later claim that he used Thomson's writings as a reference during the time he developed his audion. In an article published by De Forest in 1947, he wrote an account of how he had invented the audion that included this sentence: "Through all this work, the writings of J. J. Thomson were my bible—and constantly were consulted."¹¹ The most important book that he consulted was the 1903 edition of a textbook by J. J. Thomson entitled *Conduction of Electricity Through Gases*, which first appeared on the market in November 1903.¹² Another important book by Thomson entitled *The Discharge of Electricity Through Gases* was published earlier in 1898.¹³

Not addressed here are the many individual accounts that De Forest published in the thirty years between his Franklin Institute lecture in 1920 and the publication of his autobiography in 1950. While there were many minor differences in these later accounts, they were generally consistent with the account he gave in his 1920 lecture.

Paper Organization

The remainder of this paper is divided into three major divisions, one for each of the three most important accounts that were published in the years 1906, 1916, and 1920:

1. De Forest's AIEE Lecture Account (October 26, 1906)
2. Judge Mayer's Opinion in Marconi v. De Forest Trial (September 20, 1916)
3. De Forest's Franklin Institute Lecture Account (January 15, 1920)

Significant excerpts from the paper that documented his AIEE lecture were soon published in many prominent electrical and scientific journals. As a result, there were many acrimonious exchanges of letters between De Forest and Fleming that were published in several prominent electrical journals for years after the lecture. Judge Mayer's opinion published in the *Federal Reporter* in 1916 summarized some of De Forest's most relevant testimony and also provided some legal insights. The account De Forest gave in his 1920 lecture at the Franklin Institute was very different from both the account at his lecture to the AIEE in 1906 and the account based on his testimony documented at the 1916 trial. The account from the lecture at the Franklin Institute must have been De Forest's favorite because that was the account that he included in an appendix to his autobiography published in 1950.

De Forest's AIEE Lecture Account (October 26, 1906)

Overview of De Forest's AIEE Lecture

De Forest's AIEE lecture, which focused entirely on his two-electrode audion and flame detectors, was his most comprehensive account of the genesis of his two-electrode audions. For purposes of this presentation, the published version of his lecture can be conveniently separated

into three parts. The first part consisted of six pages in which he gave two distinctly different and conflicting versions of how he discovered his flame detector. The first version was an experiment in which he inserted two electrodes into the mantel fabric of a Welsbach lamp that he had soaked in an alkaline salt solution to increase the conductivity of the flame. The second version was an experiment in which he inserted two electrodes directly into the flame of a Bunsen burner, one of which was a trough electrode holding an alkaline salt that was placed directly into the hottest part of the flame. After introducing the second version of his flame detector, he gave a dissertation on how this flame detector worked using an I-V characteristic curve that he inferred was generated by his flame detector. In a bizarre twist, the I-V characteristic curve he presented turned out to be from an obscure experiment disclosed by Egon von Schweidler in a lecture entitled "On the Photoelectric Phenomena." This experiment, designed to investigate the photoelectric effect using an evacuated cavity without a flame, will be described in due course. Apparently, De Forest did not realize that the curve was not generated in a flame experiment.

The second part of his AIEE lecture, also consisting of six pages, consisted of an account of the genesis of a new vacuum bulb audion detector. However, instead of introducing the original version of his audion that appeared in his first audion patent application filed on January 18, 1906, he introduced a new configuration that he documented in his second patent application filed on

August 27, 1906, just two months before his lecture. De Forest claimed that the genesis of this audion was a configuration that appeared in a paper published by German scientists Julius Elster and Hans Geitel in 1882. To support his claim, De Forest compared his audion configuration to the Elster and Geitel configuration that he claimed he reproduced from their paper. It turns out that the actual configuration in the Elster and Geitel paper De Forest referenced did not match the audion configuration he presented in his paper. To hide that fact, De Forest purposely misled the AIEE audience by altering the actual Elster and Geitel configuration in three significant ways to make their configuration conform to his preconceived version of the audion.

It is now clear that the genesis of De Forest's audion was not the Elster and Geitel paper, as he asserted. De Forest's wholesale deception has never been documented, not even by John Fleming in his classic book published in 1919 in which he recounted the many issues associated with De Forest's AIEE lecture.¹⁴ It is notable that De Forest retroactively characterized all of his audions as "flame audions," although in his AIEE lecture, he never asserted that the genesis of his evacuated bulb audion was a flame detector. That claim would arise in 1916 as a defense in the lawsuit brought by the Marconi Company claiming that all of De Forest's audions infringed on the Fleming patent.

In the third and longest part of his AIEE lecture consisting of 16 pages, De Forest attempted to describe the theory of how his evacuated audion bulb

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worked. He began with this statement: "In framing any theory of the action of electric oscillations in the audion a variety of complex, contrary, contradictory phenomena are met with, exceedingly puzzling to explain."¹⁵ While his technical account appeared to be insightful, he pieced together paragraphs of his lecture from J. J. Thomson's book, *Conduction of Electricity Through Gases*, by paraphrasing them without much insight. De Forest's relationship to this important book by a Nobel Laureate will be described in due course. In the end, he admitted he did not know how his audion detectors worked: "I have arrived as yet at no completely satisfactory theory as to the exact means by which the high-frequency oscillations affect so markedly the behavior of an ionized gas."¹⁶

Virtually all of the claims that De Forest made at his AIEE lecture turned out to be false. He eventually abandoned most of the claims he made at the lecture, with the notable exception of the claim that his two-electrode audion was a relay in which the energy from a battery in the plate circuit increased the sensitivity of his audion. He asserted that the use of the battery distinguished his audion from Fleming's valve, which did not use such a battery. He also continued to claim that his audion with a battery in the plate circuit was much more sensitive than Fleming's valve.

The remainder of this section provides the detail needed to support the assertions made in the previous paragraphs. These paragraphs constitute a critical review of each claim that De Forest made in his AIEE lecture for both

his flame and evacuated bulb audions. The first three titled paragraphs address accounts associated with his flame detectors while the next four titled paragraphs address accounts associated with his evacuated bulb audion detectors. The results of this assessment are summarized in a section entitled "Takeaway from De Forest's AIEE Lecture."

First Account of the Genesis of De Forest's Flame Detector

De Forest used this introduction in the publication of his AIEE lecture with the following words:

"The story of the development of a device of a distinctively new order, from its first inception to its practical reality, adds a human interest to its description which is perhaps too often lacking among scientific records. In 1900 when I was beginning experiments on the electrolytic responder, it was my good fortune to have to work upon it at night in my own room, at a table beneath a solitary gas burner with Welsbach mantle. My source of Hertzian waves was the discharge of a small induction coil placed in an opposite corner and set into operation by a key closed by pulling a string."

"For several days I was elated over the tremendously sensitive and altogether novel type of Hertzian-wave responder thus accidentally discovered.... But alas for the over-sanguine spirits of the young investigator!

"I found I had merely discovered an extremely responsive form of the sensitive gas-flame, and that a bunch

of jangling keys or a smart clapping of the hands were almost as efficient generators [of a response in the lamp] as was my induction coil.”¹⁷

He later provided an image that documented this early observation in an account he prepared for *Radio News* (see Fig. 3).¹⁸ There is documentation in the form of a short item that De Forest published in *Electrical World* on April 12, 1902, which provided an account that

was consistent with the account he gave in the AIEE lecture.¹⁹

De Forest did not say when he first discovered that he could detect Hertzian waves with electrodes inserted in a flame, but in his AIEE lecture, he did say that he began by measuring the conductivity of an incandescent mantle. However, it can be presumed that he had not yet found the electrical response at the time he wrote the magazine article in April 1902:

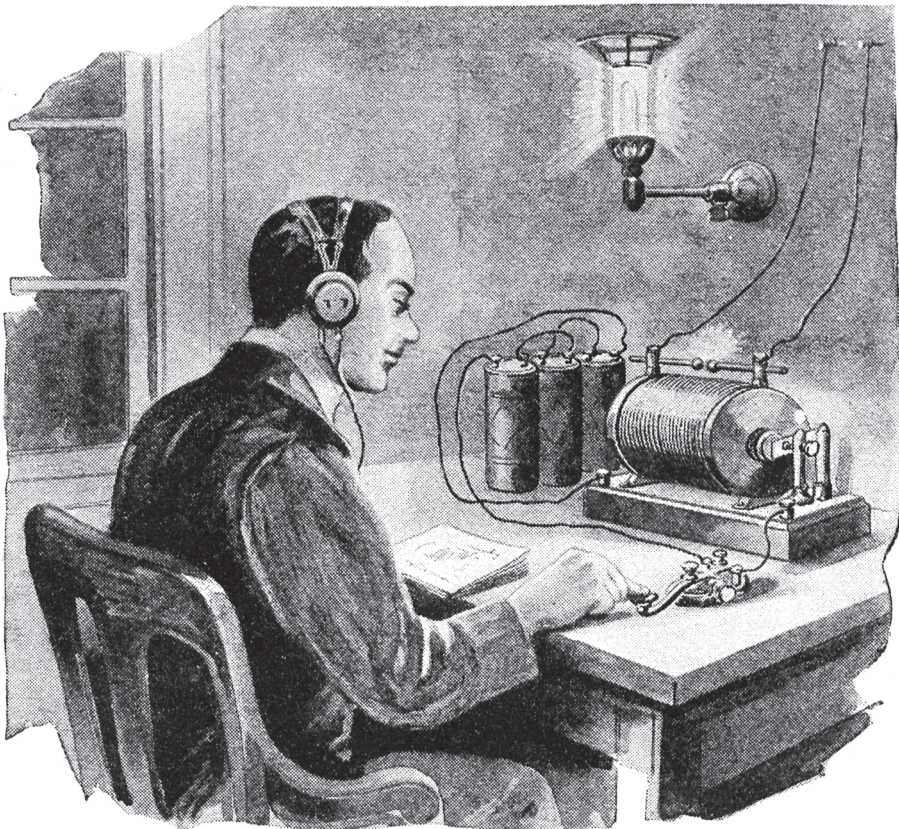


Fig. 3. De Forest published an image memorializing his observation that a spark discharge from his induction coil affected the brilliance of the Welsbach lamp in his room. (*Radio News*, Jan. 1925, p. 1154)

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“Unable to dislodge this conviction from my mind, I began later to search for the genuine response to electric vibration in the gas flame. I found the conductivity of the incandescent mantle surprisingly small for any voltages which would be practical in a wireless receiver.”²⁰

At some point, De Forest learned that the conductivity of a flame could be greatly enhanced by seeding the flame with various salts, most likely by reading the works of J. J. Thomson entitled *The Discharge of Electricity Through Gases*. Thomson published this textbook in 1898 where he wrote, “When solutions of salts of the metals of the alkali group are thrown into the flame by a spray producer, the conductivity of the flame is very greatly increased.”²¹ De Forest claimed that the next step in the development of his flame detector was an experiment in which he found the response of electrical signals in the flame of an incandescent mantle that was soaked in alkali salts:

“By soaking the mantle in a potassium or sodium solution and drying, I was finally able to pass a small current from a dozen dry cells through the flame surrounding it, using two platinum electrodes with a telephone receiver in circuit, and get a faint response to the genuine Hertzian wave. The discovery that the effect predicted was actually present was intensely gratifying.”²²

The statement that De Forest was “intensely gratified” when he first dis-

covered the faint response to Hertzian waves in the mantle of a flame is contrary to all of his later claims. There is no documentation to support this claim, and it is unlikely that soaking a mantle in a potassium or sodium solution (e.g., potassium or sodium chloride) would have any effect on the conductivity of a flame that is contained mainly within the mantle used in a lamp. The mantles of lamps of the day consisted of a fabric bag made from a weave of silk or rayon (see Fig. 4), which was impregnated with metallic salts. For example, Welsbach mantles of the day were impregnated with a mixture of 99% thorium dioxide and 1% cerium dioxide. When a mantle was first ignited (e.g., by a match), the

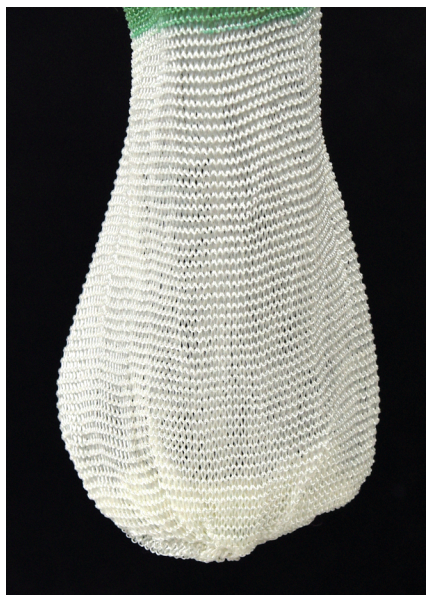


Fig. 4. The mantle of a Welsbach lamp consisted of a fabric bag made from a weave of silk or rayon that was impregnated with metal salts such as a mixture of thorium dioxide and cerium dioxide. (Author's photograph)

fibers that would have absorbed De Forest's salt solutions would have burned away in seconds, and the remaining metallic salts would have formed a rigid but fragile mesh of metal oxides in the shape of the original fabric. It is unlikely that any of De Forest's salts would have been absorbed by the metal oxides that remained. The metallic salts that formed the lattice of the remaining mantle were known to be excellent insulators, even at high temperatures, and it is unlikely that the remaining mantle structure could have contributed to the conductivity flame.

In any event, this claim was in direct conflict with the claim he would make in his lecture at the Franklin Institute in 1920, where he said he did not find a response in an incandescent mantle:

"For failing to find in an incandescent mantle the genuine effect of response to electrical vibrations I next explored the Bunsen burner flame, using two platinum electrodes held close together in the flame, with an outside circuit containing a battery of some 18 volts and a telephone receiver. See Fig. 1—the form used in 1903."²³

It will be shown in due course that the "Fig. 1" he referred to above in his 1920 lecture at the Franklin Institute happens to be the same configuration that appeared as Fig. 1 in the patent application for his first flame detector that he filed on February 2, 1905 (see Fig. 5). This flame detector has two electrodes that are inserted on opposite sides of the flame without a mantle (see Fig. 6).

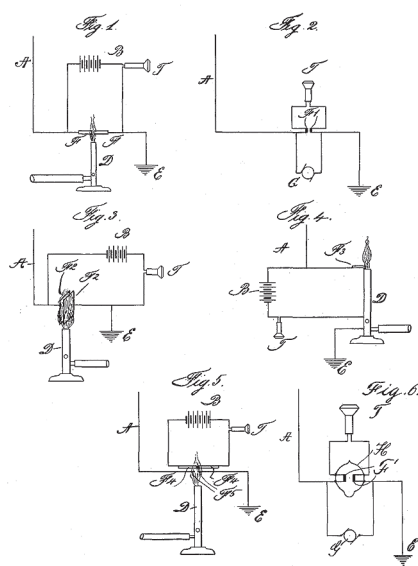


Fig. 5. De Forest filed a patent application for U.S. Patent 979,275 on February 2, 1905, that described images for four different flame detector configurations and two different arc detector configurations. (U.S. Patent 979,275)

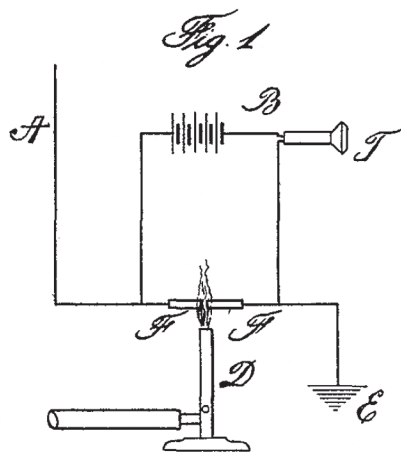


Fig. 6. In De Forest's lecture to the Franklin Institute in 1920, he identified this flame detector from his U.S. Patent 979,275 application as his earliest successful flame detector. (U.S. Patent 979,275, Fig. 1)

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Thus, De Forest gave two different and conflicting descriptions of the configuration he used when he discovered that a flame could be used to detect Hertzian waves—the first with a flame contained in a lamp mantle that was pre-soaked in a salt solution, and the second in the open flame of a Bunsen burner, without a mantle, which was seeded with salts in an unspecified manner.

De Forest's Second Account for the Genesis of his Flame Detector

While De Forest claimed that he found the response to electric waves for the first time in an incandescent mantle soaked with salts, he never provided a diagram of the “incandescent mantle” detector, nor did he even describe the configuration. Instead, he introduced a very different version of a flame detector in his lecture, which he claimed was an “early form” of audion (see Fig. 7).²⁴ It turns out that this “early” form of audion was a later form of an audion flame detector that was first documented in a patent application for U.S. Patent 824,638 that he filed on January 20, 1906 (see Fig. 8).

De Forest did not provide any evidence that this was an early form of audion, and he would never again claim this detector configuration was an early form—with one exception. In March 1919 De Forest wrote an article exclusively for the *Electrical Experimenter* entitled “How I Invented the Audion” in which he included the flame configuration shown in Fig. 9.²⁵ De Forest doubled down with his caption by claiming it was “The First State in the Development of the Audion by Dr. Lee De Forest.” This

figure is the same one he introduced in his AIEE lecture as being his early form of audion. He correctly identified this configuration as being documented in his application for U.S. Patent 824,638 dating to January 20, 1906. However,

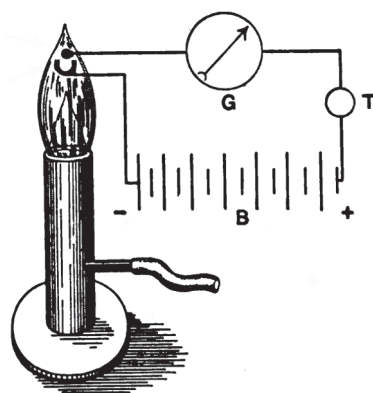


Fig. 7. De Forest introduced this version of a flame detector in his lecture as an “early form” of audion. (AIEE Lecture, p. 721)

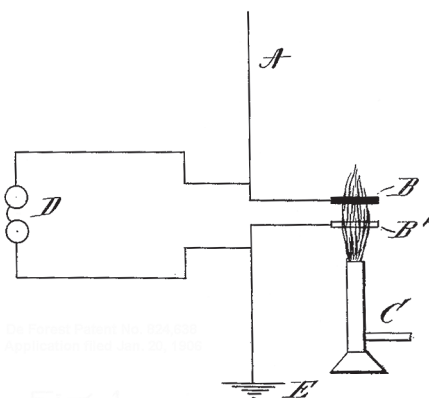
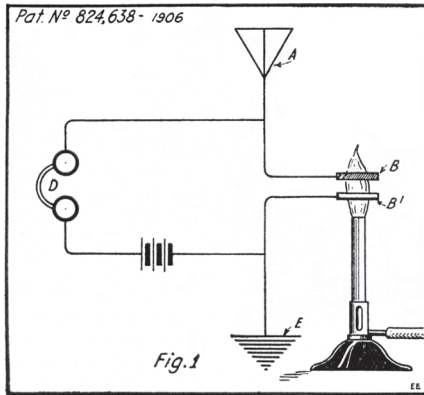


Fig. 8. The first time that De Forest ever documented a two-electrode flame detector with one electrode situated over a second electrode was in the form shown, which first appeared in a late patent application he filed for U.S. patent 824,638 on January 20, 1906, two days after he filed his first audion bulb patent. (De Forest U.S. Patent 824,638, Fig. 1)

De Forest was addled when he wrote this account because he also wrote the following paragraph in the text that referred to this figure:



The First State in the Development of the Audion by Dr. Lee de Forest. The Aerial and Ground Were Connected to Two Electrodes Placed in the Flame of a Bunsen Burner, with Successful Results.

Fig. 9. De Forest doubled down on his claim that the flame detector shown in Fig. 7 was an early form with his caption that stated: "The First State in the Development of the Audion by Dr. De Forest." (*Electrical Experimenter*, Vol. 6, Mar. 1919, p. 790)

"I then investigated the flame of a Bunsen burner and soon found a point *in the outside envelope of the flame* [emphasis added] where an appreciable current did pass between the two electrodes, making a soft fluttering sound in the telephone receiver. (See Fig. 1, Patent No. 824,638, issued in 1906.)" [The parenthetical statement at the end was De Forest's.]

He claimed that he found a point "in the outside envelope of the flame" where an appreciable current flowed between the electrodes, but the figure shows two electrodes inserted across the entire flame at the hottest point of the flame with one electrode situated over the other. He confused the configuration of Fig. 1 in this article with the configuration labeled "Fig. 1" from his flame detector application dating to February 2, 1905 (see Fig. 10). These two configurations appear to be very similar but there was a very important difference. The configuration

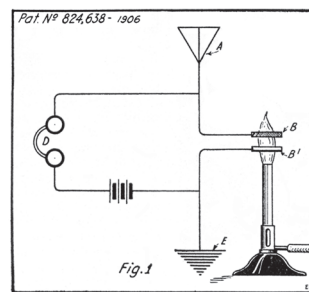
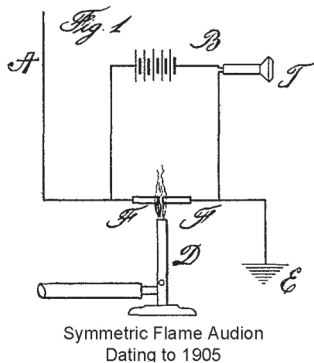


Fig. 10. The flame detector that De Forest described in his earliest flame detector patent (left) was characterized as "symmetric" because identical electrodes were inserted symmetrically on opposite sides of the flame, whereas the flame detector he introduced in his AIEE lecture (right) was characterized as "asymmetric" because the two electrodes had a different size and shape and they were inserted asymmetrically into the flame. (Author's aggregation of Fig. 6 and Fig. 9)

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on the left, taken from his earlier flame patent application, has two identical electrodes inserted symmetrically in the flame. A flame configuration with electrodes inserted symmetrically in the flame was characterized as a “symmetric” flame configuration by early flame researchers. The configuration on the right, introduced in his AIEE lecture, has two very different electrodes that were inserted in the flame with one electrode situated over the other. This configuration with asymmetric electrodes was characterized by early flame researchers as an “asymmetric” configuration.

It turns out that some early researchers studying flame conductivity found that the measured current of a symmetric flame configuration was virtually identical when the polarity of the battery used to make the measurements were reversed. The experimental results obtained by Arthur Smithells, Harry Dawson, and Harold Wilson in 1899 will be presented in due course. They also found that the current measured for an asymmetric flame configuration was not the same when the batteries were reversed. The asymmetric conductivity displayed by a two-electrode configuration was and still is characterized as being unilateral, or unipolar. It will be shown in due course that the I-V characteristics of the flame and evacuated bulb detectors are the key to understanding the response of both, and it is also the key to determining that the physics of the flame detector is different from the physics of the evacuated bulb detector.

By 1906, De Forest was well aware of the difference in the response of a flame

detector depending on the degree of symmetry or asymmetry of the electrodes. The following words can be found in his patent application filed in 1906 for the flame detector configuration he presented at the AIEE:

“If both electrodes are of the same material, they should preferably be of different sizes, and if of different materials they may be of the same or different sizes. When said electrodes are heated by the flame from the burner or other source of heated gas, an electromotive force is developed and creates current in the local circuit which includes the telephone or other signal indicating device.”²⁶

It remains a mystery as to why De Forest chose to represent his late form of the flame detector as the early form in his AIEE lecture when it was not. There are at least three possibilities:

1. The flame detector that he identified in his AIEE lecture turned out to be a more sensitive detector than the earlier version appearing in his 1905 patent application.
2. The asymmetric form he described in his AIEE lecture was more like his vacuum bulb audion than the symmetrically placed electrodes that appeared in his 1905 flame patent.
3. The experimental data available on the physics and chemistry of the conductivity of flames in the day was generally obtained by researchers using asymmetric configurations with one electrode situated over the

other; no examples of data on De Forest's symmetric flame configuration could be found in the literature.

De Forest Presents the I-V Characteristic Curve for his Flame Detector

De Forest opened his dissertation on the flame detector he featured in his AIEE lecture as being remarkably sensitive to weak high-frequency oscillations. He stated that the current flowing between the two electrodes of this flame detector did not increase linearly with applied voltage and the conductivity of the flame did not follow Ohm's law:

"It was observed that the increase of current with electromotive force did not follow ohms law; a saturation value of the current was observed. Wilson found that the maximum [i. e., saturation] current with salt vapor in a flame can carry is equal to the current which

if passed through an aqueous solution of that salt would electrolyze the same quantity of the salt as was imparted during the same unit of time to the heated gas.

"Beyond this saturation value the current will not rise until the electromotive force is great enough to enable the field itself to ionize the gas; that is, until the velocity imparted to the negative ions by the field is sufficient to enable them to separate the gas molecules with which they collide into positive and negative ions."²⁷

This statement was accompanied by an I-V characteristic curve of unspecified origin (see Fig. 11). De Forest provided no references for this figure, so the only clue to its origin was the reference in the previous paragraphs to an anonymous person named Wilson.

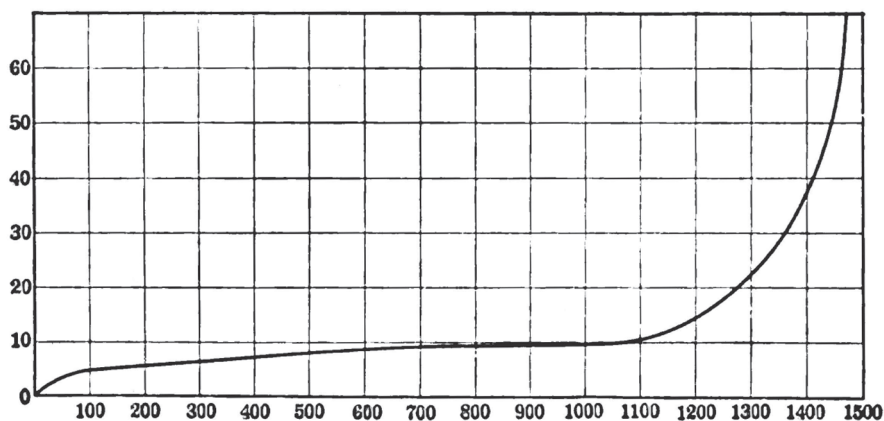


Fig. 11. De Forest claimed this I-V curve was from a flame experiment when in fact it was from an experiment by Egon von Schweidler in 1899 using a cylindrical chamber containing an adjustable plate located approximately 3 to 5 mm from the wall of the chamber, which was evacuated to an air pressure of one-sixth of an atmosphere without a flame or heated electrode. (AIEE lecture, p. 721)

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Who is Wilson?

The index of Thomson's book, *Conduction of Electricity Through Gases*, listed two Wilsons, one with initial C.T.R and the other with initials H. A. It turned out that Harold A. Wilson had published many papers on the subject of conductivity of flames. However, a thorough search of Wilson's papers published before 1907 did not reveal an I-V characteristic curve that looked anything like the one in this figure.

It also turned out that the introductory paragraph cited above was a paraphrased version of a paragraph that appeared on page 210 of Thomson's book, *Conduction of Electricity Through Gases*:

"Wilson measured this limiting current and found that it was equal to the current which when passing through an aqueous solution of the salt would electrolyze in one second the same quantity of salt as was sprayed in that time into the hot air."²⁸

This confirmed suspicions that De Forest was paraphrasing Thomson's book

when he described the physics of the conductivity flames. This prompted a page-by-page search of Thomson's book to see if he had referenced the source of this I-V curve. A search of his book not only revealed a citation to this figure, but it also revealed the actual curve shown here was copied from page 13 in a section dealing with the conductivity of gases between parallel plates.

Thomson stated that this curve was generated by measuring the current through the gas at reduced atmospheric pressure contained between two parallel plates exposed to "some ionizing agent," in this case the ionizing agent was an arc lamp that liberated electrons from the surface of a solid by the photoelectric effect, not heating. Thomson also gave the original reference for this I-V curve as being an experiment by one Egon von Schweidler that was first published in 1899.²⁹ Egon von Schweidler disclosed this figure in a lecture entitled "On the Photoelectric Phenomena" (see Fig. 12),³⁰ which he gave at the University of Vienna on February 16, 1899. The horizontal scale

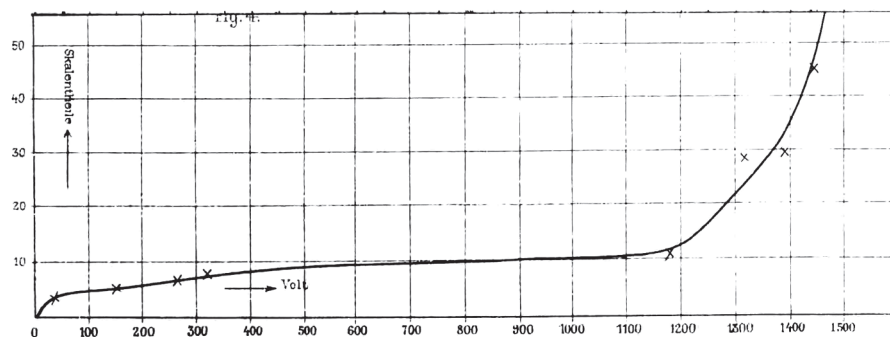


Fig. 12. According to J. J. Thomson, the I-V characteristic curve of Fig. 11 was reproduced from this original curve that Egon von Schweidler generated and published in 1899. (E. Von Schweidler, *Wien. Bricht*, Vol. 108, 1899, p. 280)

is “volts” and the vertical scale is “skalentheile” or “scale divisions,” meaning the scale is relative, not in units of current.

The experimental apparatus von Schweidler used to generate this curve was a small cylindrical vacuum chamber with a plate attached to a rod used to adjust the position of the plate with respect to a screen mesh located behind a transparent window (see Fig. 13).³¹ To generate this curve, the plate was set at a distance of 3 to 5 mm from the conducting mesh and the atmospheric pressure in the chamber was set at approximately 130 mm. The source of ionizing radiation was an arc lamp that ionized atoms at the surface of the plate and ejected them from the surface via the photoelectric effect. Von Schweidler generated the I-V curve by measuring the current as the arc lamp output was increased until the electric field across the plates reached the breakdown threshold of air. The resulting breakdown voltage shown in the von Schweidler figure is approximately 1,500 volts, which translates into an electric field of 300–500 kV/m for

a spacing of 3 to 5 mm—a reasonable breakdown threshold for air at a pressure of 130 mm, approximately one-sixth of an atmosphere.

This curve has nothing to do with a flame configuration or an experiment with heated electrodes or even an experiment at atmospheric pressure. It was amusing to read the next few pages of De Forest’s paper, where he waxed eloquently about the physics behind his flame detector using an experimental curve that was generated by using an evacuated cavity in which the chamber was exposed to the light of an arc lamp to ionize gas from one surface of the two parallel plates by means of the photoelectric effect. The best part is where De Forest explains why the electrode containing the salt must be incandescent to produce this curve: “The conduction through flames under the conditions I am describing is due chiefly to the negative ions generated, and these are chiefly in the vicinity of the metallic cathode. It is necessary that the alkali vapor comes in contact with the glowing metal.” There

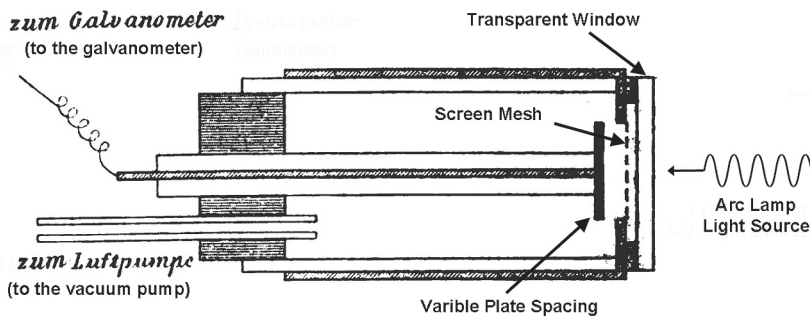


Fig. 13. The experimental apparatus von Schweidler used to generate this curve was a small cylindrical vacuum chamber with a plate attached to a rod used to adjust the position of the plate with respect to a screen mesh located behind a transparent window. (E. Von Schweidler, *Wien. Bricht*, Vol. 108, 1899, p. 274)

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are no electrodes heated to incandescence in this experiment, and the “negative ions” are electrons that are liberated (ionized) from one surface of a cavity by the photoelectric effect, not by heating. Also, the gas is at a pressure of one-sixth of an atmosphere.

De Forest’s use of this I-V characteristic curve that was not derived from a flame to explain the operation of his flame detector is nothing short of bizarre. Either De Forest used this curve knowing that it did not apply to a flame, or he failed to understand the text in Thomson’s book on the page where this figure was located. Either way, it shows an incredible amount of deception or ignorance. It is also obvious that De Forest did not realize that measurements using both positive and negative voltages were required to generate a complete characteristic curve for a detector of oscillations that had both positive and negative swings.

One might ask why De Forest did not measure the I-V characteristic curve for his flame detector rather than going through the charade of using a characteristic curve having nothing to do with a flame. It turns out that it is not easy to make conductivity measurements of a flame detector that is seeded with alkali salts to enhance the conductivity. Wilson reported that the currents produced in the electrodes he used to measure the I-V characteristics of his flame configurations required the use of a Kelvin galvanometer with a sensitivity threshold of 10^{-9} amperes.³²

Worse yet, the injection of salts into the flame to increase conductivity was problematic. In their seminal 1899 paper,

authors Arthur Smithells, Harry Dawson, and Harold Wilson wrote:

“It was found that any unsteadiness of the flame produced considerable and irregular deflections of the galvanometer which prevented the current from being measured in a satisfactory manner.”

“With a view to reducing this oscillation to a minimum, so as to obtain a steady galvanometer deflection, care was taken to regulate the quantity and pressure of the gas and air supplies with as much nicety as possible.”³³

Wilson used exceedingly complex equipment to measure the I-V characteristic curves of flames seeded with salts. One example of the equipment he used consisted of two different apparatuses, one used to measure the I-V characteristics, and the other used to generate a controlled flow of a mixture of gas, air, and a salt solution that was injected into the bottom of the burner barrel to produce a very stable flame and a measurable concentration of a salt solution.³⁴ The apparatus used to measure the I-V characteristics with two disk electrodes inserted into the flame, one above the other, is shown in Fig. 14. Both disk electrodes had diameters sufficient to extend across the entire cross-section of the flame. The lower disk consisted of a mesh with a spacing that allowed the flame to reach the upper electrode. The arrow at the bottom of the figure indicates where the controlled mixture of gas, air, and salt solution entered the burner barrel.

The apparatus that generated this steady flow of the mixture was much more complex than the measurement apparatus itself (see Fig. 15). No attempt will be made to describe the details of either apparatus. The point of this discussion is to show that De Forest did not do what was required to stabilize the flame or to ensure the uniformity of the salt

concentration between the electrodes of a flame, both of which were needed to properly measure the complete I-V characteristic curve that included both polarities of applied voltage.

The three methods that De Forest mentioned for seeding his flame with salts were crude by comparison: 1) a spray of a salts solution into the flame with an

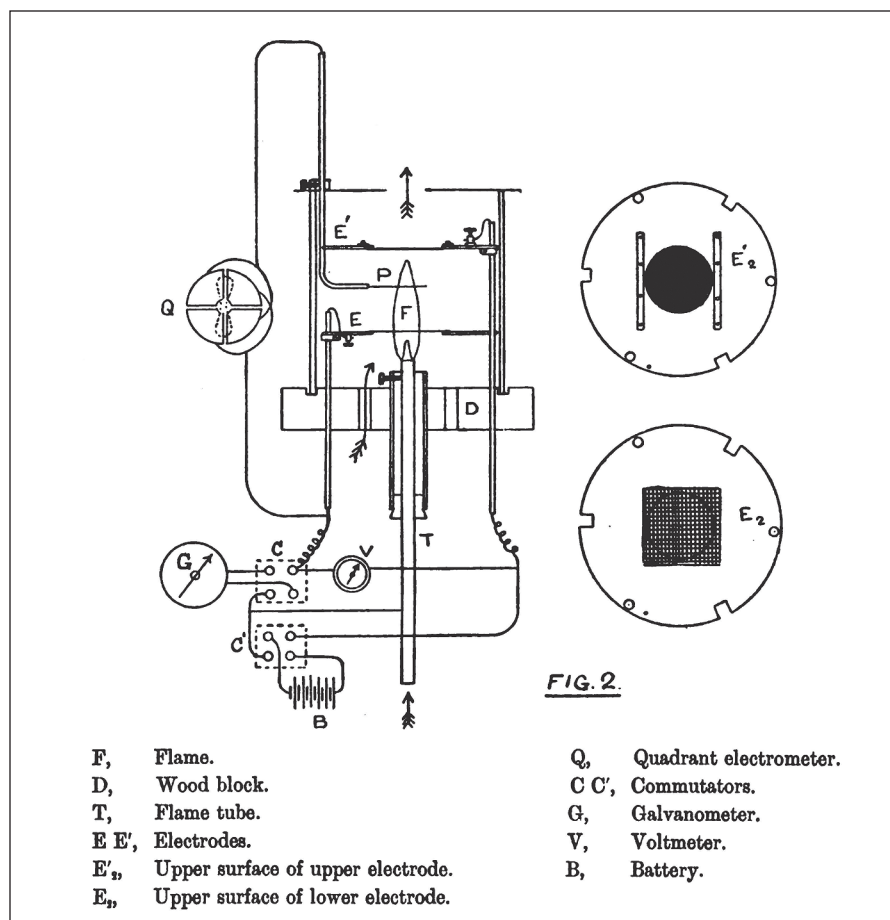


Fig. 14. Wilson used this complex apparatus to measure the I-V characteristics of a flame seeded with alkali salts using two disk electrodes inserted into the flame, one above the other; the arrow at the bottom of this figure indicates where a steady flow of gas mixed with a salt solution was inserted into the bottom of the burner barrel. (Wilson, *Trans. Royal Society of London*, Vol. 192, Apr. 27, 1899, p. 502)

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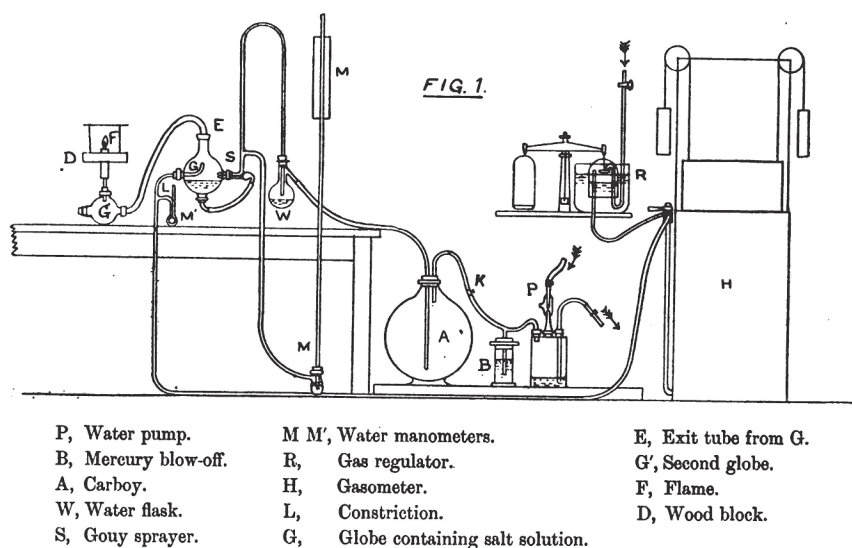


Fig. 15. Wilson used this complex apparatus to generate a steady and measurable flow of gas, air, and salt solution for injection into the bottom of the burner barrel shown in the previous figure. (Wilson, *Trans. Royal Society of London*, Vol. 192, Apr. 27, 1899, p. 500)

atomizer, 2) a trough (with dimensions of 2 mm by 1 cm) situated at the end of an electrode inserted into the flame to hold salts, and 3) a coating on the cathode electrode with a salt solution. It is difficult to imagine how any of De Forest's methods would have produced the steady flame with a constant level of salt seeding over the time needed to measure the I-V characteristic using both battery polarities.

The Unipolar Response of Flames

Even more important than what De Forest said about the I-V characteristic curve of his flame detector was what he did not say. By 1906 it was well known that the measured current flowing between two electrodes inserted into a flame had what was known as a "unipolar" response, which meant that magnitude

of the measured current flowing in a galvanometer was different when the battery terminals connected to the electrodes were reversed without changing the voltage. It is difficult to understand how he could have missed that point. De Forest claimed he often read J. J. Thomson's 1903 book during the time he developed his audion. Here is what Thomson wrote in this book:

"The current is proportional to the velocity of the ion which carries it; thus since the velocity of the negative ion is greater than that of the positive, the current for the same difference of potential between the plates [i.e., electrodes] is greater when the ionization takes place next the negative plate than when next the positive, in other words the current is greater in one direction

than in the opposite; this unipolar conductivity as it is called is very marked indeed in conduction through hot gases and flames containing salts.”³⁵

If De Forest had read any of the papers in the literature describing the conductivity of flames seeded with salts he would have found virtually all of these papers had data that specifically showed the conductivity of salted flames was found to be unipolar. The characteristic curve for a flame experiment that appeared in a paper published by Smithells, Dawson, and Wilson is an excellent example of how the I-V characteristics of a flame with a unipolar response were displayed (see Fig. 16).³⁶ They graphed their data using only two

of the four quadrants that are formed by the combination of positive and negative current axes with positive and negative voltage axes. At first glance, it might appear that the curves show results for only one polarity of applied voltage. However, the upper curve would appear in the upper right quadrant of a four-quadrant graphical representation, and the lower curve would appear in the lower left and upper left quadrants. No part of this curve would have appeared in the lower right quadrant.

This is not the same format that electrical engineers of the day used for the I-V characteristics of crystal detectors. They generally plotted the curves graphically by displaying all four quadrants. Twelve years after this figure was

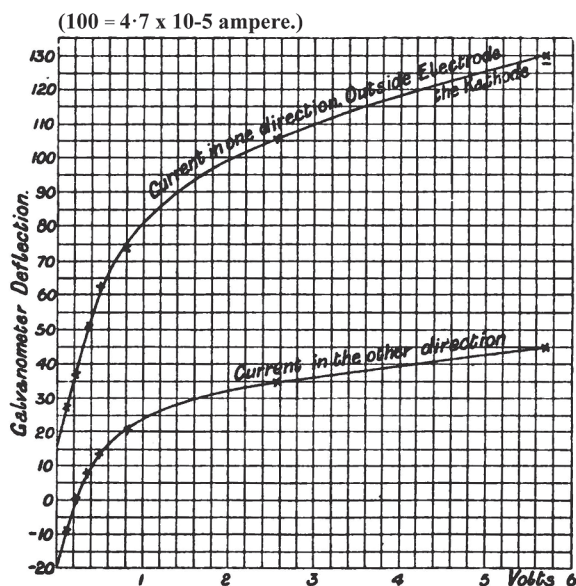


Fig. 16. The I-V characteristics for flames reported by Wilson and his colleagues exhibited a significant unipolar response such as the one shown in this curve where a reversal of battery polarity resulted in a large change in the magnitude of the measured current. (A. Smithells, et al., *Phil. Trans.*, Vol. 193, 1899, p. 99)

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published, Wilson wrote a book in which he replotted the curves from this figure using all four quadrants (see Fig. 17).³⁷ This form of the I-V curve, which most radio engineers are familiar with today, clearly shows the unipolar nature of this particular flame detector. For example, a positive voltage of two volts produced a current with a magnitude of 100 units (4.7×10^{-7} amperes), while the same voltage with the polarity of the battery reversed produced a current with a magnitude of about 35 units. Thus, a change in polarity without a change in voltage produced a difference in current amounting to a factor of three.

It does not necessarily follow that the flame detector De Forest presented at the AIEE lecture also had such a unipolar response. For example, if two identical electrodes are inserted symmetrically

into a flame and the flame is also symmetric, a change in polarity of the battery attached to the two electrodes would not change the magnitude of the resulting response. Wilson must have followed this line of reasoning when he designed an experiment to measure the asymmetry of a configuration that had a symmetric placement of electrodes. Wilson's description of this experiment was very brief: "The electrodes consisted of two platinum plates equal in size and placed as symmetrically as possible in the flame. A $\frac{1}{16}$ normal solution of KCl was used in these experiments."³⁸ The results were entered into a table, which indeed revealed a relatively small unipolar response for voltages between 1.5 and 43.5 volts (see Table 4). The difference in the magnitude of the current measured due to a change in battery

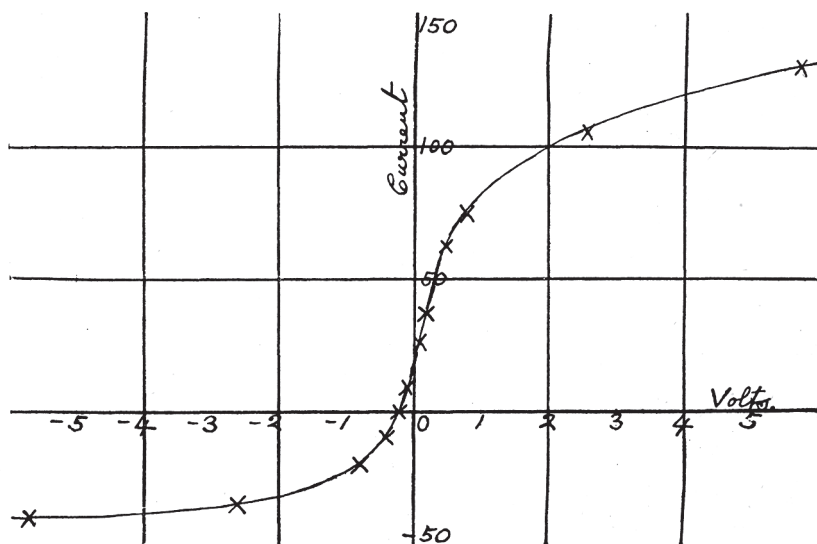


Fig. 17. Wilson replotted the I-V characteristic curve pictured in the previous figure using all four quadrants of the two variables (voltage and current); this form of the curve clearly shows a unipolar response. (Wilson, *The Electrical Properties of Flames and of Incandescent Solids*, 1912, p. 76)

Table 4. H. A. Wilson's I-V characteristic data measured with electrodes inserted symmetrically into the flame.

E.M.F. in volts	Galvanometer deflection	Galvanometer deflection (current reversed)
43.5	+39.7	- 48.8
29.0	+33.2	- 41.0
14.5	+24.7	- 29.3
7.3	+19.4	- 23.0
2.9	+15.1	- 16.9
1.5	+12.8	- 14.2

polarity was only 10% at 1.5 volts and it rose steadily to 20% at 43.5 volts. Wilson correctly concluded that electrodes inserted symmetrically into a flame produced symmetric I-V characteristics and asymmetric electrodes resulted in an asymmetric, or unipolar I-V characteristic curve.

Another important point is that none of the I-V characteristics for seeded flames published in the literature displayed a valve effect in which the current for only one polarity was essentially zero over a wide range of applied voltages useful in radiotelegraphy. This is no surprise because the currents in the seeded flames for both battery polarities were a result of the ionized gas between the electrodes. The currents were different because of the difference in the mass of the positive ion and the electron, but in neither case were the currents even close to zero. The flow of current in both directions in a flame distinguishes the response of a flame detector from the response of an evacuated bulb detector with one highly incandescent electrode—which displays not

only a unipolar response but also a valve effect.

Returning to the discussion of the I-V curve that De Forest presented at his AIEE lecture, it turns out that the flame detector he described was highly asymmetric:

“The size and shape of the electrodes are of small moment. I prefer a trough anode 1 cm long by 2 mm wide, holding the potassium salt, as [the] cathode, and a small platinum wire parallel thereto and held 2 to 10 mm above it as [the] anode. The trough electrode should preferably be at the upper tip of the oxidizing flame at its junction with the reducing flame. When this is made negative the current is saturated with a comparatively small potential difference.”

Because his flame detector was highly asymmetric it would have exhibited an asymmetric I-V curve similar to the one that appears in Fig. 17. By using a characteristic curve that did not apply to a

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flame, De Forest missed the fact that the flame detector he presented at his lecture should have exhibited unipolar a response. In doing so, he would have also missed the fact that there would have been two points on his characteristic curve with rapid changes in current where the detector was most sensitive—not just the one he showed in his AIEE lecture.

Genesis of De Forest's Vacuum Bulb Audion Detector

De Forest claimed the genesis of his vacuum bulb audion was an article written by Elster and Geitel in 1882. De Forest opened his discussion on his vacuum bulb audion by citing their paper in an issue of Wiedemann's *Annalen der Physik* dating to 1882:

"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 passes a fine metallic filament brought to incandescence by an electric current."

"*Elster and Geitel, *Wied. Ann.*, xvi, 1882."³⁹

He presented an image of what he claimed to be the experimental configuration from the Elster and Geitel publication (see Fig. 18). Using this image, De Forest then went on to describe what Elster and Geitel found:

"If the metal plate be connected by an outside wire to the positive terminal of

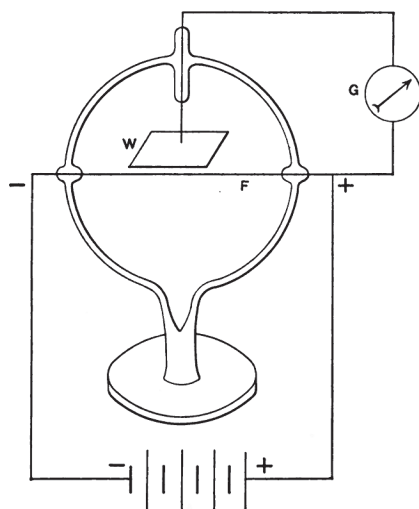


Fig. 18. De Forest represented this figure as being the experimental configuration that Elster and Geitel used in 1882 to demonstrate "the remarkable unidirectional quality of a gas at low pressure when the cathode is an incandescent wire or filament, and illustrated the exact device employed subsequently by Prof. Fleming and myself." (AIEE lecture, p. 725)

the hot filament, a leak-current from the plate to the filament through the gas will be set up, as Elster and Geitel first found, passing mainly to that portion of the filament near its negative terminal. If the resistance of the lamp filament and the lamp's voltage be high, a very considerable leak current may thus be set up."⁴⁰

De Forest added a battery and a telephone receiver to the Elster and Geitel configuration (see Fig. 19), and he claimed that the saturation (maximum) current in the plate circuit of this vacuum bulb increased rapidly as the temperature of the wire was raised by increasing the current in the filament:

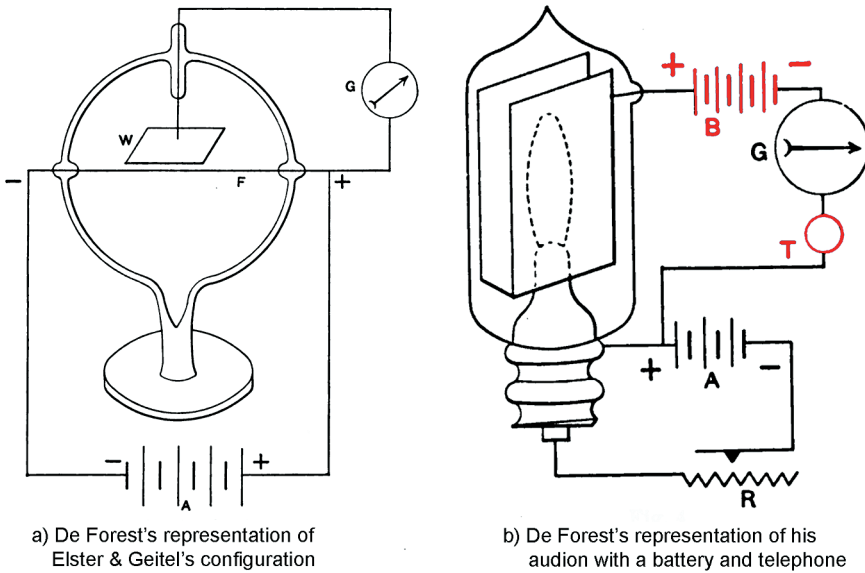


Fig. 19. De Forest claimed that Elster and Geitel's configuration on the left was the genesis of his audion bulb detector, which he invented by adding a battery and a telephone receiver to their configuration that resulted in the audion configuration on the right. (AIEE lecture, p. 727)

"A battery of from 3 to 18 dry cells is connected between the positive end of the filament and the platinum plate *w*, the latter being connected to the positive pole. The saturation current increases rapidly with the heating current through the filament, which also increases the velocity of the negative ions, as does also an increase in the applied electromotive force between plate and filament."

It is important to note that De Forest used the generally accepted convention that the long line of a battery in a schematic diagram represented the positive terminal and the short line represented the negative terminal. Thus, the positive terminal of the battery in the plate circuit was connected to the cold plate, and the

negative terminal of the plate battery was connected to the positive terminal of the filament battery. He reinforced this by placing the positive and negative symbols appropriately.

De Forest then concluded that the external battery made his device much more sensitive than the device in Fleming's patent, which did not have a battery in the plate circuit:

"Fleming points out that when the cold plate of the Elster-Geitel tube is connected to the positive end of the filament, and the two put in a high-frequency oscillation circuit, only the positive half of the oscillation can pass from the plate to the filament across the gas. He uses this principle to rectify the Hertzian oscillations, and applies the

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unidirectional currents of the oscillations themselves to operate a sensitive galvanometer, or direct current instrument, for quantitative measurements over very short distances. When an independent external source of electromotive force is applied, in the manner I have described, the action becomes quite different. It then operates as a *relay* to the Hertzian energy instead of merely rectifying this energy so that it can be used directly to give the sense signal. The Audion therefore is tremendously more sensitive and available in practical wireless.”⁴¹

While De Forest’s statement implied that the genesis of his audion invention was the Elster and Geitel experiment, he did not explicitly make that claim in his AIEE lecture. However, he did make an explicit claim in response to a letter that Fleming wrote to *The Electrician* after reading the above paragraph that was published in an earlier issue of *The Electrician* dated November 23, 1906.⁴² Fleming was incensed by the above paragraph in his paper and responded with a letter of his own to the editor of *The Electrician*, which appeared in the next issue dated November 30, 1906. Fleming scolded De Forest in his letter and corrected him by stating that he (Fleming) had discovered his valve as a result of studying the Edison effect in 1890, not from the Elster and Geitel experiment in 1882:

“As far back as 1890, when investigating the so-called ‘Edison effect’ in glow lamps, I discovered the unilateral conductivity of the space between

the incandescent filament and a cold metal plate held on a platinum wire sealed through the glass, and in November, 1904, discovered that this unilateral conductivity held good for high frequency currents.... and described the use of this device as a receiver in connection with electric wave telegraphy....”⁴³

De Forest responded to Fleming with a letter that appeared in an issue of *The Electrician* dated December 12, 1906.⁴⁴ In this letter he explicitly stated that the Elster and Geitel experiment was the genesis of his audion:

“Sir: In reply to a letter appearing in your recent issue by Prof. Fleming, I will say that not only in my original paper before the American Institute of Electrical Engineers, but also in the abstract printed in *The Electrician*, it is seen that I mention not only the device described by Prof. Fleming in 1904, but point out the real genesis of this device by Elster and Geitel in 1882, or eight years prior to its ‘re-discovery’ by Prof. Fleming in 1890. The German investigators were at that early date demonstrating the remarkable unidirectional quality of a gas at low pressure when the cathode is an incandescent wire or filament, and illustrated the exact device employed subsequently by Prof. Fleming and myself. However, the figure in the abstract of my paper clearly shows the local battery in the telephone circuit, which makes all the difference between a possible rectifier of alternating current of very considerable voltage

and a relay or trigger device, whereby the flow of the local current is affected to an extraordinary degree.”⁴⁵

This paragraph constitutes the smoking gun in which De Forest asserted “the real genesis of this device was by Elster and Geitel in 1882,” which he followed by an assertion that they “illustrated the exact device employed subsequently by Prof. Fleming and myself.” De Forest then distinguished his invention from Fleming’s invention by stating that he had added a local battery to the external circuit of the Elster and Geitel configuration whereas Fleming had not. The conclusion reached here is the same as the conclusion reached by an unnamed editor or correspondent for the *Electrical Age* based on De Forest’s lecture:

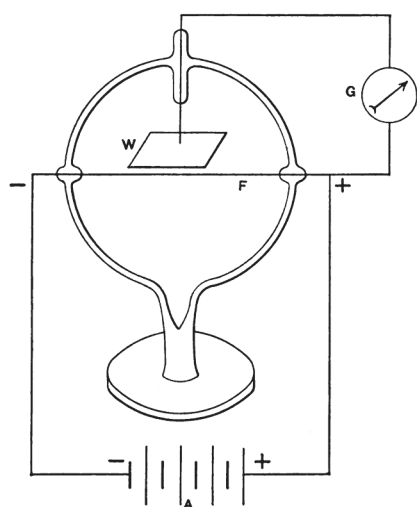
“The audion, the wireless receiver which Dr. De Forest described in his recent paper before the American Institute of Electrical Engineers...is printed elsewhere in this issue.... In its present form it appears to be based on the Elster and Geitel tube for showing the ionization of a gas, or the electrification of a platinum plate using an incandescent filament, which device, as Dr. De Forest points out in his paper, Fleming has used for rectification of Hertzian oscillations.... De Forest adds the external electromotive force in the flux [i.e., plate] circuit, whereupon, as he states, the audion is born. In his paper, Dr. De Forest expresses the opinion that the addition of the external flux battery causes the audion to act as a relay to the Hertzian remedy.”⁴⁶

De Forest Misrepresented the Elster and Geitel Experiment

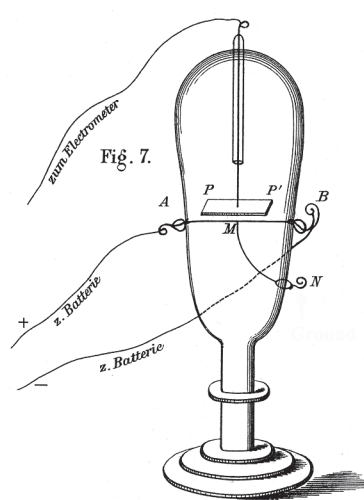
De Forest claimed that the evacuated audion bulb configuration he presented in his AIEE lecture represented the figure that Elster and Geitel published in their 1882 paper. However, the configuration that Elster and Geitel published in their paper, shown on the right of Fig. 20, was very different from the configuration that De Forest represented as being from their paper, which is shown on the left of this figure. There are three critical differences between the two versions:

Substitution of a Galvanometer for an Electrometer: De Forest replaced the electrometer that appeared in the Elster and Geitel configuration with a galvanometer denoted by “G.” An electrometer is a high-impedance measuring device often used to measure the potential difference between two points in a circuit isolated by a high impedance, while a galvanometer is a relatively low-impedance device (on the order of a few thousand ohms or less) often used to measure a current flowing in a circuit. De Forest claimed that Elster and Geitel measured currents: “If the metal plate be connected by an outside wire to the positive terminal of the hot filament, a leak-current from the plate to the filament through the gas will be set up, as Elster and Geitel first found, passing mainly to that portion of the filament near its negative terminal.”⁴⁷ If De Forest had read Elster and Geitel’s paper he would have found tables of voltage measurements associated with this figure, not current measurements. During another part of his discourse on the

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DE FOREST DRAWING



ELSTER & GEITEL DRAWING

Fig. 20. The configuration that De Forest represented as being from the Elster and Geitel paper (left) was very different from the configuration that actually appeared in their paper (right). Most importantly, the plate of the Elster and Geitel figure was connected to the horizontal wire at M through an electrometer (not a galvanometer) that was connected to terminal N, not to either battery terminal as indicated in De Forest's circuit. (Left: AIEE lecture, p. 725; Right: *Ann. d. Physik*, Vol. xxxi, 1887, p. 109)

Elster and Geitel experiments, De Forest reported that potential differences were measured with this circuit that he claimed used a galvanometer: "Ordinarily at atmospheric pressures and red heats a positive charge was produced upon the plate, of the order of a few volts."⁴⁸ Potential differences between isolated electrodes cannot be measured with a galvanometer.

Missing Wire (MN) to Balance Charge:

De Forest's representation of the Elster and Geitel configuration was missing the wire MN that connected the center of the filament wire at M to the terminal N on the outside of the glass, which according to the text of the Elster and Geitel

paper was grounded. The purpose of the ground wire was to balance the negative charge on one half of the filament wire AB with the positive charge on the other half of the wire so the net charge on the wire would not influence the potential of the isolated plate as the filament current was increased.

Erroneous Connection of the Plate Circuit to the Filament Battery:

In De Forest's configuration the plate circuit was connected to the positive pole of the battery, whereas in the actual Elster and Geitel circuit the plate circuit was connected to one side of an electrometer but does not show where the other terminal of the electrometer is connected. However, the

text stated that the other terminal of the electrometer was connected to terminal N. Thus, the plate circuit was actually connected to the center of the horizontal wire by the wire MN, not by connecting the plate circuit to either the battery terminal, as it is in De Forest's circuit.

The circuit that Elster and Geitel used to measure potential differences of isolated electrodes in a flame with an electrometer appeared in a figure from another nonrelated paper they published earlier (see Fig. 21).⁴⁹ In this figure, each electrode from the flame is connected to each of the two electrometer terminals through a double-pole double-throw switch. The purpose of the switch was to initialize the electrometer by shorting both the electrometer and the electrodes in the flame to ground to drain off all the charge and set the potential difference of the electrometer input terminals and the two flame electrodes to zero. To make a measurement, the switch was then thrown to connect the two electrodes to the two terminals of the electrometer, one of which remained grounded at the switch to provide a reference electrode for measuring the change in potential of the second electrode.

To summarize, De Forest not only replaced the electrometer with a galvanometer, but he eliminated the connecting wire MN and instead showed a connection of the galvanometer to one lead of the battery—specifically to the positive lead of the battery. In doing so he created a deceptive configuration to match the configuration of the audion that he introduced. The configuration that De Forest represented as being the Elster and Geitel

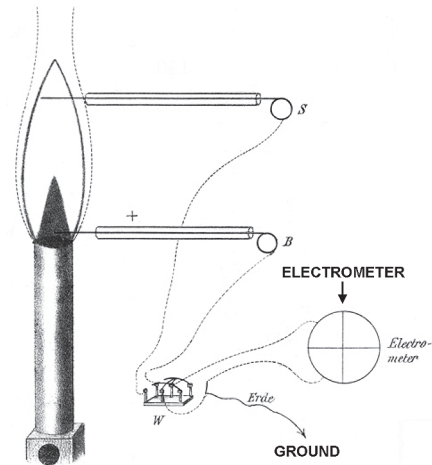


Fig. 21. The circuit that Elster and Geitel used to measure potential differences of isolated electrodes with one grounded electrometer lead appeared in a figure from another unrelated paper that they published earlier where they were measuring the potential difference between two isolated electrodes in a flame. (*Ann. d. Physik*, Vol. 16, 1882, p. 223)

configuration was actually identical to the Edison effect bulb configuration that Edison used to measure his Edison effect current. It will be shown in an addendum to Part II that the actual Elster and Geitel configuration shown here was not used by Elster and Geitel to demonstrate the unipolar response of a hot wire in an evacuated chamber. The actual configuration that they documented in their paper for that purpose, which was completely different, will be presented.

De Forest Misrepresented the Publication Date of the Elster and Geitel Paper

In a letter to the editor of *The Electrician* dated December 29, 1906, Fleming pointed out that the Elster and Geitel

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configuration to which De Forest had referred in his AIEE lecture was not published in 1882 as he claimed. Fleming claimed the paper to which De Forest had referred was entitled "On the Electricity of Flames." He corrected him by stating that the paper was published in 1887.⁵⁰

"Sir: In his letter published in your issue of Dec. 28th in reply to mine of Nov. 30th last Dr. De Forest seems to have committed the common mistake of failing to verify his references. If he had consulted the original paper of Elster and Geitel published in *Wiedemann's Annalen* for 1882, to which work he makes reference, he would have seen that its title is 'Ueber die Electricität Flamme,' and that it has nothing whatever in it which anticipates my subsequent invention of an oscillation valve for high-frequency currents.

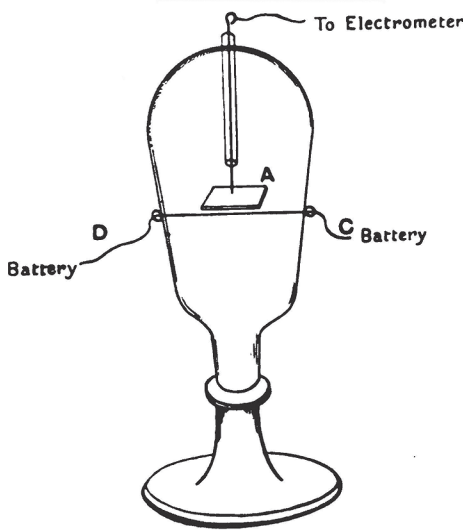
"It is true that in 1887 they published a paper "Ueber die Electrisirung der Gase durch Glühende Körper," in which an apparatus is described consisting of a glass bulb having a platinum wire electrically heated sealed across it and an insulated plate contained in it."⁵¹

When De Forest responded to Fleming's letter, he ignored Fleming's objection to the date of the Elster and Geitel paper and continued to maintain as late as 1913 that the date of this Elster and Geitel paper was 1882: "The vacuum valve, as first discovered by Edison and carefully studied by Elster and Geitel*

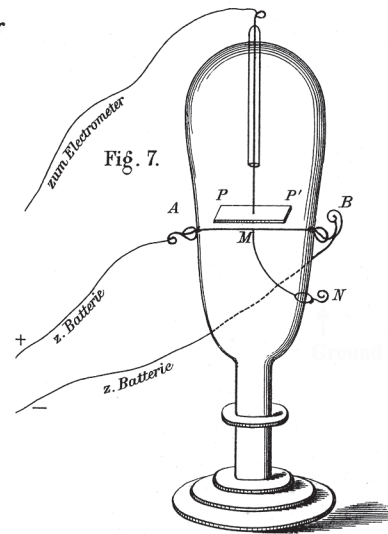
has most marked rectifying properties, excelling in efficiency any electrolytic or crystal rectifier."⁵² The asterisk in this sentence referred to a footnote citing the 1882 date: "*Wiedemann's Annalen*," xvi, 1882."

How was it possible that De Forest maintained his position on the erroneous 1882 date long after Fleming corrected him? Fleming suggested that De Forest never actually read the Elster and Geitel paper that he referenced. It turns out that J. J. Thomson reproduced an image of the Elster and Geitel configuration on page 26 of his 1903 book, which De Forest claimed was a bible that he often consulted during this period. This configuration was very similar to the one that appeared in the original Elster and Geitel paper, but there was one significant difference. Thomson deleted the wire MN that connected the center of the wire AB to the external binding post MN, which appeared in the Elster and Geitel paper (see Fig. 22). While Thomson deleted this wire from his figure, he did refer to the existence of this wire in the text where he explained the purpose of the missing wire. Perhaps he deleted the wire so he could more easily describe the purpose of the experiment. While the wire was required for a successful experiment, it did not involve its purpose or contribute to the interpretation of the results:

"To prevent any disturbing effect arising from the change produced by the current in the electric potential of the wire, the middle point of the wire was connected with the earth."



J. J. THOMSON DRAWING



ELSTER & GEITEL DRAWING

Fig. 22. J. J. Thomson reproduced an image of the Elster and Geitel configuration in his 1903 book (left) that was similar to the one that appeared in the original Elster and Geitel paper (right); however, Thomson deleted the wire MN from the Elster and Geitel configuration that appeared in their paper, which connected the center of the wire AB to the external binding post N. (Left: Thomson, *Conduction of Electricity*, 1903, p. 156; Right: Elster & Geitel, *Ann. d. Physik*, Vol. 31, 1887, Plate 1, Fig. 7)

Notably, Thomson's interpretation of the Elster and Geitel configuration without wire MN was much closer to De Forest's audion configuration than the actual Elster and Geitel configuration (see Fig. 23). This difference supports a contention that De Forest read Thomson's book rather than the original Elster and Geitel article, but it does not explain why De Forest made two other major alterations to the figure so that it matched his audion configuration. The most logical conclusion is that De Forest made those changes on purpose in an attempt to support a claim that he copied his audion configuration from Elster and Geitel's earlier disclosure in

1882, believing that it predated Edison's disclosure of the Edison effect configuration in 1883 and De Forest's disclosure of his valve configuration in 1904.

The error in the stated date of publication of the Elster and Geitel paper can also be explained by the presumption that De Forest discovered the Elster and Geitel configuration in Thomson's book but failed to check the actual reference in *Annalen der Physik*. It turns out that Thomson was the one who made the error in the date of Elster and Geitel's paper. Thomson added a footnote to the Elster and Geitel configuration with a reference containing the erroneous date. Thomson's footnote contained six entries

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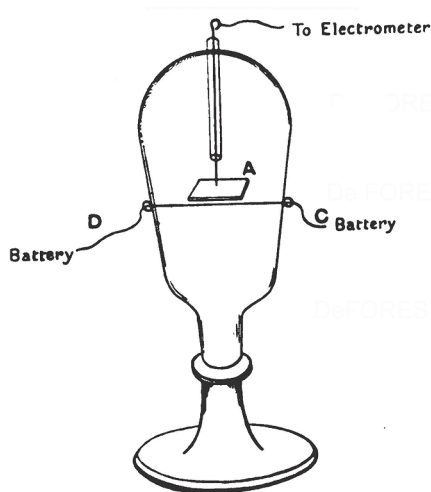


Fig. 23. J. J. THOMSON DRAWING

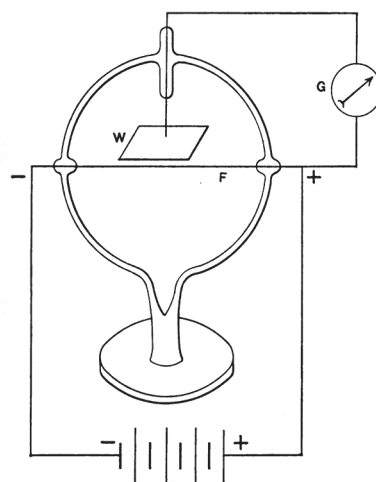


Fig. 23. De FOREST DRAWING

Fig. 23. De Forest's detector configuration shown on the left was almost identical to Thomson's incomplete version of the Elster and Geitel configuration on the right because both of these configurations were missing the wire MN that connected the plate circuit to the horizontal wire rather than to either battery terminal. (Left: AIEE lecture, 1906, p. 725; Right: Thomson 1903, p. 156)

on the subject of ionization produced by incandescent metals that were published by Elster and Geitel in *Annalen der Physik*, the first and incorrect entry being: "Elster and Geitel, *Wied. Ann.* xvi. p. 193, 1882." This is the same reference that appeared in De Forest's AIEE lecture. The correct reference to the Elster and Geitel paper with the experimental configuration in question was actually the fifth entry out of six to *Annalen der Physik* that appeared in the footnote of Thomson's book: "xxxi. P. 109, 1887."

Thomson also made the same error in a reference he made to the same Elster and Geitel article in his earlier book, *The Discharge of Electricity Through Gases*:

"Elster and Geitel, *Wied Ann.*, 16, p. 193, 1882; 19, p. 588, 1883; 22,

p. 123, 1884; 26, p. 1, 1885; 31, p. 109, 1887; 37, p. 815, 1889."⁵³

De Forest was not the only one to be fooled by the two erroneous references to the Elster and Geitel experiment in Thomson's books. Owen Richardson, who developed the theory of thermionic emission from heated solids, cited the same Elster and Geitel paper using the same erroneous 1882 citation that appeared in Thomson's 1898 book. In a paper Richardson wrote as a graduate student in 1901, he began with the following sentence containing a reference to the Elster and Geitel paper at issue: "Ever since the original discovery by Messrs Elster and Geitel that the air in the neighborhood of a hot metal discharged electricity, several physicists have

investigated the laws of this phenomenon.”⁵⁴ The reference in this sentence was to this footnote that appeared at the bottom of page 286 in his paper: “Elster and Geitel, *Wied., Ann.* xvi. 1882, p. 193, and later papers.”

De Forest Misrepresented the I-V Characteristic Curve of his Audion Bulb

De Forest presented an I-V characteristic curve that he claimed was measured

for a double-wing audion of the type he presented in his AIEE lecture (see Fig. 24): “These curves were all taken with audions of the double-wing type.”⁵⁵ The axes on his curve were reversed from the conventional way that scientific data was and still is presented. The independent variable (in this case, voltage) is normally displayed on the horizontal axis (abscissa), and the dependent variable (current) is normally displayed on

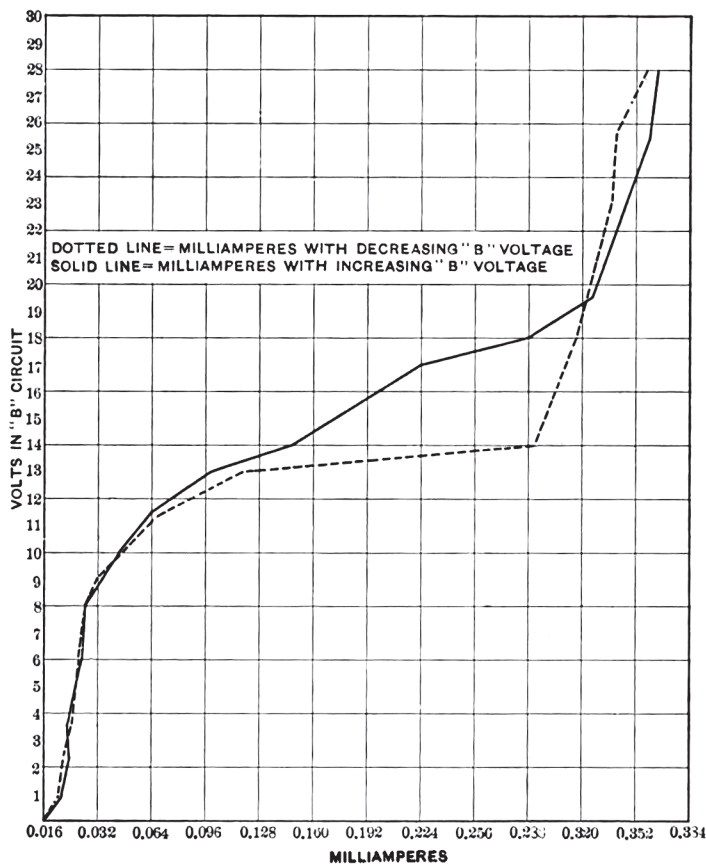


Fig. 24. De Forest claimed he measured this I-V characteristic curve for his double-wing bulb detector in which the voltage and current axes are reversed when compared to the accepted scientific convention where the x-axis represents voltage as the independent variable. (De Forest, AIEE lecture, 1906, p. 373)

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the vertical axis (ordinate). De Forest reversed them for no apparent reason. He may have done so in an attempt to make his curve look different from Fleming's I-V characteristic curve for his valve that he published in March 1905. Regardless of why he reversed the axes, the conventional way to plot his data has been restored by rotating and flipping his curve (see Fig. 25).

It should be apparent to anyone familiar with the Edison effect that this I-V curve was not created by using data collected using the double-wing audion that he presented in his AIEE lecture with the plate circuit connected to the

positive electrode of the filament battery (see Fig. 26). When the plate circuit lead is attached the positive terminal of the filament battery and the plate circuit voltage is set to zero, the resulting configuration is identical to Edison effect bulb where the galvanometer in the plate circuit registers a considerable current without a battery. Fleming developed a demonstration experiment to illustrate this effect for the Edison bulb (see Fig. 27).⁵⁶ When the switch on the left (connected to the negative pole of the filament battery) was closed, there was no flow of current in the galvanometer. However, when the switch on the right

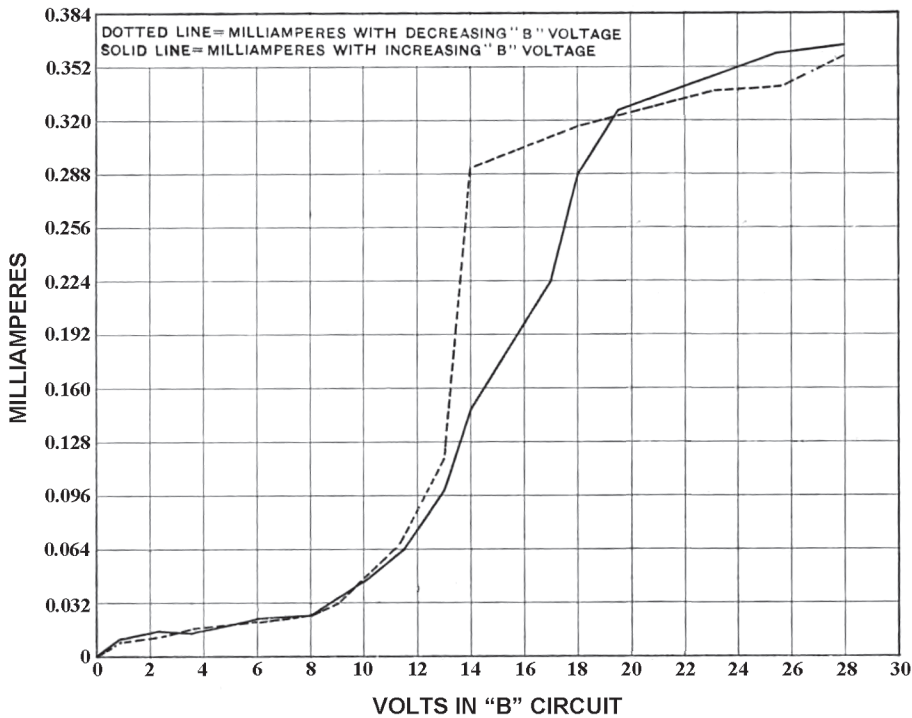


Fig. 25. The I-V characteristic of the previous figure is corrected by a 90-degree clockwise rotation and a 180-degree flip about the x-axis that places the voltage on the x-axis as the independent variable and the current on the y-axis as the dependent variable. (Author's curve correction)

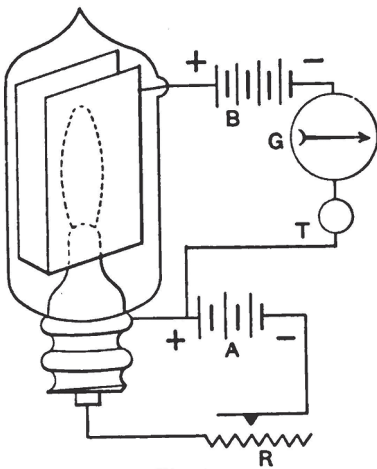


Fig. 26. De Forest connected the plate circuit of his double-wing audion to the positive terminal of the filament battery. (De Forest, AIEE lecture, 1906, p. 727)

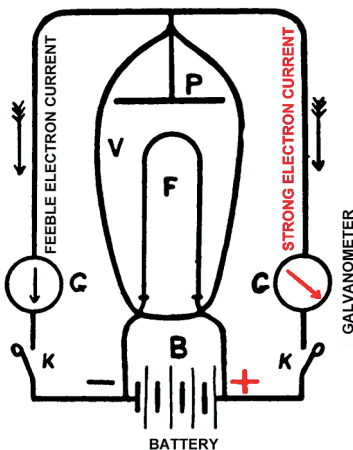


Fig. 27. Fleming developed this experiment to demonstrate that the Edison effect current in the plate circuit of an evacuated bulb is significant without a battery in the plate circuit when the galvanometer in the plate is connected to the *positive* terminal of the filament battery and it is essentially zero when the galvanometer is connected to the *negative* terminal of the filament battery. (Fleming, *Meetings of Royal Inst. of Great Brit.*, Vol. 23, June 1924, p. 162)

(connected to the positive terminal of the filament battery) was closed, there was a significant flow of current in the galvanometer.

De Forest's configuration should have exhibited a relatively strong current when the battery voltage in the plate circuit was zero, but the I-V characteristic curve shows the current in the plate circuit was zero when no voltage was applied. This is possible only when the battery in the plate circuit is connected to the negative pole of the filament battery. There is no error in the polarity of the filament battery in this figure because De Forest had confirmed that the plate circuit was connected to the positive pole of the filament battery in his patent application covering the double-wing audion:

"Better results are obtained if the negative pole of the [plate circuit] battery B be connected to that end of the filament F to which the positive pole of the [filament] battery B' connected."⁵⁷

This statement is proof that De Forest's I-V characteristic curve was not measured for the double-wing configuration, which had a plate circuit connection to the positive pole of the filament battery. From this statement is also apparent that De Forest tested his audion first with a plate circuit connection to the negative pole because he found that he got a better response when it was connected to the positive pole. This makes sense because De Forest's first patent application for an audion bulb was filed with the plate circuit connected to the negative terminal of the filament battery (see Fig. 28)—the

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same polarity that De Forest indicated in his patent application (see Fig. 29).

Note that De Forest used a different convention in marking the polarity of his batteries in his 1906 AIEE lecture than he did in either of his two-electrode audion patent applications. In his AIEE lecture, he designated the long lines of the two batteries in the double-wing audion circuit as the positive poles, while in his patent application for the same double-wing audion he designated the short lines as being the positive poles of the two batteries in the circuit. De Forest used the same battery convention in both of his audion patents, but he did not specifically mark the polarities of the batteries with plus and minus symbols in his first audion patent with a single

plate, as he did with the double-wing audion. The reason for his change in battery polarity convention in his AIEE lectures from the convention he used in both of his audion patent applications is unknown.

Takeaway from De Forest's AIEE Lecture

The account De Forest gave in his October 1906 AIEE lecture was filled with erroneous statements and intentional deceptions. With one notable exception,

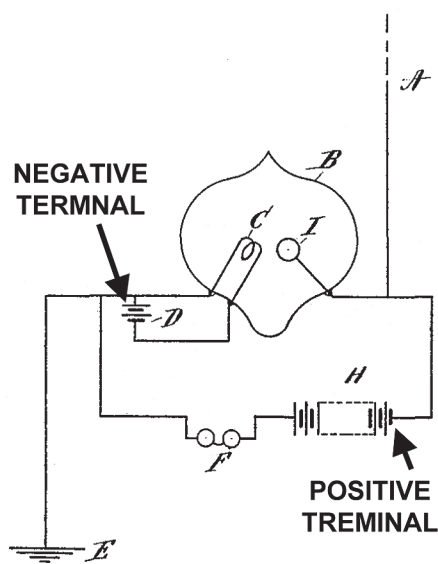


Fig. 28. The galvanometer in the plate circuit of the Fleming valve was connected to the negative terminal of his filament battery, as indicated in this figure from his U.S. patent application. (Fleming, U.S. Patent 803,684)

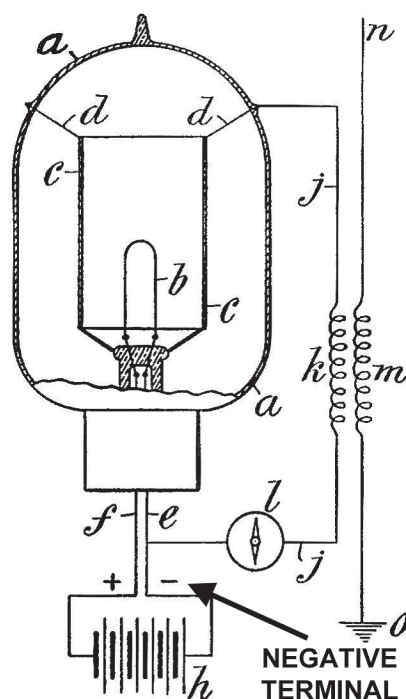


Fig. 29. De Forest's first patent application for an evacuated bulb audion shows the plate circuit connected to the negative terminal of the filament battery, which was indicated by a short line at the end of both batteries for the positive poles and a long line for the negative poles. (De Forest application for U.S. Patent 824,637, Fig. 3)

virtually all of the claims that he made during his AIEE lecture were abandoned in later accounts. The only claim he made for his two-electrode audion in this lecture that he maintained throughout his life was that his evacuated bulb audion acted as a relay or amplifier and therefore was much more sensitive than Fleming's valve. In the end, this claim also turned out to be false, although he never admitted it. The most significant false or deceptive claims that he soon abandoned were the following:

1. De Forest claimed that the genesis of his audion bulb was the Elster and Geitel configuration that appeared in a paper they published in 1882. This claim proved to be false because he misrepresented the configuration that appeared in their paper by altering it in three very significant ways so that it conformed to the audion configuration that he presented at the AIEE lecture. There can be no doubt that the Elster and Geitel configuration was not the genesis of his audion.
2. De Forest maintained for years that the Elster and Geitel paper was published in 1882, even after Fleming informed him more than once that their paper was published in 1887. Fleming was correct and De Forest was incorrect.
3. De Forest claimed that the flame detector he presented at his lecture was an "early state" of audion, but it was first documented in a patent application he filed on January 20, 1906—after he filed his first audion patent. He failed to mention that he had filed a patent application a year earlier, on February 2, 1905, for a much different flame detector of Hertzian radiation.
4. De Forest presented an I-V characteristic curve for his flame detector that turned out to be an I-V curve generated by Egon von Schweidler using an evacuated cavity with a surface exposed to the light from an arc lamp source to liberate electrons from the surface by the photoelectric effect.
5. De Forest presented an I-V characteristic curve that he claimed was measured using his double-wing audion with a plate circuit connection to the positive pole of the filament battery, but the curve was actually measured with the plate circuit connection to the negative pole of filament—just like the Fleming valve circuit.
6. De Forest erroneously claimed that Fleming connected the plate circuit of his audion to the positive terminal of the filament battery in the Elster and Geitel configuration appearing in an 1882 publication; Fleming actually attached his plate circuit to the negative terminal of the Edison effect tube circa 1887, about the same time the Elster and Geitel paper was published.

Judge Mayer's Opinion in Marconi vs. De Forest Trial (September 20, 1916)

Judge Julius Mayer was the judge who presided over the 1916 trial that resulted from the litigation between American Marconi and the De Forest Radio Telephone and Telegraph Company. He

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documented his decision on September 20, 1916, when he ruled that Fleming's two-electrode valve patent and De Forest's two- and three-electrode audion patents were valid and that Fleming's valve patent did not infringe any of De Forest's patents. He also found that De Forest's two- and three-electrode audion patents infringed Fleming's two-electrode valve patent.

Judge Meyer's ruling, published in the *Federal Reporter* in 1917,⁵⁸ revealed significant information on De Forest's testimony describing how he invented his two- and three-electrode audions. The focus of this section is on Judge Mayer's observations of De Forest's testimony and exhibits relating to his discovery and descriptions of his two-electrode audions. The actual trial testimony and exhibits will be recounted in Part II.

De Forest Changed his Story for the Genesis of his Audion

In his 1906 lecture, De Forest claimed the genesis of his two-electrode audion was the configuration in the Elster and Geitel paper. However, according to Judge Mayer's findings, De Forest claimed the genesis of both his two- and three-electrode audions was a flame detector configuration that he described in his U.S. Patent 979,276, which he filed on February 2, 1905 (see Fig. 5). Judge Mayer characterized this patent as his "parent patent," meaning that it was the genesis of his audions:

"In endeavoring to resist plaintiff's attack, defendants have proceeded on the theory that, beginning with his

parent patent, No. 979,275, antedating Fleming, De Forest gradually developed his first conception until finally it found practical exemplification in the two so-called three-electrode 'Audion' devices as to which plaintiff has confessed judgment. In line with this plan of defense, defendants have elaborately built up an unsteady theoretical structure, and upon this have superimposed an observatory from which they can see in the mind's eye only that which they call 'Audion' action."⁵⁹

If his U.S. Patent 979,275 was his parent patent, then the asymmetric flame configuration he introduced in his AIEE lecture could not have been his early audion. Surely, De Forest chose his U.S. Patent 979,275 to be the parent of all his audions in this litigation because it was the only detector device with heated electrodes that he had documented before the priority date accorded to Fleming's valve patent application. De Forest would never have been accorded priority in a court of law for any kind of detector, flame or otherwise, that was not documented before the priority date of the Fleming valve. De Forest would continue to claim for the rest of his life that the genesis of his vacuum tube audion bulb was a flame configuration described in his U.S. Patent 979,275.

De Forest had Prior Knowledge of Fleming's Patent

Judge Mayer made the following statement in his written opinion, which he recalled from testimony given in the 1916 trial:

"It must be remembered that De Forest in December, 1905, knew of Fleming's Royal Society paper of March, 1905, as appears from a reference to that effect in his application for a certain patent not here in issue (No. 823,402), where he used the expressions 'exhausted vessel' and 'heated to incandescence.'"⁶⁰

The patent he referred to was entitled "Static Valve for Wireless Telegraphy," for which De Forest filed his application on December 9, 1905. Here is the paragraph cited by De Forest in this patent to which the judge referred:

"The device V¹, [shown in Fig. 30] connected between the antenna at point b and earth, is an asymmetric resistance or electric valve which has been fully described by J. A. Fleming in a paper published in the *Proceedings of the Royal Society of London*, March 16, 1905, to which reference may be had for a more complete description thereof than need to be set forth herein. Suffice it to say that the exhausted glass vessel Q" contains the filament F' heated to incandescence by the battery B' and a metal cylinder D', which surrounds the filament F'. This type of valve passes positive electricity from the cold terminal D' to the heated terminal F' more readily than in the opposite direction."⁶¹

The device "V¹" shown in "Fig. 1" of this patent was a Fleming valve that is reproduced here as Fig. 30. De Forest referenced an article by Fleming that appeared in the *Proceedings of the Royal*

Society of London,⁶² which contained a complete description of Fleming's valve. It included a schematic diagram of the Fleming valve that actually appeared in Fleming's valve patent (see Fig. 29); it showed how the valve was connected to an antenna and ground to function as a detector for radiotelegraphy. The article also included a set of I-V characteristics for three different filament voltages (see Fig. 31). The article even revealed three possible plate configurations, one of which was a two-plate configuration (see Fig. 32 c), which appeared in the audion in De Forest's 1906 AIEE lecture.

Fleming also revealed the following information in the paper cited by De Forest that provided all the information that De Forest needed to engage a glass blower to fabricate a sensitive, functioning detector:

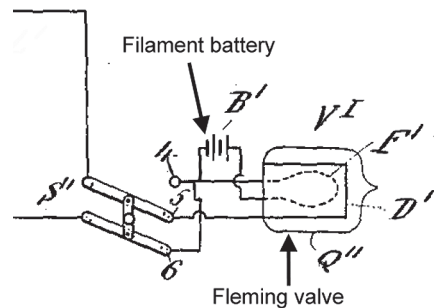


Fig. 30. De Forest filed an unrelated patent on Dec. 9, 1905, complete with this image of Fleming's valve; this patent application also revealed that De Forest had read an article by Fleming that appeared in the *Proceedings of the Royal Society of London*, which included a schematic diagram of the valve he used in his patent application accompanied by a detailed description of its technical parameters. (De Forest U.S. Patent 823,402)

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1. The curves in Fig. 31 indicated that the vacuous space would possess a maximum conductivity when a potential difference of about 20 volts was applied to the electrodes.
2. The bulb should be highly exhausted

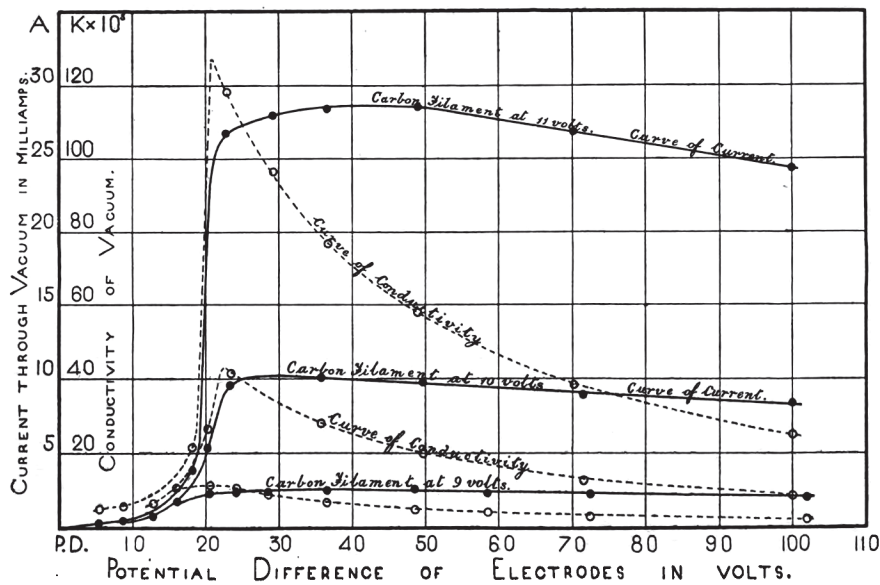


Fig. 31. De Forest admitted that he had read an article by Fleming that appeared in the March 1905 issue of the *Proceedings of the Royal Society of London* featuring three I-V characteristics for his valve detector, one for each of three slightly different filament voltages. (Fleming, *Proc. of the Royal Society of London*, Vol. 74, Mar. 1905, p. 483)

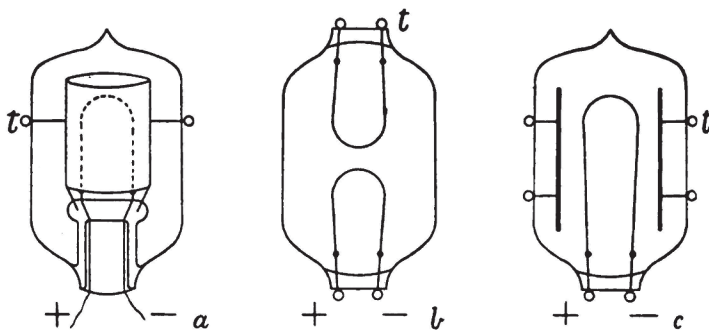


Fig. 32. Fleming disclosed three possible plate configurations for his Fleming two-electrode valve detector in his article in his March 1905 publication: (a) a cylinder surrounding a filament, (b) two opposing electrodes consisting of filaments that could be heated with an external battery, and (c) two opposing plates on opposite sides of a filament with external leads that could connect the plates together or allow them to be used separately as a three-electrode device. (Fleming, *Proc. of the Royal Society of London*, Vol. 74, Mar. 1905, p. 478)

to the pressure normally used in an incandescent light bulb with a carbon filament, and the metal cylinder or plate should be free from occluded air.

3. One carbon filament should be used, and a platinum wire should be sealed into the bulb terminating in a plate or cylinder of platinum, aluminum, or other metal surrounding the filament.
4. The cylinder should be cool and the carbon filament should be at a temperature not much above the melting point of platinum (1768 °C).
5. The primary coil of this oscillation transformer should have one terminal connected to the earth and the other to a long insulated rod that acts as an aerial or electric wave collector. To prevent the direct action of the transmitter upon the secondary coil by simple electromagnetic induction, it would be best to wind the secondary coil in two equal parts in opposite directions and to wind the primary in a corresponding manner.

Recall that De Forest was well aware of Fleming's valve before he signed his first audion patent application for U.S. Patent 824,637 on January 13, 1906. He documented the fact that he had read Fleming's March 1906 publication describing Fleming's valve detector in some detail in an unrelated patent application describing a static valve eliminator (U.S. Patent 823,402), which De Forest signed on December 6, 1905. However, there was no evidence that De Forest knew Fleming had filed a U.S. patent for his valve because Fleming's U.S. valve

patent was not issued or published until November 7, 1905.

Judge Mayer reported one more important fact, namely that De Forest had sent a letter to his patent attorney dated December 21, 1905, that revealed De Forest was aware of Fleming's patent before he signed the patent application for his first vacuum tube audion:

"It must be remembered that De Forest in December, 1905, knew of Fleming's Royal Society paper of March, 1905.... Further, on December 21, 1905, he instructed his solicitor to 'look out for Fleming's recent patent.'"⁶³

In the last line of this citation, Judge Mayer revealed that De Forest was aware of Fleming's patent before he signed his vacuum bulb audion patent application, but he did not reveal certain contents of this letter that would prove De Forest had read Fleming's entire patent before he prepared a draft of the patent application that he sent to his attorney. In Part II of this paper, the contents of this letter and the facts surrounding its preparation will be revealed. This letter is the smoking gun that proved De Forest copied Fleming's patent.

De Forest's Audion as an Amplifier/Relay was not Novel

Recall that De Forest had admitted his audion bulb was identical to the Fleming valve, but he claimed that the battery he used distinguished his audion from the Fleming valve. He asserted the battery provided the energy to amplify the signal, thus making his audion much more

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sensitive and suitable for radiotelegraphic applications, whereas the Fleming valve without a battery was insensitive and useful only for measurement in the laboratory. Judge Mayer claimed this issue was one of the most contested points in controversy during the trial:

“Fleming’s theory, as has already been stated, was that of rectification; while defendants account for the action of their ‘Audion’ on the theory that it is a telephone relay, or, in other words, that its products are alternating currents of ‘audio’ frequency and of the local energy, and not of the ‘input’ energy. As a result of these differences, the effect and relation of the local battery was one of the sharply contested points in controversy.”⁶⁴

Judge Mayer concluded that a battery had been used in virtually all previous wireless detector circuits and there was no novelty for the battery in De Forest’s detector circuit. He also pointed out that Marconi had documented the use of a battery in his coherer circuit with earphones and he was entitled to use the same circuit he had used before with the new device he had invented. Perhaps the best example of Marconi using a battery in a detector was the one he described in his patent application filed in 1901 (see Fig. 33).⁶⁵ Judge Mayer made this finding:

“The local battery is used to bring the lamp detector to the sensitive point of its characteristic curve, and the potentiometer is the simple and effective

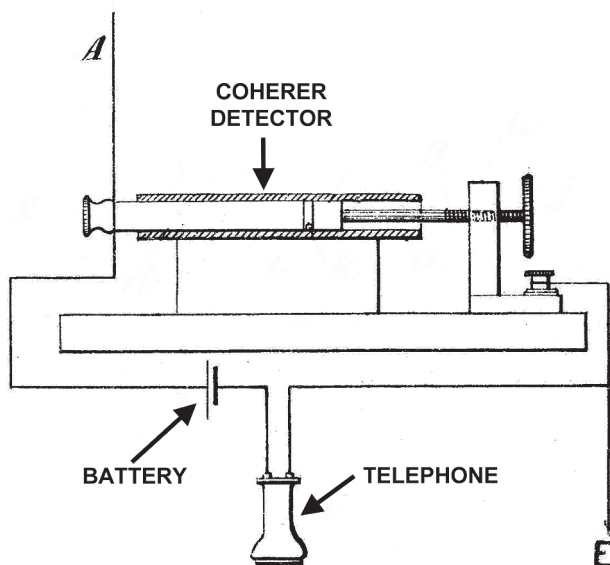


Fig. 33. Perhaps the best example of Marconi using a battery and telephone receiver in a wireless detector circuit was the one he used with the Italian Navy coherer, which was documented in a patent application he filed on Sept. 10, 1901. (G. Marconi, UK Patent 18,105)

device which, varying the local battery, accomplishes this task. Nearly all prior art detectors were used in this way—the coherer of Marconi and Lodge; the microphone of Hughes and Branly; the electrolytic of Fessenden, Vreeland, and others; and the crystal of Bose. Plaintiff's Exhibits 77 and 82.

“The use of the local battery to locate the sensitive point on the characteristic curve was well known and accepted as of Fleming's time, and, as appears by his 1905 lecture, was fully understood by him. See, also, particularly, Vreeland patent, No. 780,842, Plaintiff's Exhibit 82. Plaintiff is undoubtedly entitled to use the Fleming detector with a well-known instrumentality, and therefore to employ the variable local battery, for practically all the prior art detectors required local batteries to locate the operating points. Plaintiff is likewise entitled to use the Fleming device in the ordinary detector circuits of the prior art. The circuits of the Marconi patent, No. 627,650, are the specific circuits which plaintiff has used, and the modern operative Fleming device has simply been substituted for the coherer in old and familiar circuits (Q. 145, 146, et seq.).”⁶⁶

De Forest Infringed Claims 1 and 37 of Fleming's Patent

Judge Mayer ruled that De Forest's two-electrode audion bulb, described by the claims in his U.S. Patent 824,637 and divisional U.S. Patent 836,070, infringed Claims 1 and 37 of Fleming's

U.S. Patent 803,684. (The U.S. Patent Office required De Forest to file the divisional patent because an examiner ruled that the one device with a single heated electrode in the original patent application was a different invention from the other five configurations in that patent.) The divisional patent used essentially the same configuration and language that appeared in the original patent. The bulb configurations in both De Forest patents were identical and they were also the same as the configuration in Fleming's valve patent (see Fig. 29), with the only difference being the shape of the single cold plate.

That the claims in De Forest's divisional patent were virtually identical to the claims in Fleming's patent is obvious by comparing independent claims in both patents (see Table 5). The Fleming patent had two independent claims (1 and 37), while the De Forest patent had one. The first claim of a patent, generally known as the independent claim, is a stand-alone claim that contains all the limitations necessary to define an invention.⁶⁷ The claims following the independent claim are dependent claims that refer to the independent claim and must further limit the independent claim. By law, each claim must be a single sentence that starts with a capital letter and ends with a period. Multiple limitations that appear in each claim must be separated by commas. Most often there is only one independent claim per patent, but in the case of Fleming's patent, Claim 37 was a second independent claim. Claim 1 defined Fleming's valve invention, Claims 2–36 were dependent claims to

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Table 5. Comparison of the single independent claim that appeared in De Forest’s divisional U.S. audion patent (U.S. Patent 836,070) with the two independent claims that appeared in Fleming’s U.S. valve patent (U.S. Patent 803,684).

Fleming Valve Patent 803,684 Claims 1 and 37	De Forest Audion Patent 836,070 Claim 1
What I claim is—1. The combination of a vacuous vessel,	I claim—1. An oscillation-responsive device comprising a partially-exhausted receptacle,
two conductors adjacent to but not touching each other in the vessel,	two separated electrodes sealed in said receptacle,
means for heating one of the conductors,	means for heating one only of said electrodes,
and a circuit outside the vessel connecting the two conductors.	a local circuit including a source of electrical energy and a signal-indicating device electrically connected with said electrodes,
37. At a receiving-station in a system of wireless telegraphy employing electrical oscillations of high frequency a detector comprising a... means for detecting a continuous current in the circuit, and means for impressing upon the circuit the received oscillations.	means whereby electrical oscillations may be impressed upon the gaseous medium intervening between said electrodes,*

* This phrase in De Forest’s first independent Claim 1 is realigned with the very similar words in Claim 37 in Fleming’s patent. The missing words represented by the dots in Claim 37 are not repeated because they are identical to the same words that appear verbatim in Claim 1.

further limit Claim 1, and Claim 37 was a single independent claim that specified the invention was to be used in the receiving station in a system of wireless telegraphy.

A description of how the two devices worked appeared in the descriptive portion of their respective patents that constitute the main body of the patent known as the “Specification.” Fleming claimed his valve detector was based on the nonlinear principle of rectification that converted high-frequency currents to low-frequency currents that could be detected by a galvanometer or any other

suitable detection device used in radio-telegraphy. He also claimed that a very high vacuum was most desirable. De Forest’s patent claimed: “Electromagnetic signal waves may be impressed upon said gaseous conducting medium to alter its conductivity, and a signal indicating device operatively connected with said gaseous conducting medium, whereby alterations in the conductivity of the latter may be made manifest.”

De Forest’s device depended on the conductivity of a gaseous medium in the bulb and a source of heat to ionize the gas that produced the conductivity.

Fleming's device did not require any gas in the bulb, conducting or otherwise, but it did depend on having a highly incandescent filament to emit copious amounts of electrons that produced a current across the electrodes when the applied potential on the cold electrode was positive. Note that an inventor does not have to know how a device works to be awarded a patent, but it does have to work. Conversely, an inventor cannot escape patent infringement by simply claiming that the same device operates by a different principle.

Judge Mayer Declared De Forest's Double-wing Audion to be Worthless

In De Forest's AIEE lecture, he described a double-wing audion bulb that had a different configuration and function than the one covered by his original patent. Here is how he described the function of this version of his audion in his lecture:

"The Audion, to a greater extent than any other responder, is self-tuned. I mean that by regulating the heating current, the potential between wing and filament, or the distance between these, the Audion can be made to a great extent selective *per se* to certain received impulses. And the determining factor here is not merely the frequency of the electrical oscillation; the spark frequency, or factors determining the total amount of energy received during a very brief unit of time, determine to an extent the amount of its response. Thus with 12 volts across it, it may give a loud response to a transmitter A; and with 10 volts 'bring in'

another transmitter B to the almost complete exclusion of A, although A and B are of equal power and of approximately the same wave-length, but differing considerably in spark frequency."⁶⁸

This device was covered by a second patent filed in August 1906, which described an audion that he claimed was self-tuning without the need for a separate tuning circuit that was required in all other wireless systems of the day. This tuning was supposed to be achieved in part by altering the distance between the hinged double-wing plates with a magnet (see Fig. 34):

"A convenient means of varying the distance between the electrodes F' F' is to hinge the wing which constitute the electrode F to the base 2 by the hinges 1 1.... When the audion is to be attuned to oscillations of a given frequency by varying the separation of the electrodes, the adjustment produced by the magnets 6 6 must be empirically determined."⁶⁹

De Forest was asked to demonstrate the self-tuning feature of this audion at the trial, which was given the name "selective *per se* audion," but he was unable to do it. Julius Mayer took note of this demonstration because he wrote this statement in his opinion: "The so-called selective *per se* patent, No. 841,386, is so utterly useless that it might well be declared invalid." While he did not invalidate De Forest's audion patent, the appellate court later agreed with Judge

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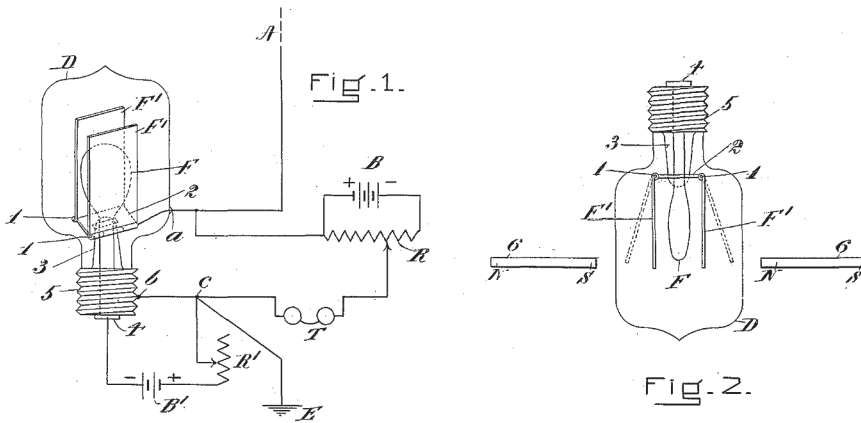


Fig. 34. De Forest claimed his double-wing audion was self-tuning so there was no need for a separate tuning circuit that was required in other wireless systems of the day. This tuning was supposed to be achieved in part by altering the distance between the hinged double-wing plates with a magnet. (De Forest U.S. Patent 841,386, filed Aug. 27, 1906)

Mayer because appellate Judge Charles Hough did invalidate this patent during the appeal that De Forest filed after losing the suit in Judge Mayer's district court:

"The seventh counterclaim patent (841,386) is proved to be inoperative. The patentee declares that by 'suitably varying the length of interelectrode medium' he can make the audion 'per se selectively responsive.' Assuming this last phrase to mean 'make it work,' defendant at the trial did not do it, and we think refused to try. It follows from the foregoing that we hold patent No. 841,386 void."⁷⁰

It is difficult to understand why De Forest would choose this second and unusual form of audion to introduce his audion invention at his AIEE lecture rather than the basic audion form

described in his first audion patent application. Perhaps he wanted to present an invention that was different in function from what Fleming had described in his patent.

Takeaway from Judge Julius Mayer's Opinion

1. **De Forest Revised the Genesis of his Audion:** The most important conclusion that can be drawn from Judge Mayer's opinion is that De Forest abandoned the assertion he made in his AIEE lecture that the genesis of his evacuated bulb audion was the Elster and Geitel paper. Presumably, he made this decision because he could not prove in court that he documented his evacuated bulb detector configuration before the priority date of Fleming's valve patent. The only relevant document De Forest had prepared before the priority date of

Fleming's valve was his flame detector patent that he filed on February 2, 1905. De Forest was able to prove in the trial that he signed the application on November 4, 1904, which preceded the priority date of Fleming's patent. By U.S. patent law, the priority date of Fleming's U.S. patent was set at the filing date of his UK Patent 24,850, which was November 16, 1904. Since De Forest's earliest flame detector patent had a priority date that preceded the priority date of Fleming's patent by eight days, De Forest developed a new strategy by arguing the flame detector he described in the patent application filed in 1905 was the genesis of his evacuated bulb audion.

2. **De Forest Admitted Prior Knowledge of the Fleming Valve:** Another important conclusion from Judge Mayer's opinion was that De Forest was aware of the Fleming valve and virtually of all technical details required to define or fabricate a Fleming valve almost a year before De Forest filed his first audion patent application. In an unrelated patented application, De Forest had revealed that he knew all about the Fleming valve detector and even cited the paper that Fleming had published in March 1905 that described all of the details of his valve patent and revealed that it could be used as a detector of Hertzian radiation in wireless telegraphy.
3. **De Forest Could Not Differentiate his Audion by Citing his External Circuit:** In 1906, De Forest had claimed in his 1906 lecture that his audion bulb

was identical to Fleming's valve but that his audion invention was distinguished from Fleming's valve because he used a battery in the plate circuit whereas Fleming did not. Whether or not the vacuum tube worked differently with or without a battery was hotly debated in the trial but in the end, Judge Mayer ruled that Fleming had the legal right to use a battery in his external circuit even though he did not specify its use in his patent. Judge Mayer pointed out that a battery appeared in virtually every radio detector that had preceded the Fleming valve patent—including and in particular a coherer circuit that Marconi had used with both a battery and telephone. In the end, Judge Mayer ruled that the presence of an external battery in De Forest's circuit could not be used as a factor in differentiating De Forest's audion bulb invention from Fleming's valve bulb invention.

De Forest's Account in his Franklin Institute Lecture (February 1920)

De Forest's lecture that he gave at the Franklin Institute in 1920 was the second and last major lecture in which De Forest described in some detail how he invented his two-electrode audion. His other detailed audion lectures focused mainly on his three-electrode audions, which are not at issue here. The account in this lecture did not materially change in the thirty years between the Franklin lecture and his autobiography. The detailed account that appeared in his 1950 autobiography was taken almost

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verbatim from the 1920 lecture. The account in the Franklin Institute lecture was very different from the version he gave at the AIEE lecture.

De Forest began the lecture at the Franklin Institute with the same story about his observation of the Welsbach lamp in 1900 but provided a different account of the configuration he used to discover the flame detector:

“The first ‘commercial’ audion, as it originally appeared in 1906, was therefore no accident, or sudden inspiration. For failing to find in an incandescent mantle the genuine effect or response to electrical vibrations I next explored the Bunsen burner flame, using two platinum electrodes held close together in the flame with an outside circuit containing a battery of some 18 volts and a telephone receiver.”

This description conflicts with the version that De Forest gave at his 1906 AIEE lecture where he stated he first found the response in an incandescent mantle: “By soaking the mantle in a potassium or sodium solution and drying, I was finally able to pass a small current from a dozen dry cells through the flame surrounding it, using two platinum electrodes with a telephone receiver in circuit, and get a faint response to the genuine Hertzian wave.”

The remainder of De Forest’s account was concise, if not accurate, but lacked any documentation to support it. De Forest described three different phases of audion development accompanied by three different configurations, the first

dating to 1903, the second dating to 1904, and the third dating to 1905. Since the three configurations were dated by year but not by month, it is impossible to accurately date the accomplishments. The time that passed between any two of his developments could have been as short as one month or as long as two years. It will become evident in Part II that his entire account was highly inaccurate.

Worse yet, the developments of the two-electrode audion cannot be correlated to the dates of the three detector technologies that he used in De Forest Company systems between 1901 and 1906. The adage “necessity is the mother of invention” was particularly applicable to De Forest. The only time De Forest was interested in developing a new detector technology was when an existing technology was failing and needed to be replaced. The electrolytic receiver he appropriated from Fessenden in late 1903 was spectacularly successful for almost two years between December 1903 and October 1905, and there is no indication in the literature that he was interested in any other detector technology during this period. It was not until October 16, 1905, when the De Forest Company was found guilty of infringing the Fessenden patent and was subsequently proscribed from using the electrolytic detector that De Forest became interested in finding a new non-infringing detector technology.

The account in De Forest’s autobiography in 1950 was virtually identical to the account in the *Journal of the Franklin Institute* in 1920, although the paragraphs do not follow in quite the same

order. Also, the paragraphs describing the characteristic I-V curve of his audion detector in his Franklin Institute lecture did not appear in his 1950 autobiography. The following three titled paragraphs constitute a synopsis of the lecture taken from the published account.

Phase 1: De Forest's Flame Detector (1903)

De Forest claimed that after he failed to find the desired response of Hertzian waves in the incandescent mantle of a Welsbach lamp, he then explored the use of a Bunsen burner flame for that purpose. Referring to the flame detector configuration of Fig. 35, he claimed that in 1903 he "clearly heard in the telephone receiver the signals from a distant wireless telegraph transmitter." In the text of his autobiography, he expanded on this claim by stating that he heard signals from ships transmitting Hertzian waves from the New York harbor, which was located at a distance of about one mile

from his laboratory. Since the wireless signals he received at a distance of one mile were orders of magnitude higher than those received at practical distances of interest at that time, say 50 to 100 miles, the reception of these "clear signals" does not support his later contention that this flame detector was quite sensitive.

De Forest's patent application for his flame detector, U.S. Patent 979,275, which was accorded a priority date of November 4, 1904, supported his contention that he developed a flame detector, but the late priority date neither supported nor conflicted with his contention that he discovered this detector as early as 1903. Having said that, an unpublished document was submitted into evidence at the 1916 trial that provided irrefutable evidence De Forest had documented this form of flame detector configuration even before 1903. The circumstance of this unpublished document will be presented in Part II.

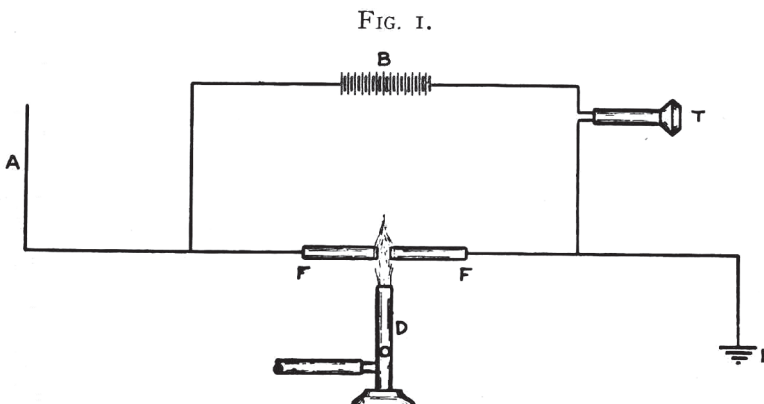


Fig. 35. Using the flame detector configuration pictured here, De Forest claimed in his Franklin Institute lecture that in 1903 he had "clearly heard the signals from a distant wireless telegraph transmitter in a telephone receiver." (*J. Franklin Inst.*, Vol. 190, 1920, p. 3, Fig. 1)

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Phase 2: De Forest's Transition to a Vacuum Bulb (1904)

Referring to the configuration reproduced from his Franklin Institution lecture in Fig. 36, De Forest claimed that introduced a plan in 1904 for an early carbon filament detector in an evacuated bulb:

“At the period now under consideration, 1903–1905, I was familiar with the Edison effect and with many of the investigations thereof carried on by scientists, Prof. Fleming among others. In 1904 I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector, in place of the open flame. But here the rectification effect between hot filament and a cold electrode was not considered. Two filaments, heated from separate batteries would give the desired effect equally well.”⁷¹

The key word in his account was the word “plan.” He did not say that he documented, fabricated, or tested an evacuated bulb with two separate filaments, heated or otherwise. In fact, De Forest admitted that he could not fabricate evacuated bulbs at this time. It turns out that De Forest was unable to identify a document or even a single person to whom he had disclosed such a plan in 1904. How could De Forest possibly know in 1904 that “two filaments, heated from separate batteries would give the desired effect equally well”?

According to the sworn testimony from De Forest and his patent attorney, George K. Woodworth, De Forest disclosed this “plan” for the first time to his patent attorney at a meeting on November 24, 1905. Woodworth documented this disclosure with a handwritten note with a sketch that he initialed and stamped with the date of the meeting (see Fig. 37). Note that the notation on

FIG. 2.

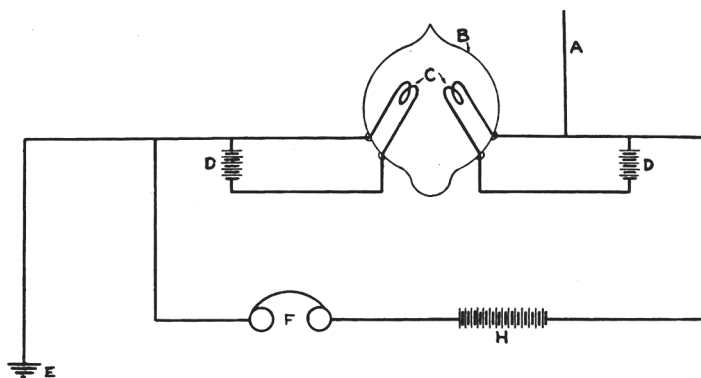


Fig. 36. De Forest referred to this figure in his Franklin Institute lecture when he claimed that in 1904 he had “outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted vessel as a wireless detector in place of the open flame.” (*J. Franklin Inst.*, Vol. 190, 1920, p. 4, Fig. 2)

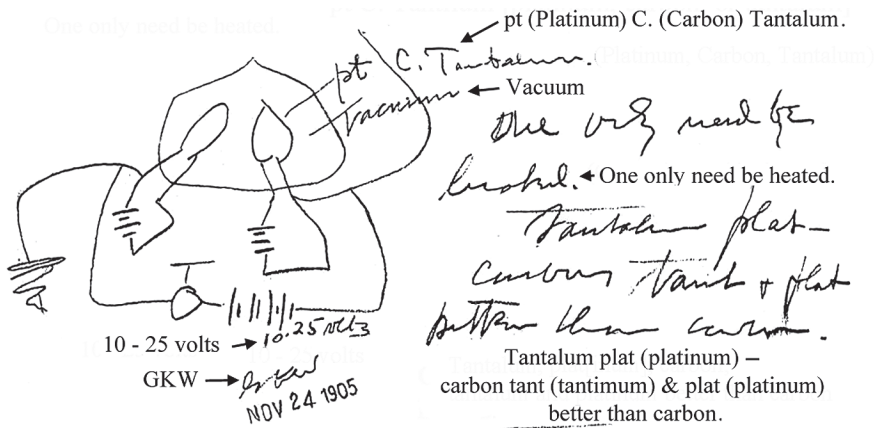
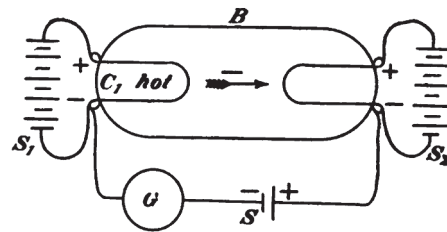


Fig. 37. According to sworn testimony in the 1916 trial, De Forest disclosed this plan for the first time to his patent attorney, George K. Woodworth, at a meeting on November 24, 1905; the plan was documented with this sketch drawn by his patent attorney. (Preview of unpublished 1916 trial exhibit documented in Part II)

the sketch stated: “only one [filament] need be heated.” The complete document and the circumstances surrounding the disclosure of this document will be presented in Part II.

The same configuration that De Forest revealed to Woodworth in the November meeting was documented and described in detail by Fleming in a paper that was published seven months before in the April 1905 issue of *Technics* (see Fig. 38).⁷² Referring to this figure from his article, Fleming wrote: “A bulb containing two carbon filaments forming the two electrodes, one of which can be rendered incandescent, will act as a vacuum valve.” Fleming’s observation presages the same sentiment that Woodworth noted on his sketch seven months later:

“Only one need be heated.” It is likely that De Forest read this paper because he admitted in his Franklin Institute lecture that he was familiar with many of Fleming’s investigations published during his period.⁷³



B.—Vacuum bulb.
C₁.—Carbon filament to be rendered incandescent by insulated battery *S₁.*
G.—Galvanometer.
S.—A single cell sending negative electricity from hot filament to the cold one.

Fig. 38. The same configuration that De Forest revealed to Woodworth in their November meeting was documented and described in detail by Fleming in a paper that was published seven months before in the April 1905 issue of *Technics*. (Fleming, *Technics*, Vol. 3, Apr. 1905, p. 317)

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Phase 3: De Forest's First Audion Bulb Configuration (1905)

Referring to Fig. 39 reproduced from his lecture at the Franklin Institute, De Forest introduced his first two-electrode audion in 1905 with the following words:

"The ordinary small incandescent lamp of that epoch supplied admirably the conditions I required, merely by the introduction of a second electrode. That added electrode could be either hot or cold. Obviously therefore, use it cold, avoiding thus the unnecessary battery. Then obviously, too, I must so connect my telephone "B" battery as to make this cold electrode positive, for otherwise no local current could flow through the gaseous space in the lamp between the unlike electrodes."

Before analyzing De Forest's account associated with the configuration in this figure, it is important to note that the configuration in this figure is not the same as the configuration that appeared in his first audion patent application for

U.S. Patent 844,637, which was reproduced here as Fig. 28. The configuration in this figure, which he has dated to 1905, shows the plate circuit is connected to the positive pole of the filament battery. However, the plate circuit was connected to the negative pole of the filament battery in his first audion patent filed on January 18, 1906. It was not until August 1906 that De Forest filed his second audion patent application, the first one to show the connection to the positive pole of the filament battery. It will be clearly shown in part II that the polarity of the connection to the filament battery was fundamental to the demonstration test that De Forest devised, which enabled him to give the false impression that the Fleming valve was insensitive. Also, note that De Forest is once again not using the accepted convention that the long plate of the battery in a schematic diagram represents the positive pole of the battery.

There is little doubt that De Forest introduced his first two-electrode audion bulb in the latter part of 1905, but the real question is whether he introduced

FIG. 3.

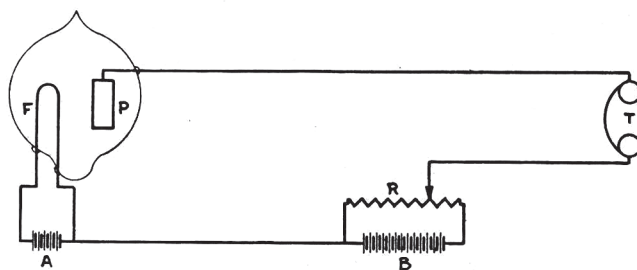


Fig. 39. De Forest claimed that in 1905 he found the ordinary small incandescent lamp of that epoch would be a suitable detector by introducing a second electrode and adding a "B" battery and telephone receiver into the circuit. (*J. Franklin Inst.*, Vol. 190, 1920, p. 5, Fig. 3)

his audion bulb before or after he read the papers that Fleming published earlier in 1905 where he described his valve detector in detail. For example, De Forest admitted reading the article he published in the March 1905 issue of the *Proceedings of the Royal Society of London*, but he never admitted exactly when he read it. This article contained the same evacuated bulb configuration that appeared in Fleming's patent (see Fig. 29), and the text contained all the detail that De Forest needed to describe the same audion configuration that Fleming had published. Fleming also provided the I-V characteristic curves in this publication that were almost identical to the I-V curve that De Forest produced in his 1906 AIEE lecture.

Judge Mayer revealed that De Forest had requested the firm of H. W. McCandless & Company to fabricate the evacuated bulbs for the first time in December 1905: "That these patents dealt only with the heated gas idea is clear from De Forest's correspondence with his solicitor in December, 1905 and January, 1906, from his ordering incandescent lamps from one McCandless in the same December and January." Gerald Tyne, who was originally in possession of the 1916 trial documents, was kind enough to provide George H. Clark in 1944 with McCandless Company records, many of which had been produced at the trial. A McCandless record sheet documented these two orders as being on December 4, 1905, and January 5, 1906. McCandless testified that these were the first two orders to be placed by the De Forest Company. This McCandless record sheet

was published by the Tube Collectors Association in 2003.⁷⁴

While this record supports the claim that De Forest had documented his audion bulb in 1905, it does not prove whether he documented it before or after reading Fleming's paper published in March 1905. De Forest never did provide any documentation or other evidence to prove that he created this bulb configuration before the date he documented the configuration for his patent attorney.

De Forest's I-V Characteristic Curve

After presenting an account of how he developed his two-electrode audions, De Forest presented a sketch of what he claimed was representative of a typical I-V characteristic curve for his early audions. He once again mislabeled the two axes in this figure, an error that is corrected here by interchanging the labels "current" and "voltage" on the two axes. This change also required changes to the spacing of the lines that he had placed at the upper knee of the curve (see Fig. 40). A few additional words have also been added to his original drawing to clarify De Forest's explanation of how the audion worked. These alterations to his original figure are highlighted in red.

De Forest claimed that he could adjust the "B" battery so the audion could operate at either knee of the curve, both of which are readily apparent in the figure. De Forest chose the upper knee to describe how his audion operated:

"If now the "B" battery potential [i.e., battery voltage] was so adjusted that the detector was operating on

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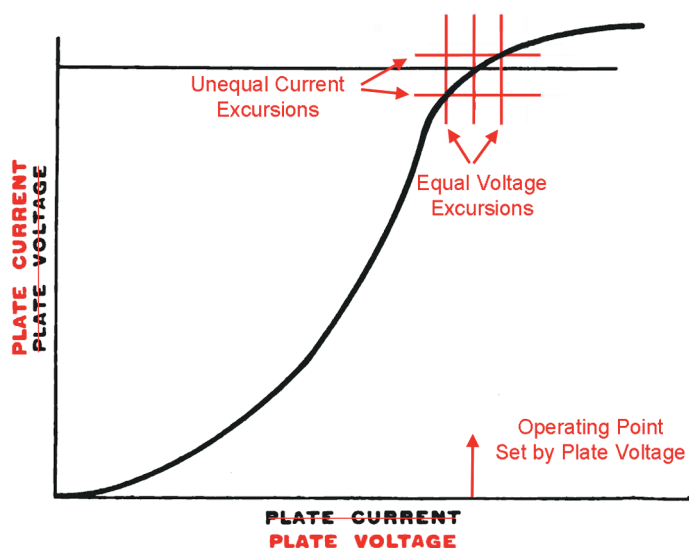


Fig. 40. In his Franklin Institute lecture, De Forest presented a drawing of what he claimed was the general form of an I-V characteristic curve for an early audion that he employed; an error in his sketch has been corrected in red by interchanging “plate voltage” and “plate current” labels on the two axes. (*J. Franklin Inst.*, Vol. 190, 1920, p. 5, Fig. 4)

either knee of this curve the increase to this locally applied voltage, resulting from the positive halves of the wave-train, would produce a greater (or less) increase in the local current flowing across the gap than would the negative halves of the wave-train produce a decrease (or increase, as the case might be). In other words, the responsive action of this two-electrode audion was due to the asymmetry of its characteristic curve, rather than its rectifying property. The latter property [i.e., rectification] could be made to aid, to increase the intensity of the signal produced originally and mainly by the so-called ‘trigger,’ or genuine *relay* action of the device, which was always *controlling* and local energy by means of a much smaller incoming

energy.” [italics and parentheses by De Forest]

In plain English, he meant that when the excursions of voltage (caused by Hertzian oscillations) about the operating point were equal, the resulting excursions in currents were unequal, which over many oscillations resulted in a net DC current component that could be detected with a galvanometer or telephone receiver. This is the process Fleming defined as rectification, but De Forest rejected that view by stating: “In other words, the responsive action of this two-electrode audion was due to the asymmetry of its characteristic curve, rather than its rectifying property.”

This is an astonishing statement for De Forest to make in 1920 when

most knowledgeable scientists and radio engineers knew that the two-electrode thermionic tube operated by the principle of rectification, which was first revealed by Fleming in early 1905. De Forest's unfathomable description had been soundly rejected by then: "The so-called trigger, or genuine relay action of the device, which was always controlling the local energy by means of a much smaller incoming energy." What is a "so-called trigger" or "genuine relay action," and how could De Forest determine that the "trigger action" contributed much more to the detection of Hertzian waves than the "rectification property." De Forest would have you believe that there were two completely different processes operating at the same time when the operating point was at the knee of the curve. De Forest went on to make this closing statement in the portion of his lecture dealing with his two-electrode audion:

"In other words, then, the two-electrode audion, with A and B batteries, was not primarily a 'valve.' And I have always objected to this misapplication of the name valve to the audion; a name which our British friends have from the first persisted with a stubbornness worthy of a better cause, in misapplying!"

By 1920 it was well known that the Fleming valve tube and the De Forest audion tube were identical. Even De Forest had admitted as much in 1906, but he claimed the big difference was the existence of a battery in his plate circuit. So how is it possible that one device was

a valve and the other device was not? It is true that the use of an external battery determined how a two-electrode device functioned in a specific circuit, but it did not change the characteristic curve, which is what determined the designation of the device. There are three options for characterizing the type of device for a Hertzian wave detector, which is determined by the type of characteristic curve produced:

1. A symmetric detector configuration produces an I-V curve that is symmetric about the origin of the I-V axes.
2. An asymmetric detector configuration produces an I-V curve that is asymmetric about the origin.
3. A valve detector configuration produces a unipolar curve that displays a valve action.

De Forest's early flame detector with symmetric electrodes had a nonlinear but symmetric curve that required a battery to move the operating point to a location where there was a knee on the curve. De Forest's later flame detector with asymmetric electrodes had a unipolar response without a battery but it did not display a valve effect because it had a significant conductivity, no matter what polarity was used. De Forest's audion with asymmetric electrodes displayed valve action, but valve action was optional because there were two sensitive operating points with a "knee in the curve," one near the origin where there was valve action with little or no external battery required, and one near the saturation

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level where a significant battery voltage was required. Apparently, De Forest did not know, or at least did not let on that he knew his audion was a valve detector—and he never used it as such.

This classification is not just an exercise in semantics because the I-V characteristics of both De Forest's audions and Fleming's valve detectors displayed valve action, even though De Forest may not have realized it or observed it. By contrast, the flame detector that De Forest introduced in his AIEE lecture had a unipolar characteristic curve but did not display valve action. This is what distinguished his flame detector from his valve detector, and this is why De Forest's claim that he found the audion action in his flame detector turned out to be false. The lack of valve action in his flame detector was a result of the ionized gas that produced a significant conductivity for both battery polarities. Both types of detectors rectified Hertzian signals, but that does not mean an ionized gas detector operated the same way as a thermionic valve detector. In fact, a crystal detector, Fessenden's electrolytic detector, De Forest's flame detector, and Fleming's thermionic valve detector all operated on the principle of rectification, but all four had different physical embodiments with different operating characteristics and were considered to be different inventions.⁷⁵

De Forest Misrepresented his Audion I-V Characteristic Curve—Again

The form of De Forest's characteristic curve of Fig. 40 is virtually identical to the curve he presented in his AIEE lecture (see Fig. 25). It was pointed out

before that this form of the curve did not apply to his early audions because before his October 1906 lecture he connected the plate circuit of his audions to the positive pole of the filament battery electrode. When that happens, there is a significant Edison effect current that flows in the plate circuit when the battery voltage is zero. That is not the case for this I-V curve.

To illustrate this point, two different characteristic curves were measured by the author for an early manufactured two-electrode vacuum tube with a filament voltage of 5 volts. The plate current represented by the upper curve was measured when the negative pole of the plate circuit battery was connected to the positive pole of the filament battery, and the lower curve was measured when the plate circuit battery was connected to the negative pole of the filament battery. It turns out that the two I-V curves are parallel to each other over the region where the two plate currents are linear (between 4 and 12 volts). In this range the two curves are offset by a voltage equal to the filament battery voltage, which in this case was 5 volts. However, the curves are not parallel over regions where one is linear and the other is nonlinear (below 4 volts and above approximately 12 volts).

For the plate circuit connection to the positive pole, the current is not zero when the applied plate voltage is zero. The plate current that flows in this case is the Edison effect current. Also, there is no lower knee in the curve for this case, contrary to what De Forest showed in his I-V curve. De Forest would have observed a second knee in the curve if

he had applied a negative voltage to the plate, which would have revealed the entire characteristic curve. De Forest's I-V curve for his double-wing audion, with the connection to the positive pole of the filament battery, would have

looked like the upper curve shown in Fig. 41. Since this curve is approximately linear between 0 and 12 volts, he would have had to apply a number of battery cells to reach an operating point where there was a knee in the curve.

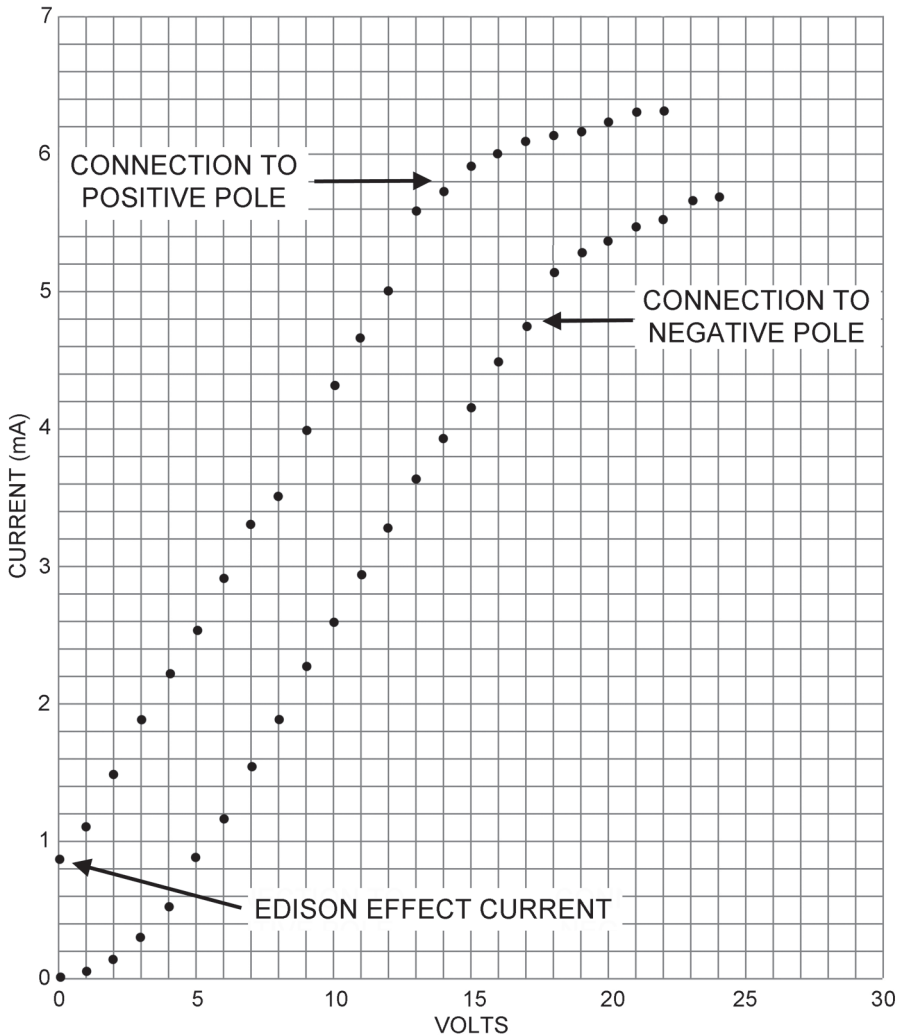


Fig. 41. Two characteristic curves for an early two-electrode vacuum tube with a filament voltage of 5 volts were measured: the upper curve shows the plate current for a battery in the plate circuit connected to the positive pole of the filament battery and the lower curve shows the current for the battery in the plate circuit connected to the negative pole. (Author's experimental results)

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De Forest claimed that there were two knees in the curve for his audion and that he chose the upper knee. However, there would have been only one knee in the curve for his audion with the plate circuit connected to the positive pole of the filament battery. He had no option but to choose the upper knee as his operating point, and he never would have observed valve action by applying only positive voltages to the plate. That is why he claimed his detector was not a valve—even though it was. He just did not realize how to operate it as a valve, or perhaps he chose not to do so.

The shape of the lower curve is virtually identical to the I-V curves measured by Fleming for his valves, all of which had a plate circuit connection to

the negative pole of the filament battery (see Fig. 42).⁷⁶ Fleming's detector had a strong valve effect for virtually all voltages applied with a negative polarity. This characteristic curve is very sensitive near the origin because contributions to the current from each oscillation are due primarily to the positive swing, while there are virtually no contributions from the negative swing. This is particularly true when the applied oscillations have a magnitude of a volt or more.

Summary and Conclusions

Summary

De Forest presented two major lectures in which he gave detailed accounts of how he invented his two-electrode audion. His first lecture was given to AIEE members on October 26, 1906, and the second lecture was given at the Franklin Institute on January 15, 1920. The accounts that he gave at the two lectures could not have been more disparate. The first account was fanciful and at times willfully deceptive. He claimed the genesis of his detector was the configuration with which Elster and Geitel experimented in 1882, and he supported this assertion by comparing his configuration with the Elster and Geitel configuration. However, the two configurations did not match, and it turned out that he surreptitiously altered the actual Elster and Geitel configuration in three

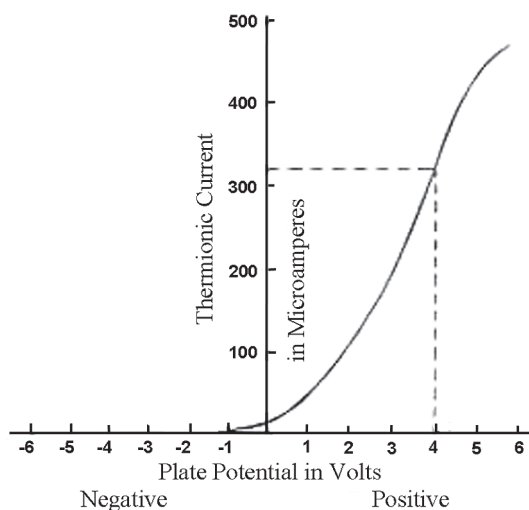


Fig. 42. This example of a characteristic curve for a Fleming valve with a connection to the negative pole of the filament battery had two knees in the curve, one near the origin of the axes where the curve began to display a valve effect for negative applied voltages, and the other near the top of the curve where the current began to saturate. (Univ. College London, Fleming Collection)

significantly different ways to make their configuration match his. This claim was provably false, and most of the other claims he made were deceptive or misleading. A summary of these bogus claims can be found in the section of this paper entitled “Takeaway from De Forest’s AIEE Lecture.”

In the second lecture he gave at the Franklin Institution in 1920, De Forest ignored virtually all the claims he made in his 1906 lecture—with the notable exception of one in which he maintained his audion acted as a relay, or amplifier because of the battery he used in his external circuit. This time he claimed that he had discovered the audion principle in a flame detector that was documented in a patent application with a priority date that preceded the priority date of Fleming’s valve patent. De Forest then claimed he perfected his invention by moving the two electrodes of his flame detector into an evacuated lamp bulb to make it a practical device. Finally, he claimed that he documented an audion detector bulb in 1905 consisting of an enclosure evacuated to the level of an ordinary incandescent lamp bulb in which he inserted a carbon filament heated to incandescence and one cold electrode. The dates of these claims are critical because De Forest admitted reading Fleming documents published early in 1905 describing the detector configuration and technical parameters that appeared in Fleming’s patent. In the end, De Forest could not produce any documents that supported his claim that the priority date of his audion invention preceded the priority date of Fleming’s valve.

The differences in the two accounts can be attributed to the results of a lawsuit that American Marconi filed against De Forest and Company in October 1914 for infringement of the Fleming valve patent owned by the Marconi Company that culminated in a trial in 1916. While De Forest was able to deceive an audience of scientists and engineers with bogus claims because they were unable to cross-examine him under oath, he could not deceive a trial judge in a court of law where proof is demanded in the form of sworn testimony and supporting documentation. Since there were no documents or potential witnesses to prove or support the claims he made at his first lecture, De Forest abandoned virtually all of those claims and developed a new account that he believed would withstand cross-examination in a trial. De Forest developed a new strategy for the trial based on a patent application for a flame detector that was accorded a priority date eight days earlier than the priority date of Fleming’s first valve patent application.

Even though the judge in the 1916 trial rejected De Forest’s argument based on the priority of his flame detector, he used the same argument in his 1920 account at the Franklin Institute. Exhibits submitted as evidence in the trial proved that De Forest revealed a two-electrode detector configuration contained within an evacuated bulb for the first time when he met with his attorney on November 24, 1905, a year after Fleming filed his patent application. A sketch of this configuration was revealed in this paper to support this

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assertion. The complete document and the events leading up to its discovery will be revealed in Part II.

Perhaps the most important difference between the accounts in De Forest's two principal lectures is how much he knew about the Fleming valve and when he knew it. In his 1906 lecture, he mentioned the Fleming valve only once in passing, and he marginalized it by saying that it was an insensitive device that was useful only for measuring larger signals that were available in the laboratory. He did not even reveal that Fleming had received a patent for his valve as a detector in wireless telegraphy. He was more candid in his lecture at the Franklin Institute when he wrote, "At the period now under consideration, 1903–05, I was familiar with the Edison effect and with many of the investigations thereof carried on by scientists, Prof. Fleming among others." De Forest documented the fact that he had read Fleming's seminal document describing all details of his valve detector that had been published in March 1905. This document contained the schematic diagram of his Fleming valve detector that appeared in his patent application filed in November 1904.

Conclusions

1. Most of the claims De Forest made in his AIEE lecture were provably false or deceptive. The willful alterations he made to the Elster and Geitel experimental configuration in an attempt to make it match his audion, coupled with his failure to check

their original reference is unforgivable. His misrepresentation of the I-V characteristics of his flame detector and audion bulb shows a surprising degree of incompetence.

2. The account that emerged from the 1916 trial was completely different from De Forest's lecture accounts. The trial account is most likely to be the most accurate one because it is based on sworn testimony and documentary evidence—including 31 pages of sworn testimony by De Forest himself.
3. The claims De Forest made in the account he gave at the Franklin Institute in 1920 were so different from his account in his AIEE lecture in 1906 and his testimony at the trial in 1916 that they are suspicious. Given the fact that there are no documents to support the claims in either of his two lectures, the account he gave under oath at the 1916 trial, with supporting documentation, is surely the most accurate.

A completely new and different account of De Forest's discovery/invention of his two-electrode audion will be presented in Part II, which will be submitted for publication in the 2024 edition of the *AWA Review*. Part II will contain many excerpts from the trial transcripts of sworn testimony by witnesses—especially by Lee De Forest—and copies of the actual exhibits that were introduced into the record in the 1916 trial.

Endnotes

1. "The Physical Society's Annual Exhibition of Apparatus," *The Electrician* (London), Vol. 66, Dec. 30, 1910, pp. 473–474.
2. A number of historians have used the "de Forest" form of spelling in their publications because they believe that was Lee's preference. Regardless of what his preference might have been, the "De Forest" spelling has appeared almost as often as the "de Forest" spelling in journals, textbooks, and other documents throughout the years. For example, the spelling that has appeared in newspapers and wire services throughout the years is predominately the "De Forest" form. Also, the legal spelling of Lee's many eponymous companies was De Forest with a capital De. Using the "de Forest" spelling in a document involving both the man and his eponymous companies results in a two-tier system in which the writer has to determine which spelling to use and the reader has to interpret: De Forest for his eponymous companies or de Forest for the man. Is it a De Forest audion or a de Forest audion? Who is being sued, De Forest or de Forest or both? Which spelling should appear in the endnotes: De Forest or de Forest, or does it depend on the spelling that is used in the article being cited? When using the de Forest spelling for the man, does the De Forest spelling (with a capital De that must be used at the beginning of every sentence) refer to the man or the eponymous company? For this paper, the choice was easy because the "de Forest" form of spelling does not appear even once in the *Federal Reporter* volumes documenting the legal opinions of judges or in the thousands of pages documenting the testimony, exhibits, and summaries in the 1916 trial referred to in Parts I and II. The De Forest form of spelling is used throughout this paper, regardless of the spelling that appears in the cited text.
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4. Hugh G. J. Aitken, *The Continuous Wave*, (Princeton University Press, Princeton, NJ, 1985) p. 195.
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6. Lee De Forest, "The Audion, Its Action and Some Recent Applications," *J. of the Franklin Inst.*, Vol. 190, July 1920, p. 1.
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11. Lee De Forest, "The Audion," *Electrical Engineering*, Mar. 1947, Vol. 66, p. 256.
12. J. J. Thomson, *Conduction of Electricity Through Gases* (Cambridge University Press, Cambridge, 1903).
13. J. J. Thomson, *The Discharge of Electricity Through Gases* (Charles Scribner's Sons, New York, 1898).
14. J. A. Fleming, *The Thermionic Valve in Radiotelegraphy and Telephony* (The Wireless Press, London, 1919).
15. De Forest, AIEE lecture (1906), p. 739.
16. *Ibid.*, p. 732.
17. *Ibid.*, p. 719
18. Lee De Forest, "The Life and Work of Lee De Forest," *Radio News*, Jan. 1925, V. 6, No. 7, p. 1154.
19. Lee De Forest, "An Interesting Sensitive-Flame Experiment," *Electrical World and Engineer*, Vol. 39, Apr. 12, 1902, p. 62.
20. De Forest, AIEE lecture (1906), p. 720.
21. J. J. Thomson, 1898, p. 103.
22. De Forest, AIEE lecture (1906), p. 720.
23. De Forest, Franklin Institute lecture, p. 2.
24. This figure was reproduced from the *Transactions of the AIEE*, Vol. 25, page 737, rather than from the *Proceedings of the AIEE* because there was a typographical error in polarity markings on the battery in this figure that appeared in the 1906 *Proceedings* paper. The *Transactions* journal traditionally published the final corrected papers that first appeared in the *Proceedings* journal. The date of his AIEE lecture was also corrected in the *Transactions* edition.
25. Lee De Forest, "How I Invented the Audion," *Electrical Experimenter*, Vol. 6, Mar. 1919, p. 790.
26. Lee De Forest, "Oscillation-Responsive Device," U.S. Patent 824,638, filed Jan. 20, 1906, p. 1, line 67.

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28. Thomson, 1903, p. 210.
29. Egon von Schweidler, "Ueber die Lichtelektrischen Erscheinungen (On the Photoelectric Phenomena), Part II," Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Classe, Vol. 108, Feb. 1899, pp. 273–280.
30. *Ibid.*, p. 280.
31. *Ibid.*, p. 274.
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43. J. A. Fleming, "Oscillation Valve, or Audion," *The Electrician* (London), Vol. 58, Nov. 30, 1906, p. 263.
44. Lee De Forest, "Oscillation Valve or Audion," *The Electrician* (London), Vol. 58, Dec. 28, 1906, p. 425.
45. *Ibid.*, p. 424.
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47. De Forest, AIEE lecture (1906), p. 727.
48. *Ibid.*, p. 726.
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51. J. A. Fleming, "Oscillation Valve or Audion," *The Electrician*, Vol. 58, Jan. 4, 1907, p. 464.
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64. *Ibid.*, p. 951.
65. G. Marconi, UK Patent 18,105, filed on Sept. 10, 1901, accepted Oct. 10, 1902.
66. *Federal Reporter*, Vol. 236, p. 952.
67. According to the U.S. Patent Office, the first claim in a patent is the independent claim, which "is a standalone claim that contains all the limitations necessary to define an invention." <https://www.uspto.gov/sites/default/files/documents/Website%20PDF%20-%20Invention%20Con%202017%20Claim%20Drafting%20Workshop%20-%20OPLA.pdf>.
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70. "Marconi Wireless T. Co. v. De Forest Radio T. & T. Co.," *Federal Reporter*, Vol. 243, May 18, 1917, p. 566.
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Eric Wenaas received his BSEE and MSEE in Electrical Engineering from Purdue University in 1963 and 1964, and his Ph.D. in Interdisciplinary Studies in Engineering at SUNY, Buffalo, in 1969.

He is a past editor of the Antique Wireless Association publication, *AWA Review*, and has published over 40 articles on the early history of wireless communication and radio. He has also authored the book *Radiola*, a definitive history of RCA in the 1920s. He is currently the editor of the book review column for the *AWA Journal* and contributes book reviews to the IEEE publication, *Technology and Society*. He has studied the works of Lee De Forest for many years and has an extensive collection of his early audions, oscillions (high-power oscillators), and detector boxes.



Eric Wenaas

The Story of How Lee De Forest Developed the Audion

Part II. The Marconi vs. De Forest Trial Account

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Lee De Forest's many accounts of how he invented his three-electrode audion often began with how he developed his two-electrode audion, a development that he claimed was an integral step in the development of the three-electrode audion. De Forest also claimed that he developed his two-electrode audion without any knowledge of John Ambrose Fleming's remarkably similar oscillation valve. De Forest published two extensive but conflicting accounts about how he developed his two-electrode audion, one at a lecture to the American Institute for Electrical Engineers in October 1906, and the other at a lecture to an audience of his peers at the Franklin Institute in January 1920. The differences between these two accounts are dramatic and cast doubt on the credibility of both. These two accounts were presented in Part I of this article, which appeared in the 2023 edition of the AWA Review. It turns out that a third and very different account of how De Forest developed his two-electrode audion was documented in testimony and exhibits from the 1916 trial that resulted from a lawsuit that the Marconi Wireless Telegraph Company of America filed against the De Forest Radio Telephone and Telegraph Company in October 1914 alleging that De Forest's two- and three-electrode audions infringed Fleming's two-electrode patent. Judge Julius Mayer ruled in favor of the Marconi Company in 1916 by finding that De Forest's two- and three-electrode audions infringed Fleming's valve patent, which he found to be valid. This account was documented in five volumes that have never been previously chronicled. The five volumes prepared for the plaintiff's lead attorney, F.L.H. Betts, became available recently, and a very different version of how De Forest developed his two-electrode audion based on trial documents emerged. This account is now revealed here in Part II—a story that is based to a large degree on De Forest's sworn testimony and previously unpublished documents that were submitted as exhibits during the trial.

Introduction

De Forest published two major accounts of how he invented his two-electrode audion, the first in a lecture to the AIEE on October 26, 1906,¹ and a very different account in a lecture at the Franklin

Institute on January 15, 1920.² In the 1906 account, he claimed that his audion was based on a configuration that Elster and Geitel published in 1882. In the 1920 account, he claimed that he discovered the audion principle in a flame detector

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experiment dating to 1903 and developed the audion based on this flame detector in two additional stages dating to 1904 and 1905. The Franklin Institute account in 1920 must have been his favorite because he reproduced this account in the appendix of his autobiography that was published 30 years later in 1950.³ These two accounts, which were described in detail in Part I,⁴ were very different and conflicted with each other, thereby casting doubts on the veracity of both.

De Forest gave a third account of how he invented his audion in his testimony during the 1916 trial that resulted from the lawsuit that the Marconi Wireless Telegraph Company of America (American Marconi Company) filed against the De Forest Radio Telephone and Telegraph Company (De Forest Company) in 1914 alleging that De Forest's audions infringed Fleming's U.S. Patent 803,684 for oscillation valves. This previously unpublished account contained in five volumes (see Fig. 1) is remarkably different from either of his two very different published accounts. Three of the five volumes contain the testimony and exhibits from the original trial held in the District Court of Southern New York in 1916:

- Volume I. *Pleadings and Testimony*
- Volume II. *Pleadings and Testimony*
- Volume III. *Exhibits and Publications of Both Parties Arranged Chronologically*

The trial testimony presented here is taken from the first two volumes entitled *Pleadings and Testimony*, and the exhibits are taken from the third volume entitled *Exhibits and Publications*.

Volumes IV and V were briefs prepared for the appellate court by attorneys for the parties after defendants Lee De Forest, President Abraham White, and the De Forest Company appealed the decision of the district court in September 1916. None of the material presented here was taken from Volumes IV or V because they are secondary sources with potentially biased opinions that were not necessarily accurate.

The title page on the first volume contains the following information: "Marconi Wireless Telegraph Company of America, vs. De Forest Radio Telephone & Telegraph Company, Transcript of Record, Vol. I. Pleadings and Testimony," (United States Circuit Court of Appeals Second Circuit, no publisher or date). These three volumes were prepared as part of De Forest's appeal to the appellate court in response to the adverse



Fig. 1. These five unpublished volumes of sworn testimony, exhibits, and summations prepared during the 1916 trial in the lawsuit of Marconi v. De Forest present an entirely different account of how De Forest developed his audions than the accounts he published during his lifetime. (Author's collection)

decision rendered in the district court. The dates in these documents confirm that the testimony and exhibits were introduced in the district court trial in 1916. Because there are so many citations to testimony and exhibits, they will not be identified in the endnotes by volume and page number. Questions and answers by witnesses documented in Volumes I and II have distinct identifying letters and numbers that can be used to locate the testimonies. Exhibits are arranged in Volume III with numbers assigned in the order they were introduced. It is unfortunate that the five volumes in possession of the author are the only known copies and are not generally available.

Overview of the Trial Testimony and Exhibits (1916)

Because the trial testimony and introduction of exhibits did not follow the chronological order of the events that were the subject of the questions asked, the questions and responses have been arranged so they are presented in chronological order according to the dates of the events in question. The testimony will be interrupted occasionally as necessary to explain the testimony or compare and contrast De Forest's testimony with other accounts that he gave. The testimony is arranged according to the same three periods De Forest cited in his 1950 autobiography:

- 1) A continuous period of activity between April 1902 and September 1903 during which De Forest developed and tested his flame detectors.
- 2) A short period of experimentation

confined to August 1904 when De Forest described a failed experiment to examine the effect of a magnetic field on a flame and an evacuated bulb configuration with three electrodes.

- 3) An intense period of activity between October 1905 and August 1906 during which De Forest claimed he developed and tested his audion bulb detectors.

Notably, De Forest did not describe any audion-related activities in his testimony outside of these three periods.

Witnesses, Exhibits, and Patents Identified during the Trial

Eight witnesses gave testimony for the American Marconi Company and thirteen gave testimony for the De Forest Company. Of these witnesses, the story of how De Forest invented his audion was told primarily by four witnesses for the De Forest Company: Lee F. De Forest, inventor and defendant; Henry W. McCandless, president of McCandless & Company; Jacob C. Grogan, foreman of McCandless & Company; and George W. Woodworth, De Forest's patent attorney. There were other witnesses for the defense that are not cited here, most notably Frederick M. Sammis, William H. G. Bullard, and Greenleaf Whittier Pickard. The only testimony by a witness for the plaintiff that was relevant to the story of how De Forest invented his two-electrode audion was Roy A. Weagant, who performed many experiments for the court to quantify and compare the responses of De Forest's and Fleming's

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detector types with each other and with a sensitive crystal detector. Other notable witnesses for the plaintiff, whose testimonies are not cited here, included John Ambrose Fleming, Frank N. Waterman, John L. Hogan, and Edwin Armstrong.

There were hundreds of exhibits introduced by both the plaintiff's and defendant's attorneys during the trial, but there were twelve in particular that had a direct bearing on the story of how De Forest invented his two-electrode audion. The exhibits listed in Table 1 will be reproduced at the appropriate points of this presentation. There were

also references to eight relevant patent applications, one of which was abandoned (see Table 2).

Format of the Testimony

To distinguish the trial testimony from other citations, the questions and answers are highlighted in italics rather than quotation marks, which are used for all other quotations. Questions asked under direct examination by De Forest's attorney were prefaced in the transcript by the letter "Q." Questions asked under cross-examination by the Marconi Company attorneys were prefaced by the letters

Table 1. Pertinent exhibits introduced during testimony in the 1916 trial.

Exhibit No.	Exhibit Date	No. of Pages	General Description
A	Feb. 2, 1905	5	De Forest's Patent application for U.S. 979,275
A-35	Dec. 21, 1905	6	Instruction Letter from De Forest to Woodworth
A-36	Aug. 31, 1902	1	Letter from De Forest to his attorney, Mr. Reynolds
A-37	Sept. 12, 1902	5	De Forest's abandoned flame patent application
A-38	Aug. 4, 1904	7	Letter from De Forest to Babcock
A-39	Jan. 20, 1906	2	Letter from De Forest to Woodworth
A-40	1906	1	McCandless Order Records
A-41	1906	1	McCandless Order Records
A-42	Nov. 24, 1905	2	Woodworth notes at first meeting with De Forest
72	Undated	1	Weagant Demonstration Board Photograph
73	Undated	1	Weagant Demonstration Board Schematic Diagram
79	Undated	1	Variation in Fleming Valve I-V Characteristics

Table 2. Relevant patents referenced during the trial (listed according to filing date).

Inventor	Issued Patent Number	Application Filing Date	Date Issued or Abandoned	Description of Patent Application
Fessenden	U.S. 727,331	Apr. 9, 1903	May 5, 1903	Electrolytic Detector
Fleming	U.K. 24,850	Nov. 16, 1904	Sept. 21, 1905	Oscillation Valve
De Forest	Abandoned	Sept. 12, 1902	Sept. 29, 1903	Flame Detector
De Forest	U.S. 979,275	Feb. 2, 1905	Dec. 20, 1910	Flame Detector
Fleming	U.S. 803,684	Apr. 19, 1905	Nov. 7, 1905	Oscillation Valve
De Forest	U.S. 823,402	Dec. 19, 1905	June 12, 1906	Static Valve
De Forest	U.S. 824,637	Jan. 18, 1906	June 26, 1906	Two-electrode Audion
De Forest	U.S. 841,386	Aug. 27, 1906	Jan. 15, 1907	Two-electrode Audion (bi-wing)

“XQ,” and questions asked on redirect by the De Forest Company attorneys were prefaced by the letters “RDQ.”⁵ These letters were followed by ascending numbers beginning with “1” for each witness to indicate the chronological order in which the questions were posed.

There were three examining attorneys:

- Mr. Hoguet and Mr. Bull were the examining attorneys for the American Marconi Company.
- Mr. Scull was the examining attorney for the De Forest Company.
- Judge Julius Mayer was the judge for the trial; he often interrupted the testimony to ask questions of his own (there was no jury).

Since the names of the examiners and the responses by the witnesses were not attached to each question or answer, to keep the record straight, the names of the questioner and respondent are inserted in brackets after each question and answer. In the transcript, Judge Mayer was identified as “The Court.” The questions and answers in the text presented in this paper are generally organized according to the chronological date of the event that is the subject of each question, not by question number.

As for the spelling of the De Forest name in the trial testimony, Lee was sworn in with his legal name spelled Lee F. DeForest, and he was referred to with the “DeForest” spelling in all trial testimony records, for example, Lee F. DeForest, Dr. Lee DeForest, Dr. DeForest, or simply DeForest. However, the

eponymous company name appeared in the trial testimony records with both the “De Forest” and “DeForest” forms, even though the legal name of the company in its filings was De Forest Radio Telephone and Telegraph Company, spelled with the “De Forest” form. The variation in the spelling of Lee’s surname and company names in various references and sources has confounded De Forest historians for over a century. I chose to use the “De Forest” spelling with a space everywhere except when reproducing the trial transcript testimony itself because it matches the spelling of the De Forest Company. To keep the reproduction of the transcript as accurate as possible here, the spelling used for all trial testimony uses the form of spelling exactly as it appeared in the record.

A Point of Departure

It is instructive to compare De Forest’s final account of how he discovered his two-electrode audion that appeared in his 1950 autobiography with the account he gave in sworn testimony supported by exhibits during the 1916 trial thirty-four years before. To facilitate that comparison, his 1950 account is briefly summarized here as a prelude to the trial account in 1916. In 1950, he claimed that he invented his two-electrode audion in three stages dating to 1903, 1904, and 1905. His account was accompanied by three figures illustrating the state of development in each stage. As a point of departure from these accounts, the three stages of development De Forest documented in his autobiography are briefly summarized.

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First Stage of Development (1903)

De Forest claimed that after he failed to find the desired response to Hertzian waves in the incandescent mantle of a Welsbach lamp, he then explored the use of a Bunsen burner flame for that purpose. Referring to the flame detector from his autobiography reproduced here as Fig. 2, he claimed that in 1903 he “clearly heard in the telephone receiver the signals from a distant wireless telegraph transmitter.”⁶ In the text of his autobiography, he refined this claim by stating that he heard signals from ships transmitting Hertzian waves from the New York harbor, which was located at a distance of about one mile from his laboratory.

Second Stage of Development (1904)

Referring to the configuration from De Forest’s autobiography, which is reproduced here as Fig. 3, he claimed that he conceived of a plan in 1904 to

use two incandescent carbon filaments in a partially exhausted gas vessel as a wireless detector:

“At the period now under consideration, 1903–1905, I was familiar with the Edison effect and with many of the investigations thereof carried on by scientists, Prof. Fleming among others. In 1904 I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector, in place of the open flame. But here the rectification effect between hot filament and a cold electrode was not considered. Two filaments, heated from separate batteries would give the desired effect equally well.”⁷

Third Stage of Development (1905)

Referring to the configuration from his autobiography reproduced here as Fig. 4,

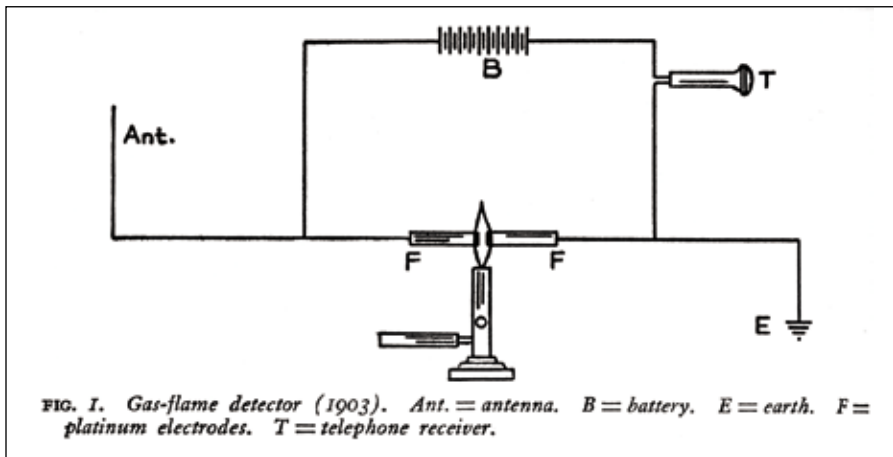


Fig. 2. In De Forest’s 1950 autobiography, he claimed that he had heard signals from a distant wireless telegraph transmitter in the headphones of this flame detector configuration in 1903. (De Forest, *Father of Radio*, p. 478)

De Forest introduced his first two-electrode, evacuated, audion bulb detector in 1905 with the following words:

“The ordinary small incandescent lamp of that epoch supplied admirably the conditions I required, merely by the

introduction of a second electrode. That added electrode could be either hot or cold. Obviously therefore, use it cold, avoiding thus the unnecessary battery. Then obviously, too, I must so connect my telephone “B” battery as to make this cold electrode positive,

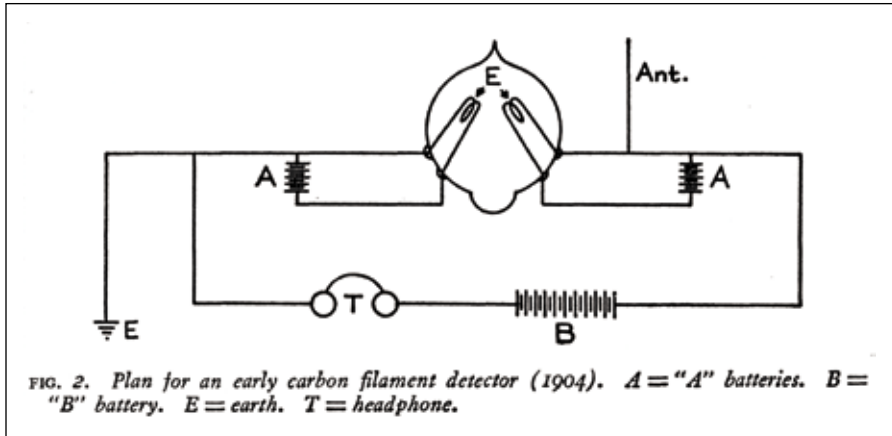


Fig. 3. In De Forest's 1950 autobiography, he claimed that in 1904 he had outlined a plan of replacing his open flame detector with a partially exhausted gas vessel containing two incandescent carbon filaments to heat the remaining gas. (De Forest, *Father of Radio*, p. 479)

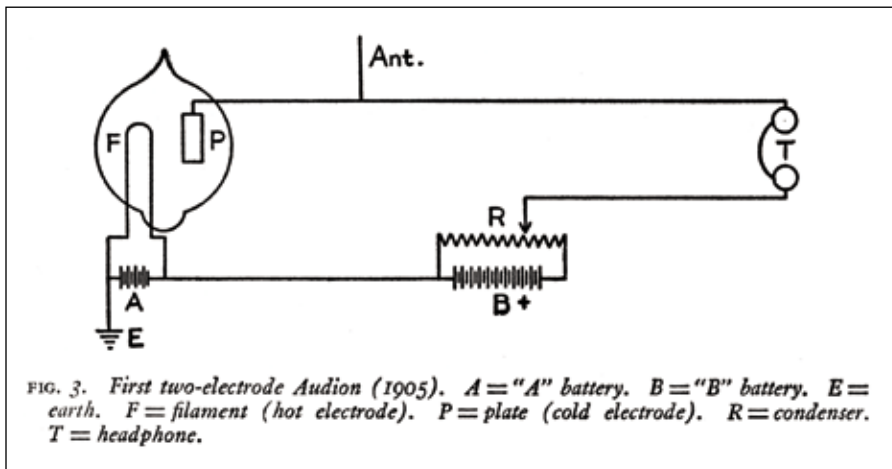


Fig. 4. In De Forest's 1950 autobiography, he claimed he introduced this two-electrode, evacuated, audion bulb detector in 1905 by stating that the small incandescent lamp of that epoch supplied admirably the conditions he required. (De Forest, *Father of Radio*, p. 479)

for otherwise no local current could flow through the gaseous space in the lamp between the unlike electrodes.”⁸

Trial Account: De Forest’s Flame Detector Development (1902–1903) *Historical Perspective*

De Forest claimed in his autobiography that after failing to find the desired response of Hertzian waves in the incandescent mantle of a Welsbach lamp, he then explored the use of a Bunsen burner flame for that purpose. Referring to the flame detector configuration in his autobiography which is reproduced here as Fig. 2, De Forest claimed in 1903 that he “clearly heard in the telephone receiver the signals from a distant wireless telegraph transmitter.” De Forest also claimed that the flame configuration in question was first documented in a patent application he filed on February 2, 1905, which was issued on December 20, 1910.

Testimony: De Forest Files and then Abandons His First Flame Detector Application

De Forest’s testimony about his flame detector patent application began when he was asked about a letter that he wrote to his patent attorney, Henry L. Reynolds, dated August 31, 1902 (see Fig. 5). The original handwritten letter was introduced in the trial as Exhibit A-36. De Forest requested his patent attorney to complete an application for a “flame patent” and submit it at once. In this letter, De Forest suggested that Reynolds mention the feasibility of using the hot gases of an electric arc as well as a mercury vapor lamp. This letter also

documented De Forest’s intense interest in eleven of Fessenden’s patents, all of which happened to cover Fessenden’s then-recent inventions of several types of very sensitive electrolytic detectors. One of these eleven patents describing Fessenden’s very sensitive Wollaston wire electrolytic detector will play a major role in this story.

After this letter was introduced into evidence, the following question and answer exchange took place between Mr. Scull, examining attorney for the De Forest Company, and Lee De Forest:

Q14. [Mr. Scull]: *Pursuant to this letter did Mr. Reynolds file an application for [a] patent?*

A. [Dr. DeForest]: *He filed an application in September, 1902.*

Q15. [Mr. Scull]: *I show you a certified copy of the File Wrapper, contents and drawings of the abandoned application of Lee DeForest filed September 12, 1902, serial No. 123,142, and ask you if that is a copy of the application to which you just referred?*

A. [Dr. DeForest]: *It is.*

Q16. [Mr. Scull]: *I note that according to the Patent Office statement on this certified copy that this application became abandoned. Did you ever file another application for the same subject matter as set forth in this abandoned application?*

A. [Dr. DeForest]: *Yes. Mr. Reynolds ceased to be my Patent Solicitor and left New York in the Fall, I believe of 1904, and his files were turned over to Mr. Phillip Farnsworth. Shortly thereafter I*

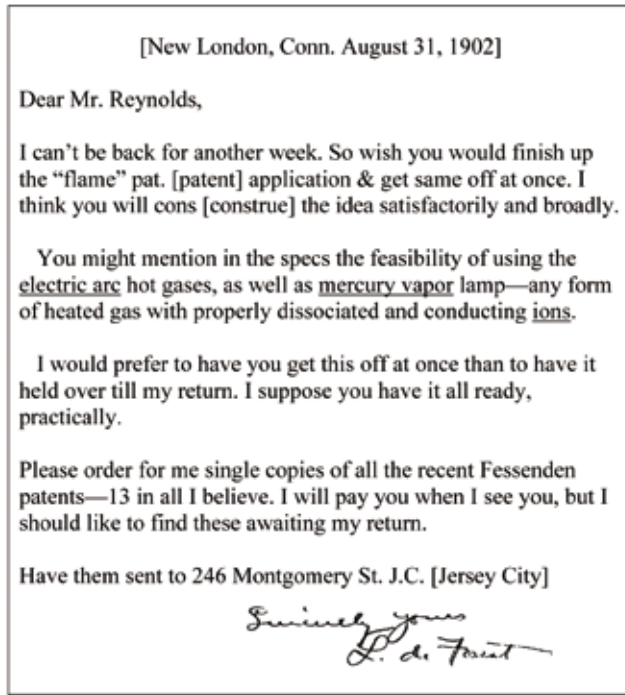


Fig. 5. This letter dated August 31, 1902, is a transcribed copy of an original handwritten letter that De Forest wrote to his patent attorney, Henry L. Reynolds, requesting him to complete an application for a “flame patent” and submit it at once. (Exhibit A-36 from the 1916 trial proceedings, Author’s collection)

enquired of Mr. Farnsworth the condition of the 1902 patent application, and was then, for the first time, made aware of the fact that it had become abandoned by Mr. Reynolds’ negligence. I immediately instructed Mr. Farnsworth to refile the original case exactly as it was in the original form. Mr. Farnsworth started upon this immediately and a new application was signed by myself in the early part of November 1904.

In a later cross-examination by Mr. Hogue, it was revealed that the Patent Office had declared this application to

be abandoned on September 29, 1903, seventeen days after the one-year anniversary of its filing:

XQ67. [Mr. Hogue]: *Let us see if we cannot get our dates fixed a little more accurately. You filed your so-called original application for your flame responder, so-called, in 1902?*

A. [Dr. DeForest]: *Yes.*

Mr. Scull: *That is a matter of law. I do not think the witness is competent to answer that.*

XQ69. [Mr. Hogue]: *The certified*

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file wrapper Defendants' Exhibit A-37 shows the last action by the Patent Office on September 29th, 1902. The rule, as I understand it, provides that an action should be taken within one year after the date of the last Office action. If that is a fact the application became abandoned on September 29th, 1903.

Note that De Forest asked Farnsworth to “refile the original case exactly as it was in the original form,” which means that the patent application filed on September 12, 1902, was identical to the application De Forest filed two and a half years later on February 2, 1905. This early patent application puts a whole new light on De Forest’s claim that his discovery was a continuous process that began with the development of his Bunsen burner flame detector in 1902–1903, which led to the development of his two-electrode audion in 1905.

One might think that this earlier patent filing would support De Forest’s claim of a continuous line of development. Not so. The fact that these two patent filings were identical indicates that De Forest made no further progress in the development of his flame detector between September 12, 1902, the date of the first filing, and February 2, 1905, the date of the second filing. Surely if he had made further progress during this period, he would have included the improvements in his second patent application for his flame detectors or filed an additional patent application for a new type of flame detector. De Forest submitted no additional patents for a flame detector before he filed his first audion bulb

patent in January 1906. This fact will be confirmed by De Forest’s later testimony about what he did between the two filing dates. The circumstances leading to the abandonment of De Forest’s earlier patent application will be addressed next.

Why De Forest Abandoned his Patent Application Effective September 29, 1903.

De Forest testified that the flame patent application he filed on September 12, 1902, had been declared abandoned by the U.S. Patent Office on September 29, 1903, as a result of Mr. Reynolds’ negligence. By both statute and common practice at the time, the U.S. Patent Office would declare a patent application to be abandoned if the applicant did not respond to an “Office Action” (e.g., correspondence) by the patent office for a period of one year after the filing. So, there must have been an office action by the patent office dated September 29, 1902, that had been ignored for one year.

De Forest’s claim that this patent was abandoned because of an incompetent attorney is not credible. De Forest’s attorney, Henry L. Reynolds, appeared to be a good and faithful patent attorney, filing no fewer than 16 patent applications for De Forest between March 8, 1902, and May 28, 1904—five of which were filed after the flame patent application was abandoned on September 29, 1903. Also, De Forest was an accomplished inventor and meticulous patentee who treasured his patents. Surely he would have become aware of the fact that no progress had been made on the prosecution of his flame detector application before the fall of 1904—more than two

years after it was first filed. The following evidence supports three reasons why he chose to abandon his flame detector patent application.

1) De Forest claimed his flame detector was impractical before September 1903:

According to De Forest's autobiography, he had concluded that the flame detector was not practical for commercial work before September 1903:

"It was perfectly obvious that the gas flame would be an impractical device on shipboard, so next I sought to heat incandescent gases directly by means of electric current. Babcock possessed a small carbon-arc lamp, and we carried out our experiments using this strange device as a detector. It responded to my spark signals too, but was terrifically noisy. We wasted little time on that device.... "Ensued then the Yacht Races [August 20 to September 3, 1903], my trips to the West, then England..."⁹

Because most of the De Forest stations were then aboard ships and there was no source of coal gas on ships of the day, De Forest concluded that the flame detector was not practical for shipboard receivers. He also found the AC dynamo was too noisy for the arc detector and he wasted little time on that device. He claimed that he reached those conclusions before the America's Cup yacht races, which began on August 20, 1903.

2) De Forest introduced Fessenden's electrolytic detector in his system in December

1903: De Forest discovered that Fessenden's version of an electrolytic detector with a Wollaston wire dipping into an acid cup was a very sensitive detector and he decided to implement it in the De Forest Company system sometime before September 19, 1903, the date the patent application was abandoned. The following testimony in a patent infringement lawsuit Fessenden filed against the American De Forest Wireless Telegraph Company in the spring of 1904 describes how De Forest discovered the details of Fessenden's detector:

"On September 19, 1903, the *Electrical World and Engineer*—the leading electrical paper of the United States—published a full account of the Fessenden system including a full description of the liquid barretter in suit (C. E. R., 253).... About the time of the description of the Fessenden liquid barretter in the *Electrical World and Engineer*, [Frederick] Vreeland, a discharged employee of Fessenden's, disclosed to Lee De Forest and Andrew White and the defendant companies the Fessenden liquid barretter and told of its success, and they secretly investigated and tested it (D. T. R., p. 739; x-Q. 353–380).... Lee De Forest in early October 1903, went to England and before the British Postal Authorities he attained startling success between Holy Head and Howth, across the Irish Sea. He had taken the Fessenden electrolytic detector with him. The London papers heralded the achievement and credited it to De Forest."¹⁰

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One of the London papers referred to in the last sentence was the prestigious journal, *The Electrician*, which published a three-page article with a detailed schematic and description of the De Forest receiver. Referring to Figure 2 appearing in the article (see Fig. 6), the editor writes: “The receiving apparatus consists of an adjustable inductance N, a ‘responder’ F,... Unfortunately, the patent rights relating to the responder are not yet secure, but Dr. De Forest informs us that it works on the electrolytic principle.”¹¹ The “responder F” in

the schematic diagram reveals a wire dipping into a cup, obviously representing the Wollaston wire of a Fessenden detector dipping into a cup of an electrolytic acid. This article constitutes documented proof that De Forest had implemented the Fessenden detector in his system by early December 1903, and so he had no use for his impractical flame detectors.

3) De Forest did not have funds to waste on impractical detectors: According to testimony in the trial that took place in the patent infringement lawsuit that

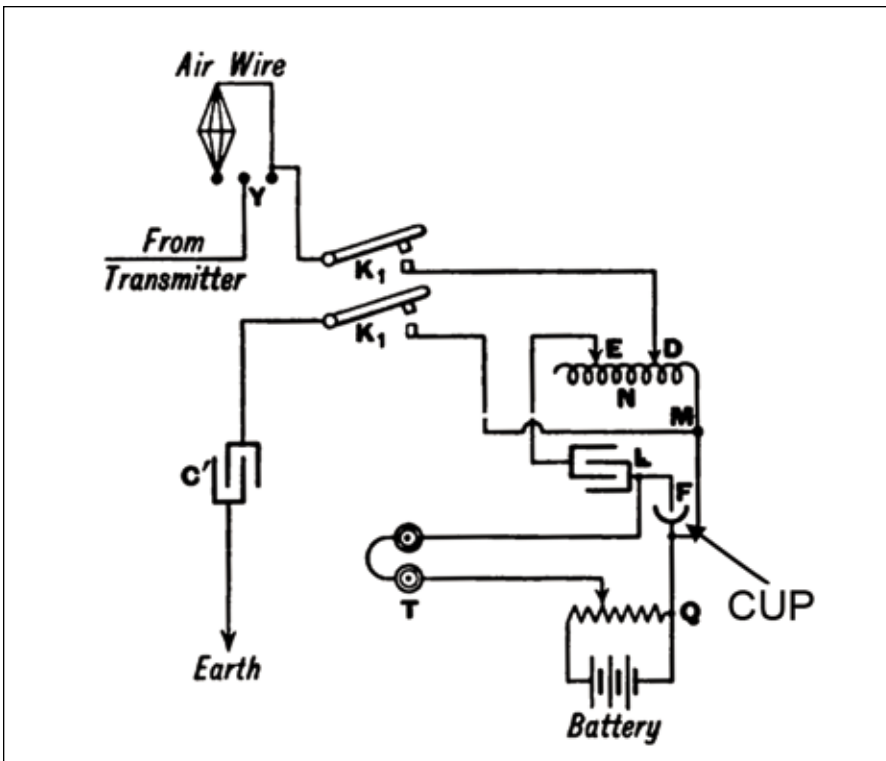


Fig. 6. De Forest published this schematic diagram of a new unidentified detector that he had installed in the De Forest system by December 1903. The wire dipping into the cup identified this detector as Fessenden’s Wollaston wire electrolytic detector. (*The Electrician*, Vol. 52, Dec. 4, 1903, p. 240)

Fessenden brought against the De Forest Company in the spring of 1904, the De Forest Company was “living from hand to mouth.” Because the company was nearly bankrupt, De Forest did not have the funds to expend on pursuing useless patents for what he believed was an impractical detector. The following is another excerpt from the document *Brief for Complainant on Final Hearing* describing the precarious financial status of the company at the time De Forest abandoned his first flame detector patent application. Note that the following testimony is not from the *Marconi v. De Forest* trial.

“The testimony shows that the defendants were living from hand to mouth. And if it had not been for the advent of the liquid barretter they would have been unable to carry on their operations even as stock jobbers. Melvin G. Lathrop who was employed by the defendants as a stock salesman and corporation secretary, Complainant’s Record, p. 626, etc., testifies that he left the employment early in October 1903:

“Q 17. Please state briefly the financial condition of the defendants at the time you left their employment, namely, on or about October, 1903.

“A. Funds were very scarce, and insufficient to meet promptly, if at all, bills for supplies, rent, telephone, service, labor, drafts, and other items payable. Money was sometimes secured from the Federal Bank of New York upon one day’s draft, payable at another

bank by the Mutual Securities Company, and the following day would be met by discounting a similar draft. A considerable number of notes went to protest, and the defendant company was unable to meet many of its promises and obligations.”¹²

De Forest would never deign to mention the precarious state of finances of the De Forest Company in the fall of 1903. However, he did allude to it by making this statement in his autobiography: “As usual I was so hampered for funds during this period that I could make but very slow progress with this new line of research [flame detector], continually busied as I was with the absolute necessity of building up, and putting on a commercial basis, the De Forest Wireless Telegraph System.”¹³ What he meant was that he could no longer pursue the flame detector because he was busy testing, fabricating, and installing Fessenden’s electrolytic detector in the De Forest’s commercial wireless system that had been proven to be both sensitive and practical. Indeed it was sensitive and practical, and it did save the company—for the time being.

Assessment

De Forest could not admit that he decided to abandon the flame detector patent application for lack of interest because his entire legal strategy was based on his claim that the invention of the two-electrode vacuum audion proceeded along a continuous line of development beginning with the flame experiments dating to 1902–1903. De Forest’s

revelation that he abandoned an earlier flame detector patent application was such a surprise and so important to the story of how he developed his audion that one must wonder if he ever revealed that fact in any other publication. It turns out that De Forest did refer to abandoning a flame detector patent application in his autobiography published in 1950 but he never identified to which patent he was referring. In an appendix of his autobiography, he listed scores of patents issued between 1902 and 1947. He marked 14 patents with asterisks, and at the bottom of the page he placed this footnote referring to these 14 asterisks:

“Patents marked (*) outline, in order of their filing, the evolution of the audion from the flame detector to the grid type. The original flame detector patent was filed in 1902 but abandoned for lack of prosecution.”¹⁴

The earliest gas flame detector with an asterisk on the list was for U.S. Patent 824,638 with the date June 26, 1906, but the filing date for this patent was January 20, 1906, not 1902. It turns out that the patents were listed in the order of date of issue, not date of filing. It also turns out that none of the flame detectors in this list with asterisks were filed in 1902. Therefore, while he documented in his autobiography that he abandoned a flame detector patent application filed in 1902, it was impossible to link the abandoned patent application referred to in the footnote to his application for U.S. Patent 979,275 filed on February 2, 1905, which issued on December 20, 1910.

Trial Account: De Forest's Evacuated Detector Bulb Concept (1904)

Historical Perspective

De Forest claimed in his 1920 Franklin Institute lecture and his 1950 autobiography that he had conceived of translating the two electrodes from his flame detector into an evacuated bulb heated by batteries in 1904 (see Fig. 3). This claim originated from testimony given by De Forest in the 1916 trial. It will now be documented that De Forest's attorneys attempted to establish the fact that De Forest had conceived of using electrodes heated by batteries in an evacuated bulb as a detector of Hertzian oscillations in August 1904 before Fleming filed his UK patent application on November 16, 1904.

Testimony: De Forest Testified About his Ideas of Using an Evacuated Bulb in 1904

De Forest's attorney began questioning De Forest about when he first came up with the idea of using an evacuated bulb configuration as a detector.

Q9. [Mr. Scull]: Prior to this date of December 21, 1905, had you ever had in mind the use of a vacuous space, or a gas at pressure less than atmospheric, in connection with wireless telegraph detectors, in which the gas is ionized so as to be sensitive to the incoming oscillations?

Before De Forest could answer, the attorney for Marconi objected, and the following dispute occurred:

Mr. Hoguet: I object to that.

Mr. Scull: Your honor, It seems to me we

have a right to carry back the date to the conception of the invention.

The Court: No. I think you cannot do anything more than show what Dr. DeForest said and did at the time; what he had in mind is evidenced by material evidence. By "material" I mean things that you can see and read and touch. There would be no security whatever about the whole Patent Law if you allowed a man to say what was in his own mind.

De Forest's attorneys continued their questioning of De Forest on this issue by introducing the only existing document De Forest had with a reference to an evacuated bulb that was dated before November 16, 1904, Fleming's priority date for filing. De Forest's document dated August 4, 1904, was a letter he wrote to his assistant and confidant, Clifford Babcock (see Fig. 7), asking him to perform a variety of experiments, one of which mentioned an evacuated bulb experiment.

Q18. [Mr. Scull]: *Between the date of the filing of your application No. 123,142, Defendant's Exhibit A-37, on September 12, 1902, and the filing of the application No. 243,913 [February 2, 1905], to which you have just referred and which is Defendant's Exhibit A, were you doing anything to carry out the inventions set forth in the abandoned application No. 123,142, and if so, please state what that was?*

A. [Dr. DeForest]: *Yes. I was frequently at work on that problem of the hot gas detector through the year 1903 and when-*



Fig. 7. Clifford Babcock was De Forest's very able assistant who performed many flame and audion experiments on behalf of De Forest. (Author's collection)

ever opportunity offered. I was at that time very little in New York, traveling a great deal for my company, and had very little opportunity to concentrate in the laboratory. Furthermore, the finances of my company at that time were in very bad condition and I had no facilities except the crudest for carrying on research work of this nature. The simple apparatus of the Bunsen flame with the electrodes in was, of course, at my disposal, and I went some ways with that. The other form, except the arc, which, of course, was a simple and inexpensive device to

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try, required skilled mechanics, pumps, and elaborate apparatus which was at that time entirely out of the possibilities of my company to furnish. However, my assistant, Mr. Babcock, in conjunction with me when I was out of New York, at certain times following my written instructions conducted experiments along these lines.

Q19. [Mr. Scull]: *What, in general, was the result of those experiments?*

A. [Dr. DeForest]: *A fairly satisfactory detector was obtained with the electrodes heated in the gas flame. The attempts to use the same principle in an evacuated bulb which we made were failures, and while the principle of the ionized gas detector existed in the arc[,] experiments showed that the arc itself was so noisy as to render this form of detector unsuitable in practice.*

Q20. [Mr. Scull]: *At the time you discovered in the fall of 1904 that your original application No. 123,142 had become abandoned were you still conducting experiments and attempting to develop the inventions set forth in that application?*

A. [Dr. DeForest]: *Yes. During that summer I was almost entirely out of New York, chiefly at St. Louis, in connection with our exhibits at the Exposition at that time so that I had practically no opportunity for laboratory work myself. Mr. Babcock was in New York and had rather a primitive laboratory, which was, however, better than we had in 1903 and what work was done at that time was done by him in response to my instructions.*

Q21. [Mr. Scull]: *I show you a letter, dated August 4, in ink, and below that immediately, "04" in pencil and ask you if you recognize that letter?*

A. [Dr. DeForest]: *Yes. That was a letter which I wrote from St. Louis in August, 1904, to my assistant, C. D. Babcock, in New York, whom I always addressed as "Bab."*

After several questions about the date of the letter and its admissibility, the letter was admitted into evidence as Exhibit A-38. This letter was signed by De Forest on the third page. There was also an unsigned attachment accompanying the letter entitled "Program for Experiment," which was written on different paper stock. The letter itself identified several tasks that Babcock was asked to perform while De Forest was occupied with his long-distance radiotelegraph demonstrations using the Fessenden electrolytic detectors at the 1904 Louisiana Purchase Exposition in St. Louis. Most of the experiments that Babcock was asked to perform were not relevant to the development of the audion bulb. However, the attachment described one experiment with an evacuated bulb detector that became the focus of many questions in the trial. The questioning of De Forest by Mr. Scull began with a focus on the first page of this attachment entitled "Program for Experiments" (see Fig. 8):

Q25. [Mr. Scull]: *On the first page "Program for Experiments" attached to this letter of August 4, 1904, I note a figure with a notation "Lamp-in vacuo-hot*

carbon filament" on it. Will you please explain what that figure illustrates?

Before De Forest could answer, Mr. Hoguet, attorney for Marconi, objected by asking a question that was followed by a brief exchange between the two attorneys, which were not numbered:

Mr. Hoguet: "What is the purpose of this testimony?"

Mr. Scull: Simply to elucidate in terms of the art a sketch which De Forest made in 1904 to show his idea of his invention; the state in which it was in at that time.

Mr. Hoguet: What relation has it to the case; that is the point.

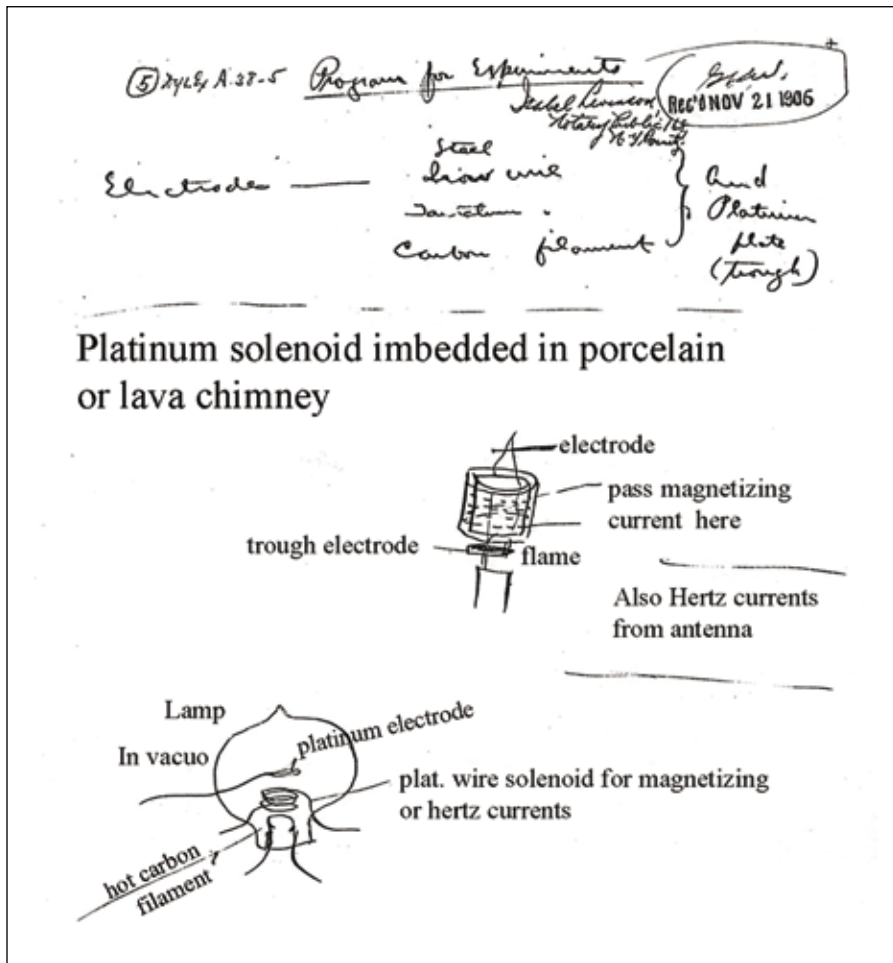


Fig. 8. This attachment to a letter dated August 1904 from De Forest to Babcock entitled "Program for Experiment" identified two experiments Babcock was to perform using a third electrode to explore the effect of magnetic fields on the electron flow between a cathode and plate electrode. (Exhibit A-38 from the 1916 trial proceedings, Author's collection)

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Mr. Scull: It is carrying back the date of the invention of patent No. 824,637 and the divisions thereof, the applications of those patents not having been filed until January, 1906.

In the end, De Forest was finally allowed to answer only the original question that was asked, which was to describe the figure labeled “Lamp”:

A. [Dr. DeForest]: This figure labeled “Lamp” shows an incandescent lamp with a carbon filament in this case in the form of a single horseshoe, or hair-pin. I have lettered underneath the word “lamp” “In vacuo” to indicate that I intended that this lamp after the additional electrodes had been inserted should be re-exhausted and put in the condition in which it was originally so as to enable me to burn the filament at the ordinary temperature of an incandescent filament in a lamp. I show a platinum electrode a short distance above this filament, and in between the platinum electrode and the filament, the fine platinum wire solenoid. My idea of inserting this third electrode at that time was to search for some magnetizing influence upon the cathode rays which were passing from the hot filament to the cold platinum electrode.

Mr. Hoguet: That is not the structure of patent No. 824,637, or anything like it, and I object to that testimony on the ground that it is incompetent to carry back the date.

Mr. Scull: Your Honor, it seems to me that if this objection were carried out we would not be able to begin to show any

conception of the invention until we had it in perfected form and just as it was disclosed in the Patent Office drawings. The Court: The objection will be noted. I will take the testimony. Of course, testimony like this is of no value, like that last sentence.

Assessment

Marconi’s attorney, Mr. Hoguet, objected to De Forest’s testimony because the three-electrode configuration designed to explore the effect of magnetic fields on the flow of electrons had nothing to do with the two-electrode audion configuration in question. He particularly objected to any testimony that would “show De Forest’s idea of his invention; the state in which it was in at that time.”

The configuration De Forest showed was a scientific experiment, not an invention. De Forest unwittingly claimed that the purpose of the experiment was “to search for some magnetizing influence upon the cathode rays [electrons] passing from the filament to the cold platinum electrode.” Magnetic field influences on the flow of charged particles had nothing to do with the flame and audion bulb detectors in question, all of which involved electrostatic field influences. In the end, De Forest was unable to show that he had conceived of the two-electrode evacuated bulb configuration in 1904 (see Fig. 3), which he continued to maintain after the trial.

As an aside, the magnetic field and direction of electron flow in both of De Forest’s experimental configurations

were in the same direction, so the magnetic field would have had little or no effect on electron flow. It is no wonder that De Forest admitted his experiments were a failure.

Trial Account: De Forest's Two-Electrode Audion Bulb Development (October 1905–October 1906)

Historical Perspective

De Forest described how he invented his evacuated audion bulb in 1905 in his 1920 Franklin Institute lecture and his 1950 autobiography. Referring to the configuration reproduced in Fig. 4, he began with the following words:

“It was not until 1905 that I had opportunity and facilities for putting to actual proof of my conviction that the same detector action that had been found in the neighborhood of an incandescent platinum wire in a gas flame existed also in the more attenuated gas surrounding the filament of an incandescent lamp.”¹⁵

While he claimed that it was not until 1905 that he had the opportunity and facilities to perform tests on an evacuated bulb enclosing two electrodes, he admitted that at no time in 1905 did he have the facilities to make the bulbs, and he had no bulbs to test until after December 5, 1905. In due course, testimony will document the fact that he approached the McCandless Company of New York City on December 5, 1905, with a request to fabricate evacuated bulbs with incandescent filaments to his specification.

De Forest admitted in the 1916 trial that he decided to seek a new detector technology on October 16, 1905—not because he had the facilities to do so, but because that was the date he was enjoined from further use of the very successful electrolytic detector that he had appropriated from Fessenden without obtaining a license.¹⁶ The real story of how De Forest developed his two-electrode audion is now revealed by De Forest himself in his sworn testimony.

Testimony: De Forest Identified the Catalyst for Developing his Audion Invention (October 16, 1905)

De Forest admitted under oath that Judge Wheeler's decision on October 16, 1905,¹⁷ to enjoin the De Forest Company from further use of Fessenden's patented electrolytic detector precipitated his decision to develop a new detector technology:

Q56. [Mr. Scull]: *It would appear from your testimony that you were carrying experiments and tests with the hot gas responder and using the Bunsen burner and the like more or less intermittently until the fall of 1905 when you took up the development which led to the tests at 42 Broadway about which you have just testified. Please explain what, if anything, it was that led you to take up the work diligently at that time?*

A. [Dr. DeForest]: *My Company was enjoined in the fall of 1905 under the Fessenden electrolytic patent from using the Wollaston wire electrode. We then used what we called the Spade Electrode in an electrolytic detector, acting upon*

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the advice of our attorneys... However, the Fessenden Company sought then to enjoin us, or hold the Company in contempt, from using this type of electrolytic detector and I thought it highly important to proceed with the development of an entirely new type of detector which could be used to supplant the electrolytic detector in case of necessity.

Immediately following Judge Wheeler's decision, De Forest directed Babcock to make a detector in the shape of a spade as a replacement for the Wollaston wire electrode Fessenden described in his electrolytic detector patent. De Forest realized this was a risky strategy, which is why he testified that he thought it was highly important to proceed with the development of "an entirely new type of detector." That new type of detector was the two-electrode vacuum bulb detector, which is described next by De Forest in his testimony.

Testimony: De Forest Disclosed his Two-Electrode Vacuum Bulb Invention to Attorney George Woodworth (November 24, 1905)

In early November 1905, a few weeks after Judge Wheeler's decision in the Fessenden lawsuit, De Forest contacted George K. Woodworth, a practicing patent attorney in Boston, and engaged him to be his patent attorney. De Forest arranged to meet with Woodworth in Boston on November 24, 1905, to review some patents that he wanted Woodworth to prepare and file. One of those patent applications was for a two-electrode vacuum tube detector.

De Forest testified about the conversation he had at that meeting with his attorney where he disclosed his two-electrode vacuum tube invention for the first time.

Q8. [Mr. Scull]: *At this interview with Mr. Woodworth to which you have referred had you explained to him the invention referred to in this letter of December 21st, Defendant's Exhibit A-35?*

A. [Dr. DeForest]: *Yes. I had gone into the matter outlined in this letter at some length and this letter was to bring the matter in concrete form before him. In that interview[,] I had explained what I considered was the theory of operation of the hot gas detector [flame detector] and outlined various methods by which this same effect could be obtained, among those methods being the use of the lamp bulb with an incandescent filament and other electrodes sealed within. While describing these devices I made it perfectly plain to Mr. Woodworth that I had in mind the incandescent lamp vacuum and filament heated as they ordinarily are in incandescent lamps.*

George Woodworth's version of this meeting, given in testimony under oath, was consistent with De Forest's testimony:

Q1. [Mr. Scull]: *Please state your residence and occupation?*

A. [Mr. Woodworth]: *Brookline, Massachusetts; attorney-at-law.*

Q2. [Mr. Scull]: *You have been attorney*

for Dr. Lee DeForest in filing applications for patents for him, have you not?

A. [Mr. Woodworth]: *Yes.*

Q3. [Mr. Scull]: *When, if you recall, did you first become his attorney?*

A. [Mr. Woodworth]: *November 1905.*

Q4. [Woodworth]: *Do you recall the circumstances or any of the facts connected with his employment of you as attorney?*

A. [Mr. Woodworth]: *Yes.*

Q5. [Mr. Scull]: *Please state what they are?*

A. [Mr. Woodworth]: *About the first part of November, 1905, he [DeForest] asked me to become his attorney, or patent solicitor. I replied that I would be glad to do so, and two or three weeks later he called at my office at Boston and disclosed to me a number of inventions, applications for patents and which he desired me to file (sic). I made notes and sketches and he made notes and sketches relating to these inventions.*

Q6. [Mr. Scull]: *I show you a paper, and ask you if you recognize that, and if you do please state what it is?*

A. [Mr. Woodworth]: *Yes I recognize the paper [Exhibit A-42]. It contains notes which I made on November 24, 1905, at the interview to which I referred between DeForest and myself.*

Q7. [Mr. Scull]: *With this paper before you, will you please state what Dr. DeForest disclosed to you on November 24, 1905, so far as it is illustrated on that paper?*

Judge Mayer interrupted before De Forest could answer:

Q8. [The Court]: *You saw him?*

A. [Mr. Woodworth]: *Yes.*

Q9. [The Court]: *Just state what he said.*

A. [Mr. Woodworth]: *Dr. DeForest told me that he had invented an oscillation detector consisting of an evacuated globe or bulb in which were sealed two filaments which might be of platinum or carbon or tantalum. They were to be heated to incandescence like the filament of the ordinary incandescent lamp, by batteries. They were to be connected by a conductor to a telephone or other receiver, and a battery. One of the filaments was to be connected to the antenna and the other to the earth.*

The single page of notes Woodworth made on November 24, 1905, is reproduced in Fig. 9. Because his handwriting is barely legible, the words on the upper half of the page are annotated in red. Woodworth's sketch at the bottom of the page documenting De Forest's new detector configuration, which is of most interest among Woodworth's other notes on this page, is enlarged and annotated in Fig. 10. The word "vacuum" that points to the enclosure reinforced testimony by both that the bulb was to be evacuated. There were two electrodes that were to be made of tantalum, platinum, or carbon. The two electrodes were connected to two separate batteries with an annotation stating: "One only need be heated." The sketch also specified that the plate voltage was to be between 10 and 25 volts.

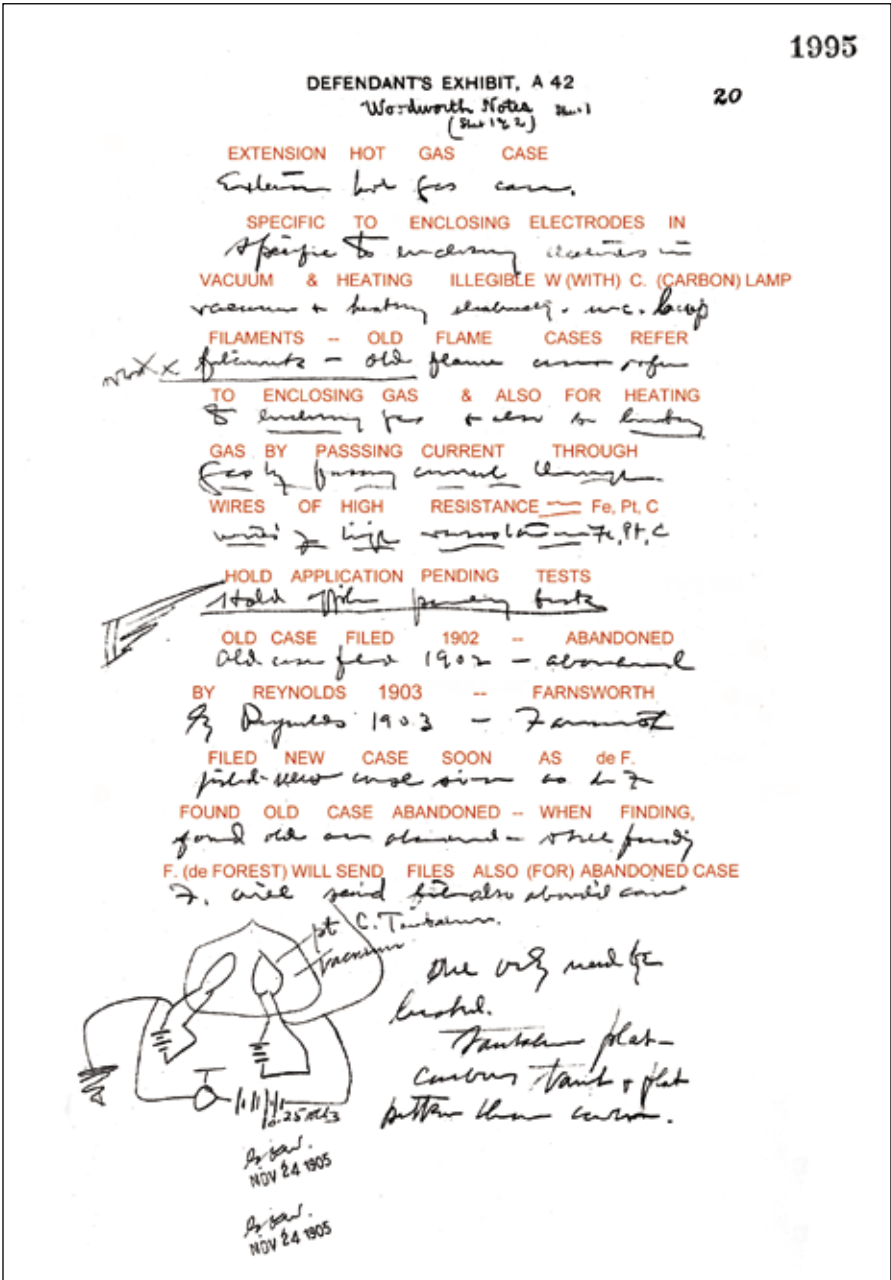


Fig. 9. The first page of notes taken by De Forest's patent attorney, George Woodworth, at their first meeting in Boston on November 24, 1905, documents De Forest's new invention consisting of two filaments enclosed in an evacuated bulb that are both heated by separate batteries. (Exhibit A-42 from the 1916 trial proceedings, Author's collection)

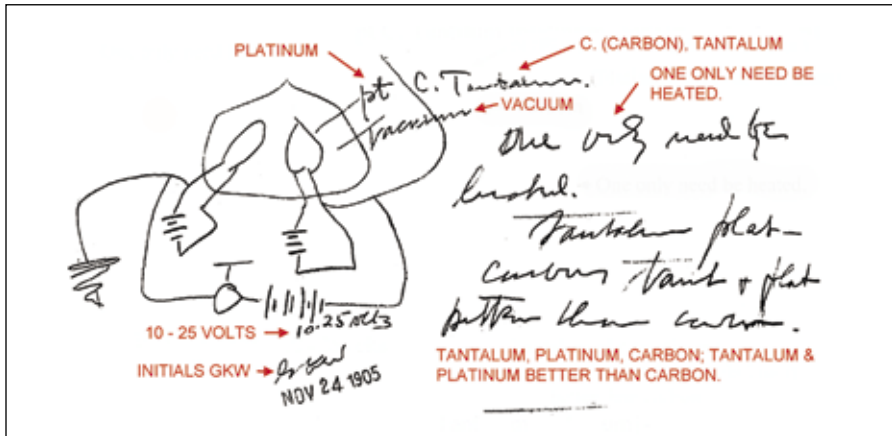


Fig. 10. This enlargement of De Forest's new invention documented in Woodworth's notes reveals: 1) the filament could be platinum, carbon, or tantalum, 2) the bulb was to be evacuated, 3) the battery in the plate circuit should be adjusted to 10–25 volts, and 4) only one filament need be heated. (Exhibit A-38 from the 1916 trial proceedings, Author's collection)

Assessment

Woodworth's sketch of De Forest's "new invention" shown in Fig. 10 is identical to the configuration that De Forest claimed he had conceived of in 1904 a year before he met with Woodworth (compare Fig. 10 with Fig. 3). In previous testimony, De Forest was unable to produce any evidence that he documented this configuration in 1904 or at any other time before he disclosed it to his attorney, George Woodworth, on November 24, 1905. It is suspicious that this exact configuration appeared in an article published by Fleming in the April 1905 issue of *Technics* in which he described his Fleming valve (see Fig. 11).¹⁸ The words that accompanied Fleming's figure presaged the words that appeared in Woodworth notes seven months later. Fleming wrote: "Hence, such a bulb containing two carbon filaments forming the two electrodes, one of which can

be rendered incandescent, will act as a vacuum valve." This configuration was a slight revision of an earlier version that Fleming originally published in 1900 when he described many of his

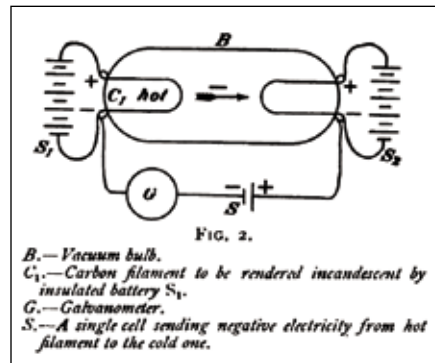


Fig. 11. In April 1905, Fleming published an article in *Technics* with this configuration that is identical to the configuration that De Forest disclosed to his patent attorney on November 24, 1905—complete with the statement that only one filament need be heated. (*Technics*, Vol. 3, Apr. 1905, p. 317)

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experiments using the Edison effect bulb configuration.¹⁹

De Forest would have us believe that five weeks after he began his search for a new detector technology on October 16, 1905, he had invented an oscillation detector with the specificity in the list below taken from trial testimony. Some of these listed items could have been determined only by test data, which De Forest was unable to take because by his admission he had no access to evacuated bulbs until after December 5, 1905. Recall the specificity that was in the previous testimony:

1. Woodworth testified: “Dr. DeForest told me that he had invented an oscillation detector consisting of an *evacuated globe or bulb* in which were *sealed two filaments* which might be of platinum or carbon or tantalum.”
2. Woodworth added: “The filaments were to be *heated to incandescence like the filament of the ordinary incandescent lamp*, by batteries.”
3. De Forest added in his testimony: “While describing these devices I made it perfectly plain to Mr. Woodworth that I had in mind the incandescent lamp, *with ordinary incandescent lamp vacuum* and filament heated as they ordinarily are in incandescent lamps.”
4. Woodworth’s image indicated: “Only one [filament] need be heated.”
5. Woodworth’s image indicated a specific range of battery voltages: “10–25 volts.”

How was this possible? The only sensible answer is that De Forest had prior

knowledge of Fleming’s valve by reading his previous publications. It turns out that all the information and data needed to define a thermionic valve with the specificity described above was published by Fleming well before October 16, 1905, the date De Forest said he began his search for a new detector technology. It also turns out that De Forest admitted he had read Fleming’s publications.

De Forest had Prior Knowledge of Fleming’s Patent (March–June 1905)

Recall that De Forest wrote in his autobiography: “At the period under consideration, 1903–1905, I was familiar with the Edison effect and with many of the investigations thereof carried out by scientists, Professor Fleming among others.”²⁰ The most relevant document Fleming wrote about his studies of the Edison effect was published in the *Proceedings of the Royal Institution of Great Britain* in 1900.²¹ The most relevant document that Fleming wrote in 1905 describing his Fleming valve with the specificity listed above was published in the March issue of the *Proceedings of the Royal Society of London*. Judge Mayer made the following statement in his written opinion, which he recalled from testimony given in the 1916 trial:

“It must be remembered that De Forest in December, 1905, knew of Fleming’s Royal Society paper of March, 1905, as appears from a reference to that effect in his application for a certain patent not here in issue (No. 823,402), where he used the expressions ‘exhausted vessel’ and ‘heated to incandescence.’”²²

The patent he referred to was entitled “Static Valve for Wireless Telegraphy,” for which De Forest filed his application on December 9, 1905. Here is the paragraph cited by De Forest in his patent:

“The device V^1 , (shown in Fig. 1) [of this patent] connected between the antenna at point b and earth, is an asymmetric resistance or electric valve which has been fully described by J. A. Fleming in a paper published in the *Proceedings of the Royal Society of London*, March 16, 1905, to which reference may be had for a more complete description thereof than need to be set forth herein. Suffice it to say that the exhausted glass vessel Q ” contains the filament F' heated to incandescence by the battery B' and a metal cylinder D' , which surrounds the filament F' . This type of valve passes positive electricity from the cold terminal D' to the heated terminal F' more readily than in the opposite direction.”²³

The device “ V^1 ” shown in Figure 1 of this patent was a Fleming valve that is reproduced here as Fig. 12. De Forest referenced an article by Fleming that appeared in the *Proceedings of the Royal Society of London*,²⁴ which constituted a complete description of Fleming’s valve that included a line drawing of three valve configurations (see Fig. 13). It also included a set of I-V characteristics (see Fig. 14) for the bulb configuration shown in Fig. 13a. Based on Fleming’s description of his valve in this publication, *The Electrician* published the schematic diagram of the circuit that Fleming used

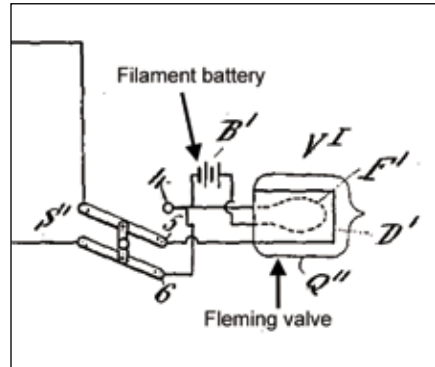


Fig. 12. De Forest knew of Fleming’s Royal Society paper published in March 1905 and the Fleming “ V^1 ” shown therein, both of which were cited by De Forest in an unrelated patent application that was prepared prior to November 24, 1905, for U.S. Patent No. 823,402 where he used the expressions “exhausted glass vessel” and “heated to incandescence by battery B and a metal cylinder D''' ” to describe the valve. (De Forest U.S. Patent 823,402, Fig. 1)

to measure the I-V characteristics (see Fig. 15).

Fleming also made the following statements in the paper cited by De Forest that provided all the information that De Forest needed to engage a glass blower to fabricate a sensitive, functioning detector:

- 1) The curves in Fig. 14 indicated that the vacuous space would possess a maximum conductivity when a potential difference of about 20 volts was applied to the electrodes.
- 2) The bulb should be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate should be free from occluded air.
- 3) One carbon filament should be used,

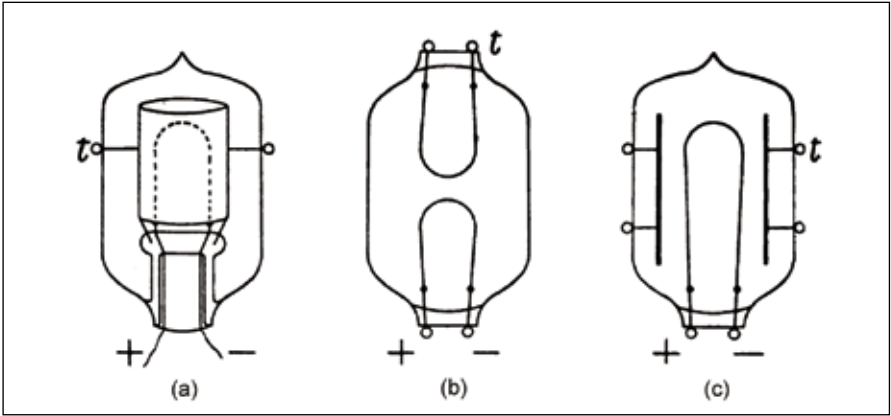


Fig. 13. Fleming defined three evacuated valve configurations in his seminal paper published in March 1905: a) a cylindrical plate surrounding a filament that appeared in the patent application for his valve in November 1904, (b) two filaments with external leads for batteries identical to the configuration that De Forest disclosed to Woodworth six months later on November 24, 1905, and c) two flat plates on either side of the filament was identical to the double-plate audion configuration De Forest presented for the first time in his October 1906 lecture to the AIEE. (Fleming, *Proc. of the Royal Soc. of London*, Vol. 74, Jan. 24, 1905, p. 478)

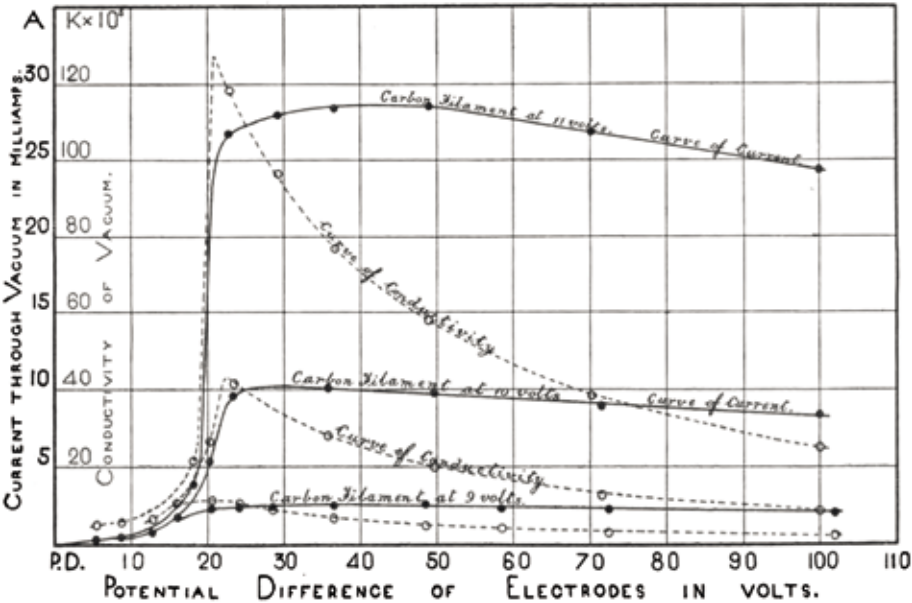


Fig. 14. Fleming measured the I-V characteristics of his valve for three different carbon filament voltages (9, 10, and 11 volts). The maximum conductivity occurred when the plate voltage was approximately 20 volts and the filament voltage was 11 volts. (Fleming, *Proc. of the Royal Soc. of London*, Vol. 74, Jan. 24, 1905, p. 483)

and a platinum wire should be sealed into the bulb terminating in a plate or cylinder of platinum, aluminum, or other metal surrounding the filament.

- 4) The cylinder should be cool and the carbon filament should be at a temperature not much above the melting point of platinum (1768 °C).
- 5) The primary coil of this oscillation transformer should have one terminal connected to earth and the other to a long insulated rod that acts as an aerial or electric wave collector. To prevent the direct action of the transmitter upon the secondary coil by simple electromagnetic induction, it would be best to wind the secondary coil in two equal parts in opposite directions and to wind the primary in a corresponding manner.

It is unlikely that De Forest was aware that Fleming had filed a U.S. patent application on his valve detector before De Forest decided to invent a new detector on October 16, 1905, because Fleming's U.S. Patent 803,684 did not issue until November 7, 1905. However, Fleming's UK patent issued on September 21, 1905, and the date of publication in *The Patents Journal* in Great Britain would generally correspond to the date the patent was granted.

Testimony: De Forest Engaged Henry W. McCandless and Company (December 5, 1905)

At one point in the testimony given by De Forest's patent attorney, George Woodworth, he was asked a question

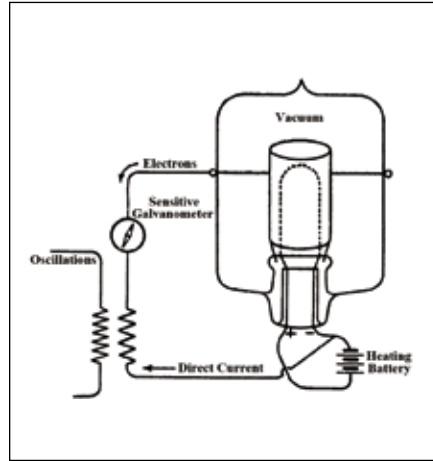


Fig. 15. *The Electrician* published this image of Fleming's valve configuration that described the test configuration he used to gather the data shown in Fig. 14, which appeared in Fleming's article published in the *Proceedings of the Royal Society*. (*The Electrician*, Vol. 54, Mar. 31, 1905, p. 967)

about one of the notes in a document introduced previously:

Q24. [Mr. Scull]: *In the paper, Defendant's Exhibit A-42, I call your attention to this quotation "Hold application pending tests." Will you please state what that refers to?*

A. [Mr. Woodworth]: *DeForest at the interview on November 24, 1905, directed me not to file the application immediately but wait for further instructions.*

Exhibit A-42 is reproduced in Fig. 9, and the quotation in question is halfway down the page where a "pointing finger" was sketched in the left margin for emphasis. De Forest had testified previously that all his tests with an evacuated

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lamp were failures: "Our repeated failures to accomplish what I was after with our own crude implements and skill finally induced me in 1905...to lay the problem of constructing an incandescent lamp... in the lap of a manufacturer of miniature lamps, McCandless by name." De Forest was waiting to obtain data from the McCandless bulbs before preparing the patent application. De Forest planned to have McCandless fabricate two-electrode, evacuated, detector bulbs to his specifications for test and evaluation before he gave instructions to Woodworth to prepare his patent application. De Forest's testimony indicates that is exactly what happened:

Q32. [Mr. Scull]: *At the time you had this interview with Mr. Woodworth prior to writing to him the letter Defendants' Exhibit A-35, were you carrying on any experiments to put in physical form the ideas expressed in that letter Defendants' Exhibit A-35? If so, please state what?*

A. [Dr. DeForest]: *Yes. At that time I had secured sufficient funds to proceed with the lamp in vacuo experiments and had secured a lamp maker by the name of McCandless who had consented to undertake construction of these various devices. Before finding McCandless, Babcock and I had searched at some length without results for such a lamp maker, or maker of X-ray bulbs. None of them seemed to be willing to attempt to construct these things for any remuneration which we were willing, or able, to pay.*

Q33. [Mr. Scull]: *Did you succeed in having lamps made for you by McCandless?*

A. [Dr. DeForest]: *Yes.*

McCandless Company records confirm that two orders for evacuated bulbs with carbon lamp filaments were received from the De Forest Company on December 5, 1905, and January 5, 1906. Testimony from both Henry McCandless and his superintendent and foreman, Joseph C. Grogan, also confirmed that these were the first two orders received from the De Forest Company and that the first order received on December 5, 1905, was placed by Babcock alone. Grogan testified that the tubes ordered by the De Forest Company were made from drawings provided by Babcock on his first visit:

Q3. [Mr. Scull]: *What were your duties as foremen for the H. W. McCandless Company?*

A. [Mr. Grogan]: *I looked after the production and manufacture of miniature lamps, and particularly after anything in the way of special lamps.*

Q4. [Mr. Scull]: *Do you know Dr. Lee De Forest?*

A. [Mr. Grogan]: *Yes.*

Q5. [Mr. Scull]: *Do you know Mr. C. D. Babcock?*

A. [Mr. Grogan]: *Yes*

Q6. [Mr. Scull]: *I show you two sheets of data which are marked Defendant's Exhibits A-40 and A-41, and ask you if you recognize what they are?*

A. [Mr. Grogan]: *This was the form which we used for recording our data at that time. These are data entries on the sheets, part of our entries.*

Q7. [Mr. Scull]: *I call your attention to the first entry on Defendant's Exhibit A-40, having two dates, January 5th, presumably 1906 and December 4th, 1905, and the name "DeForest" and bulb marked "Special" and ask you whether you know anything about the devices which were made, according to that entry, and if so, what do you recall?*

A. [Mr. Grogan]: *So far as I recall, these were special wireless apparatus made with a carbon filament, according to this data. It is a carbon filament data.*

Q8. [Mr. Scull]: *Did you from time to time, as foreman of H. W. McCandless & Company, come into contact with either Mr. Babcock or Dr. DeForest?*

A. [Mr. Grogan]: *Yes.*

Q9. [Mr. Scull]: *Do you recall when you first met either of these gentlemen?*

A. [Mr. Grogan]: *Well, I cannot recall the exact time because there was nothing transpired to fix it in my mind. It came to us more or less as a regular proposition, and I would not have any reason for trying to memorize the date that I met either Dr. DeForest or Mr. Babcock, but I know it was early in the time that the wireless was coming out. Probably about those dates [i.e., December 4, 1905, and January 5, 1906], because so far as I can recall, Mr. Babcock is the man who brought the first sketches to us, and I naturally would be called in on any special proposition of that kind.*

Q10. [The Court]: *Was this the first business that Mr. Babcock had with your concern?*

A. [Mr. Grogan]: *Yes, the first we ever made that I can recall were for wireless telegraphy.*

The most important point to make about this portion of Grogan's testimony is that De Forest could not have tested any evacuated bulb audions before December 4, 1905, because he admitted that he did not have the apparatus to do so before he found the McCandless Company to fabricate his audion. Grogan claimed that the first order the McCandless Company received was on December 4, 1905.

As an aside, Grogan's testimony contradicts Gerald Tyne's statement in *Saga of the Vacuum Tube* that De Forest's assistant, C. D. Babcock, brought a Fleming valve into the McCandless Company in December 1905: "Toward the latter part of 1905 C. D. Babcock, one of De Forest's assistants, brought to the office of H. W. McCandless & Company in New York a modified incandescent lamp which he told McCandless was a Fleming valve and asked that duplicates be made."²⁵ There is no mention anywhere in the trial testimony that De Forest was in possession of a Fleming valve in 1905 or early 1906, and Tyne makes no reference to the source of his information. There is no record that De Forest or Babcock ever admitted that they gave McCandless a Fleming valve to duplicate. If they did, then Tyne must have heard it directly from McCandless. While that is possible because Tyne was known to rub shoulders with McCandless later in life (see Fig. 16), it is unlikely because McCandless had a close relationship



Fig. 16. Gerald Tyne often rubbed shoulders with McCandless later in life. (AWA Journal, May 1980)

with De Forest and he would not have divulged the fact that De Forest was in possession of what would have been a pirated Fleming valve in late 1905.

Testimony: Jacob Grogan Disclosed the Technical Characteristics of De Forest's Audions

Grogan was asked to describe the type of tubes Babcock ordered from McCandless on December 4, 1905, and January 5, 1906:

Q14. [Mr. Scull]: *Do you recall any special construction of the bulb which you made in accordance with this entry of January 5th and December 4th, to which I have called your attention? In other words, was the device which you*

made in accordance with that entry an incandescent lamp, or did it have features unusual in incandescent lamps?

A. [Mr. Grogan]: *The first that I recall in making that special apparatus was a filament in connection with other metals adjacent to the filament mounted on the Lebian stem, as we call it, on the same mount.*

Q15. [Mr. Scull]: *Did you ever make, for either Dr. DeForest or Mr. Babcock, any lamp bulbs which did not have this construction which you have just referred to?*

A. [Mr. Grogan]: *We might have made some minor ones after we got started on these that I have mentioned. I cannot say that we never made a lamp bulb other than the wireless apparatus bulb*

for either Mr. Babcock or Dr. DeForest, but I know we made a great many of those.

Q16. [Mr. Scull]: *To what degree of pressure did you pump the bulbs which you made according to this entry of January 5th and December 4th, to which I have called your attention?*

A. [Mr. Grogan]: *We pumped them to the same degree that we did in lamp manufacturing. We did not have any McCloud gauge to read the pressure at that time, but we had the old type of mercury pump giving the highest vacuum, I should say, of any of the pumps at that time. We had a way of telling when we had all the gases out by the appearance of a small bubble at the mercury valve which checked the back-rush of air into the pump. We pumped our lamps until we got practically no bubble at that point or any further gas in the lamp expanding into the pump.*

Q17. [Mr. Scull]: *So you do not recall any special instructions either as to comparatively high pressure or relatively low pressure were given as to these first bulbs which you made for DeForest?*

A. [Mr. Grogan]: *So far as I can recall, we were always requested by them to make the vacuum higher.*

Q18. [Mr. Scull]: *That is, as high as you were making for your incandescent lamps?*

A. [Mr. Grogan]: *And, if possible, higher because in some instances we used to heat up the outside of the bulb with a Bunsen flame in order to expand any gases that*

might adhere to the inside and help get out all of the moisture.

At this point, Mr. Bull, an attorney for American Marconi, began to cross-examine Mr. Grogan on the above testimony. The questions under cross-examination in the trial transcript were indicated by the letters "XQ" preceding the question number.

XQ23. [Mr. Bull]: *And you say you assisted the pumping by heating the bulbs?*

A. [Mr. Grogan]: *Yes, the bulbs.*

XQ24. [Mr. Scull]: *And you also heated the filament?*

A. [Mr. Grogan]: *Yes.*

XQ25. [Mr. Scull]: *During the pumping operation, so as to expel all the air out of the filament itself?*

A. [Mr. Grogan]: *We turned that filament higher than it would ordinarily be turned when it was in regular operation so as to expel as much of the gases as we could.*

XQ26. [Mr. Bull]: *You mean while it was on the pump, you heated it to a higher degree of incandescence?*

A. [Mr. Grogan]: *Yes, than it would be in actual service.*

XQ27. [Mr. Hoguet]: *In actual service it was intended to be operated as incandescent?*

A. [Mr. Grogan]: *Yes.*

Grogan stated that Babcock had requested the McCandless Company

The Story of How Lee De Forest Developed the Audion: Part II

to fabricate bulbs with a single carbon filament that was meant to operate at the same level of incandescence as an ordinary light bulb. He also testified that Babcock requested the bulbs be evacuated to the highest level possible—namely to the same level as the bulbs McCandless made for purposes of electric lighting. At this point, De Forest had no data to support these requirements. The only data reported in the literature for a detector with an evacuated bulb and an incandescent filament was reported by Fleming in his paper published in the March 1905 issue of the *Proceedings of the Royal Society*, which De Forest had read before the date Babcock placed his first order.

Testimony: De Forest Admits He Saw Fleming's Published Patent Before He Prepared his Patent Application (December 21, 1905)

There was a great deal of interest by both parties in establishing when De Forest first learned of Fleming's valve patent, U.S. Patent 803,684, which was issued on November 7, 1905. De Forest was questioned on this point at three different times during interrogations by his attorney, Marconi's attorney, and Judge Mayer. The following testimony established unequivocally that De Forest had a copy of Fleming's patent and read it before he wrote a letter to his attorney dated December 21, 1905, at which time he instructed him to file his first patent application for an audion bulb. That letter will be reproduced and discussed at the end of the following testimony.

Q4. [Mr. Scull]: *You are one of the*

defendants in this case and the inventor of the so-called DeForest patents in suit, are you not?

A. [Dr. DeForest]: *Yes.*

Q5. [Mr. Scull]: *I hand you a letter in pencil, dated December 21, and stamped "Received December 22nd, 1905," and ask you if you recognize that letter?*

A. [Dr. DeForest]: *I do. This is a letter that I wrote in pencil to Mr. George K. Woodworth of Boston a little while after I had induced him to undertake the filing of the applications of patents for me.*

Q6. [Mr. Scull]: *And do you recognize the signature to the letter, and if so, please state whose it is?*

A. [Dr. DeForest]: *It is my signature.*

Somewhat later, De Forest's attorney asked him specifically when he learned of Fleming's patent. The above letter was referenced in the later testimony, which follows:

Q57. [Mr. Scull]: *At the time that you began this renewed activity in the fall of 1905 had you seen a copy of the United States patent to Fleming No. 803,684 which is here in suit and a copy of which I now show you?*

A. [Dr. DeForest]: *No.*

Q58. [Mr. Scull]: *Do you recall when you did first see a copy of this patent?*

A. [Dr. DeForest]: *Not exactly. It was sometime after the patent issued and prior to the date of my letter to Woodworth in which I make reference to the recently issued Fleming patent.*

Q59. [Mr. Scull]: *Can you fix this date with reference to your interview with Mr. Woodworth which you say you had prior to writing the letter of December 21st, 1905?*

A. [Dr. DeForest]: *That interview was in the latter part of November, 1905, and I had not at that time seen the Fleming patent.*

Q60. [The Court]: *When did you first see it?*

A. [Dr. DeForest]: *It must have been in December, 1905. It was prior to that letter and subsequent to my interview with him.*

Q61. [The Court]: *Prior to the letter of December 21st, 1905, to Woodworth?*

A. [Dr. DeForest]: *Yes.*

Judge Mayer took note of the fact that De Forest admitted he had knowledge of Fleming's patent before he wrote the letter to Woodworth dated December 21, 1905. Judge Mayer expressed continuing interest in how and when De Forest came across Fleming's patent:

XQ107. [The Court]: *How did you come across the Fleming patent? Do you remember how that came to your attention?*

A. [Dr. DeForest]: *No. I do not remember distinctly, your Honor. I think Babcock showed it to me.*

XQ108. [Mr. Hoguet]: *Who is Babcock?*

A. [Dr. DeForest]: *Babcock was my assistant in the American De Forest Company.*

XQ109. [Mr. Hoguet]: *Is he still alive?*

A. [Dr. DeForest]: *Yes.*

XQ110. [Mr. Hoguet]: *Is he available?*

A. [Dr. DeForest]: *Yes.*

De Forest's attorney compounded De Forest's problem by asking him when Babcock had shown him Fleming's patent. De Forest confirmed not only that he had knowledge of Fleming's patent, but also confirmed that Babcock had shown him a copy of the patent before he filed his patent application.

RDQ113. [Mr. Scull]: *When Babcock showed you this Fleming patent now in suit in the fall of 1905 do you recall that he made any remark, and if so, what was it?*

A. [Dr. DeForest]: *My recollection is that when he showed it to me he said that Fleming was working along the same lines and it behooved me to get busy and file my patent applications.*

RDQ114. [Mr. Scull]: *Did you follow his advice?*

A. [Dr. DeForest]: *I had already taken steps prior to that time of seeing the Fleming patent to have Mr. Woodworth file a large number of patent applications for various inventions and among them was that one of the patents in suit No. 824,637.*

De Forest's response to the last question was deceptive at best. He said that he had taken steps to file "the patent in suit No. 824,637" before he saw the Fleming patent. The only step he had

The Story of How Lee De Forest Developed the Audion: Part II

taken to file this patent application was to meet with his attorney on November 24, 1905. De Forest had arranged that meeting to engage George Woodworth to file several patents but De Forest had requested Woodworth to “hold application pending tests” of his audion. De Forest’s letter dated December 21, 1905, was the letter that instructed his attorney, George Woodworth, to file the patent application for his two-electrode audion invention. This letter contained sketches of five evacuated bulb configurations that De Forest directed his attorney to use in the preparation of the patent application, and these configurations, in fact, did appear in the issued patent. The point to grasp here is that De Forest admitted he saw the Fleming patent *before* he wrote the December 21st letter, which was the first time he documented the configurations that he wanted to have Woodworth use in his audion bulb patent application.

The first two pages of this six-page letter are the most important because they defined the only two relevant configurations that appeared in De Forest’s letter. The other three configurations described in the remaining four pages were irrelevant because none of the electrodes were heated, and later demonstration tests before the Court by Roy Weagant proved they were not operative. The first page of this handwritten letter is practically illegible (see Fig. 17), so it is transcribed in a non-cursive font in Fig. 18.

On the first page, De Forest requested Woodworth to file an application for his audion invention and directed him to use

the same language that he used for his old flame detector, namely the requirement for a sensitive conductive medium produced by heating the gas. This was in sharp contrast to the disclosure he made at his first meeting with Woodworth on November 24, 1905, where he stated the audion bulb was to be evacuated to the degree found in a lamp bulb, and the filament was to be heated to a high degree of incandescence—not the gas. This was an obvious ploy to differentiate his audion from the Fleming valve that was disclosed in the issued Fleming patent.

De Forest ended the first page with a description of two of the five audion bulb configurations that he wanted Woodworth to include in the application:

“Fig. 1 shows [a] lamp bulb containing 2 filaments, each heated from a separate source the conductivity of the gas there between being increased by the heat. A local battery & tel. [telephone] connects those 2 filaments.

“Fig. 2 shows only 1 heated filament (Look out for Fleming’s pat. [patent] in this connection).”

These two figures appeared on the second page of De Forest’s letter (see Fig. 19). The first figure was the same configuration that De Forest had disclosed to Woodworth at his first meeting on November 24, 1905, which had two heated filaments. The second figure illustrated an audion bulb with only one heated filament and one cold plate, a configuration that De Forest had not documented previously. This configuration was identical to the Fleming valve

Letter—De Forest to Woodworth dated 12/21

Exh. A-35-1

① Case W-17 N.Y. Dec 21

Dear Woodworth
REC'D DEC 22 1905

You are familiar with my "flame detector" or Responder & the Office's action enclosed find Farnsworth recent amendment & new claims.

Now I want to file an additional case covering the detector where the sensitive ^{conducting} medium is the gas—same as in the flame case, but its conductivity not to depend upon the heat of combustion—& also where there is no heating at all (or comparatively none).

Fig 1 shows lamp bulb containing 2 filaments, each heated ^{from} by a separate source the conductivity of the gas there between being increased by the heat. A local battery & tel. connects to these 2 filaments.

Fig 2 shows only 1 heated filament ^{recent} (Look out for Fleming's recent pat. in this connection)

N.Y. Dec 21

Dear Woodworth:

You are familiar with my "flame detector" or Responder & the Office's action. Enclosed find Farnsworth recent amendment & new claims.

Now I want to file an additional case covering the detector where the sensitive conductive medium is the gas—same as in the flame case, but its conductivity not to depend on the heat of combustion—& also where there is no heating at all (or comparatively none).

Fig 1 shows lamp bulb containing 2 filaments each heated by from a separate source the conductivity of the gas there between being increased by the heat. A local battery & tel. connects these two filaments.

Fig 2 shows only 1 heated filament (Look out for Fleming's recent pat. in this connection)

(End of Page 1)

(Above) Fig. 17. The first page of this very important handwritten letter from De Forest to his attorney Woodworth dated November 21, 1905, is difficult to read, so it is transcribed in the next figure. (Exhibit A-35, p. 1, from the 1916 trial proceedings, Author's collection)

(Left) Fig. 18. On the first page of the transcribed letter from De Forest to his attorney Woodworth dated November 1, 1905, he requested his attorney to file his audion bulb patent application as soon as possible; the letter also described two of the configurations De Forest asked Woodworth to include in the patent application. (Exhibit A-35 transcribed)

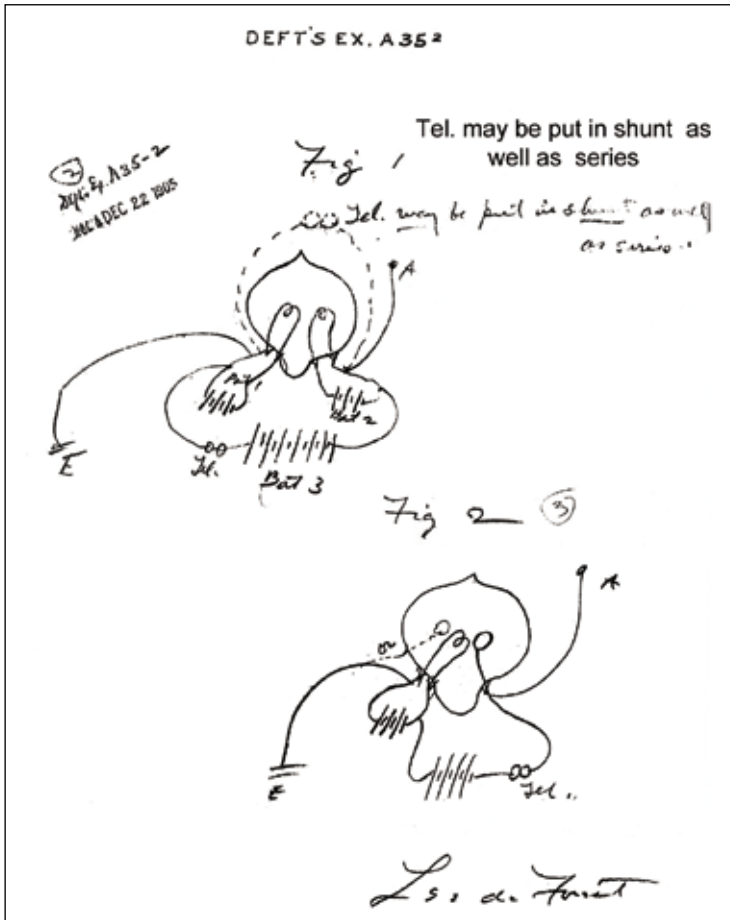


Fig. 19. The second page of De Forest's November 21 letter to his attorney contained these two audion configurations labeled "Fig. 1" and "Fig. 2", both of which De Forest had requested on the first page to be included in his patent application. (Exhibit A-35, p. 2, from the 1916 trial proceedings, Author's collection)

configuration, and De Forest clearly knew that because he wrote this cautionary note in parenthesis to his attorney: "(Look out for Fleming's recent patent in this connection.)"

There were three additional configurations in De Forest's letter to his patent attorney that were to be included in the application, and all five configurations

in the letter appeared in his patent application that was submitted for U.S. Patent 824,637 on January 18, 1906. The configuration labeled Figure 1 in his letter, which had a bulb with two heated filaments, appeared as Figure 1 in his issued patent. The configuration labeled Figure 2 in his letter, which had a bulb configuration identical to Fleming's valve

with one heated filament and one cold plate electrode, appeared as Figure 3 in De Forest's issued patent (see Fig. 20). The

other three configurations in his letter were found to be inoperative later in the trial and are not relevant to the subject.

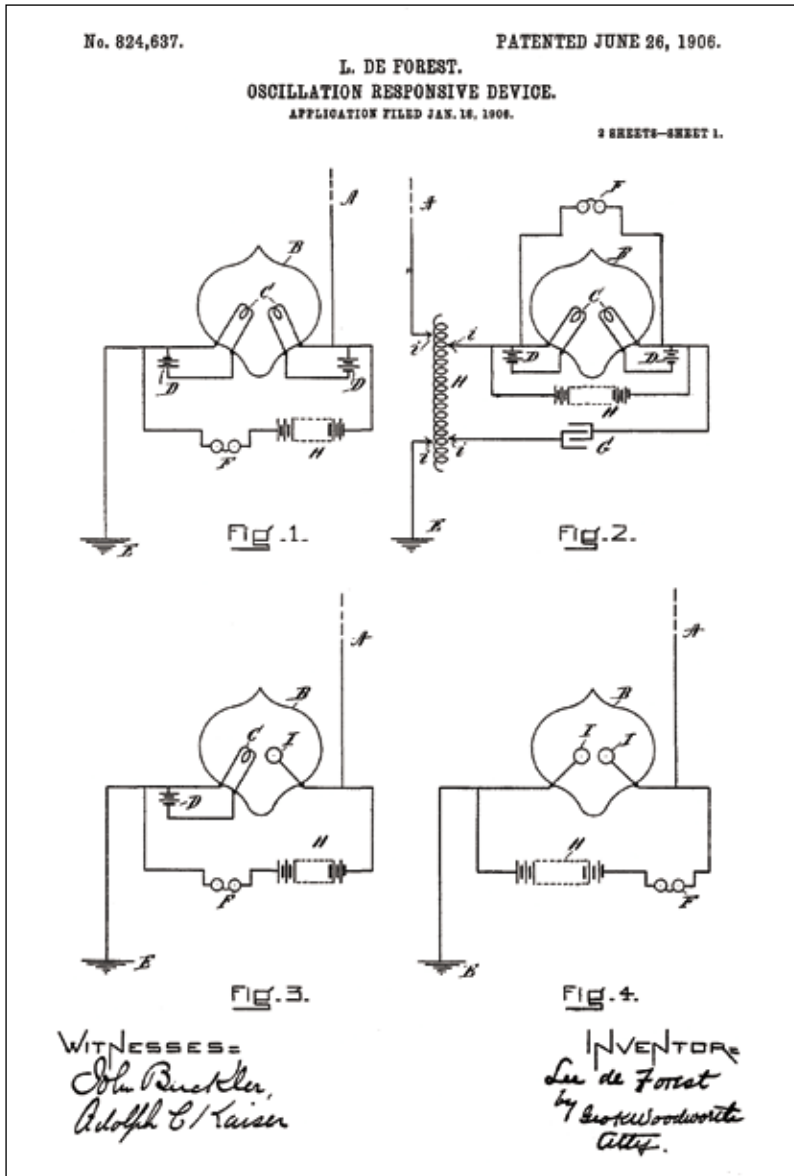


Fig. 20. The two audion configurations on page 2 of De Forest's November 21 letter to his patent attorney appeared as Figure 1 and Figure 3 on the first page of De Forest's first audion patent application. (Page 1, De Forest U.S. Patent 824,637)

The Story of How Lee De Forest Developed the Audion: Part II

De Forest signed the patent application on January 13, 1906, and it was filed on January 18, 1906. The language that appeared in the application was indeed one that described a sensitive gas detector. He did this in an attempt to evade infringing Fleming's patent:

"My invention comprises a receptacle inclosing a sensitive gaseous conducting medium, the conductivity of which does not necessarily depend upon the heat of combustion, although such conductivity may be increased by heating said gaseous medium, and which in some cases requires practically no heating at all."²⁶

"The conductivity of the gaseous medium between the two electrodes I and C is sufficiently increased to render the same sensitive to the electrical oscillations by the radiation of heat from the electrode C."²⁷

Despite the language in this patent, testimony from the employees of the McCandless Company documented the fact that Babcock and De Forest had requested the McCandless Company to fabricate bulbs evacuated to the vacuum level found in ordinary incandescent light bulbs and the carbon filaments were to be heated to incandescent levels also found in these light bulbs. Marconi Company attorneys maintained that De Forest patented a gassy audion bulb and manufactured a Fleming valve.

Assessment

De Forest's letter to his attorney dated December 21, 1905, is the smoking gun

that proves De Forest created the configurations he wanted to have his patent attorney use in his first audion patent application only after he read Fleming's U.S. Patent 803,684, which was published on November 7, 1905. De Forest was utterly unable to demonstrate that he had discovered, defined, or revealed the configuration he identified as Figure 2 in his letter of December 21 before he wrote the letter. The configuration of De Forest's Figure 2 was identical to Fleming's valve configuration, and it was the one he cautioned his attorney with this annotation: "Look out for Fleming's recent patent in this connection." De Forest attempted to distinguish his audion from Fleming's valve by claiming that the audion operation depended on a conducting gas heated by the incandescent electrodes whereas Fleming's valve specified a vacuum. This deception was exposed by McCandless employees who testified that De Forest ordered audions with the highest possible vacuum, which turned out to be the vacuum of a light bulb—the same vacuum used by Fleming.

De Forest's Early Audion Test Results (January 1906)

There was a great deal of interest during the trial in establishing what De Forest had invented and when he had invented it. McCandless employees had testified that De Forest had ordered apparatus on December 4, 1905, and January 6, 1906, but they did not testify about De Forest's test results. The following testimony by De Forest provided some information on this point.

Testimony: De Forest's Early Audion

Test Results

Q34. [Mr. Scull]: *What was the character of the bulbs which he made for you?*

A. [Dr. DeForest]: *The first ones he made were tubular in form, as I recollect, with the platinum filament, and with platinum plates or flat cylinders sealed within the lamp. One of the earliest forms I distinctly remember contained in addition to the filament a puddle of mercury with a wire leading from it, so that the anode in that case was mercury instead of platinum.*

Q35. [Mr. Scull]: *Did you set up and use these lamps made by McCandless as part of a wireless receiving organization and if so, please state the circumstances?*

A. [Dr. DeForest]: *Yes. The first test we made with the first lamp obtained from McCandless was in the little laboratory in the operating station in the pent house [sic] at 42 Broadway in connection with the regular receiving antenna in which we listened for signals from some of our ships or distant shore stations.*

Q36. [Mr. Scull]: *What was the arrangement of circuits in this test to which you have just referred?*

A. [Dr. DeForest]: *I employed two batteries, one to light the filament and the second battery in [a] circuit between the cold plate and the one side of the filament. In series with this second battery was the telephone receiver. I connected the two terminals of the large oscillating circuit either between the plate electrode and one end of the filament electrode, or as a variation of this in series with the*

telephone receiver; that is, placing the inductance of the oscillating transformer in series with the telephone receiver and a condenser in shunt around that inductance.

Q37. [Mr. Scull]: *I show you a copy of patent No. 836,070, being one of the patents here in suit and ask you how the diagrams of the circuit and the construction of the bulb differ, if at all, from the arrangement which you described in the previous question as being used in the test at 42 Broadway?*

A. [Dr. DeForest]: *The circuit arrangement is the same with the exception that we did not ordinarily connect the antenna directly to the plate and earth directly to the filament, but as was usual with all forms of wireless detectors at that date connected the antennae and earth through the primary of an oscillation transformer, the secondary of the transformer connected either across the plate and filament with a stopping condenser in series therewith or, as I have stated in my answer to the previous question, in series with the telephone receiver and the B battery, the battery in that circuit.*

Q38. [Mr. Scull]: *In these tests were wireless telegraph signals received?*

A. [Dr. DeForest]: *Yes.*

Q39. [Mr. Scull]: *From what source did these signals come, if you know?*

A. [Dr. DeForest]: *From stations of the American DeForest Wireless Telegraph Company, Galilee and Atlantic City, and sometimes from ships.*

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Q40. [Mr. Scull]: *Now, with respect to the date, December 1st [sic], 1905, of the letter Defendant's Exhibit A-35, when did these tests to which you have just referred take place?*

A. [Dr. DeForest]: *As near as I can remember they were practically coincident, about the same time. I cannot say exactly the date, but in the fall of 1905.*

Note that the date of "December 1st, 1905," in De Forest's testimony is a typographical error that was not corrected in the document that recorded his testimony. Referring to Fig. 17, the first page of the letter of Exhibit A-35 (identified as A-35-1 in the upper left corner) has the dateline "N.Y. Dec. 21" in the upper right corner—not December 1, 1905. Therefore, when De Forest testified that the tests were "coincident" with the letter, he meant coincident with December 21, not December 1.

Q41. [Mr. Scull]: *I show you a letter dated January 20th and stamped "Received January 22d, '06" and ask you if you recognize that letter?*

A. [Dr. DeForest]: *Yes. That is a letter which I wrote to George K. Woodworth of Boston.*

The letter De Forest sent to his attorney dated January 20, 1906 (see Fig. 21), informed him of the very successful test he had just performed on one of the evacuated bulb configurations that McCandless had fabricated to De Forest's specifications. This letter instructed his attorney to "keep it absolutely dark, rush all those receiver cases

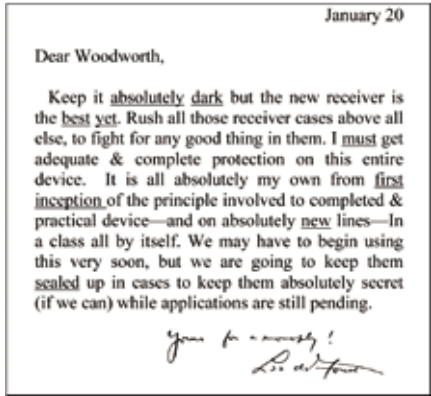


Fig. 21. De Forest sent this letter dated January 20, 1906, to his attorney that informed him of the very successful test he had just performed on one of the evacuated bulb configurations that McCandless had fabricated to De Forest's specifications. De Forest claimed, quite falsely, that the detector was "all absolutely my own from first inception of the principle involved to completed and practical device." (Exhibit A-39, p. 1, from the 1916 trial proceedings, Author's collection)

above all else, and fight for any good thing in them." De Forest also asserted, quite falsely, that the detector was "all absolutely my own from first inception of the principle involved to completed and practical device—and on absolutely new lines—in a class all by itself."

De Forest's attorney continued his interrogation of De Forest by asking him how many wireless receivers he was experimenting with prior to January 20th:

Q42. [Mr. Scull]: *In January, 1906, particularly prior to January 20th, how many wireless receivers were you experimenting with?*

A. [Dr. DeForest]: *Do you mean types?*

Q43. [Mr. Scull]: *How many different types?*

A. [Dr. DeForest]: *At that time we were experimenting with the audion which had not then received that name. We called it hot gas responder, and the electrolytic detector. I do not recall that we were experimenting with any other.*

Q44. [The Court]: *Now, by hot gas responder, what do you mean? What was the construction of that responder?*

A. [Dr. DeForest]: *The construction at that time, your Honor, was the incandescent lamp with carbon filament and an anode of platinum either in the form of a plate, or flat cylinder [see Fig. 22], surrounding, or near to the filament.*

Q51. [Mr. Scull]: *To what extent after these tests at 42 Broadway in the fall of 1905 to which you have just testified, did you use, or did the American DeForest Company use, in its commercial work, this device which you tested then?*

A. [Dr. DeForest]: *We used such a device at 42 Broadway and at Galilee in the early spring of 1906. Later in the spring, or early summer, of that year two sets of this character were sold to the United States Navy and tested out at the Brooklyn Navy Yard [see Fig. 23].*

Q52. [Mr. Scull]: *Were these tests at the Brooklyn Navy Yard conducted before or after the sets were sold to the Navy?*

A. [Dr. DeForest]: *As far as I can remember afterwards the Navy gave me the order for two sets. I remember distinctly testing them out before the experts at the Yard.*



Fig. 22. This early De Forest audion bulb dating to 1906 with a "flat cylinder anode" matches the description of the audion in De Forest's testimony. (Author's collection, Provenance: Tyne/Vanicek collection)

Q53. [Mr. Scull]: *Was this form of detector having an incandescent filament and a cold plate in a bulb adopted generally for use by the American DeForest Company at its commercial stations in 1906?*

A. [Dr. DeForest]: *No, it was not. I was in Europe from the middle of February, 1906, until the first of May during which absence the Company was enjoined, or in fact held in contempt, for its use of the Spade Electrode and it was necessary immediately to shift to another form of detector. I was not apprised of the situation at all and although, when*



Fig. 23. This early De Forest audion dating to 1906 is one of the audions that De Forest testified “were sold to the United States Navy and tested out at the Brooklyn Navy Yard.” (Author’s collection, Provenance: Tyne/Vanicek collection)

I went away, I left this device in what I considered commercial form so that it could be introduced in case the Company was stopped from using the Spade Electrode, the Company decided to use the carborundum detector, quite naturally, because the carborundum detector costs nothing in comparison with my incandescent lamp type detector.

Assessment

The key takeaway from this testimony is that De Forest claimed he had performed

tests circa December 21, 1905, inferring, but not specifically stating that he used that data to develop the configurations he sent the letter to his attorney instructing him to file the patent application on December 21, 1905. However, given his enthusiasm over the tests performed circa January 20, 1906, the tests he performed in 1905 must not have been very successful. If not, then he had no useful data to help him prepare the audion bulb configurations that he included in the letter of December 21, 1905. So, how

and when did De Forest come up with the exact configuration in his letter that appeared in Fleming's patent application? De Forest was able to include Fleming's valve configuration in his December 21 letter because he read Fleming's patent before he wrote the letter. And it is no surprise that it was the Fleming configuration that De Forest documented "to be the best yet" in his letter dated January 20, 1906.

A second takeaway is that De Forest identified two of the earliest successful two-electrode audion bulbs he developed and tested sometime between January 1 and October 20, 1906. These early audions still exist today [see Fig. 22 and Fig. 23] despite the fire that consumed his laboratory in the Parker Building on January 10, 1908, which destroyed all of the early audion tubes and other artifacts stored in his laboratory.

Roy Weagant's Demonstration Tests Before the Court (1916)

Roy Weagant testified that he was Chief Engineer for American Marconi and claimed that he was generally familiar with the design and operation of various types of detectors for wireless telegraphy. Judge Mayer declared that he was an expert witness and permitted him to demonstrate a number of experiments for the court on Fleming's valve detector, De Forest's flame detectors described in his U.S. Patent 979,275, and De Forest's two evacuated audion bulb detectors described in his U.S. Patents 824,637 and 841,386. The Bunsen burner flame detector tests were performed at the Marconi facility near the courthouse

because there was no gas available in the courtroom. The audion bulb tests were performed later in the courtroom.

Because the number of pages used to record Weagant's detailed testimony describing his test configurations and results is quite large, it would be impractical to reproduce his testimony verbatim or even to report all the test results. Therefore, only the most relevant results are summarized here. These results are divided into three groups that correspond to the devices described in the three patents identified above. Many of the results were expressed in terms of the relative responses or sensitivities of two configurations. These results were quantified by a measurement device known as an audibility meter, which is described next as a prelude to presenting the test results.

The Audibility Meter

The audibility meter was an instrument using a pair of headphones as an indicator that was used to quantify the relative magnitude of two audio signals, such as those that might be produced by two different Hertzian radio detectors. The type of audibility meter used by Roy Weagant in court was not specified, but it is likely that he used the one made by the American Marconi Company, which was described by Elmer Bucher in his book, *Practical Wireless Telegraphy*, published in 1917.²⁸ The image of the front panel in Bucher's book is not clear enough to refer to in the explanation of how it worked. Instead, an audibility meter with a very similar front panel made by the General Radio Company circa 1920 will be used for the following explanation.

The Story of How Lee De Forest Developed the Audion: Part II

The audibility meter consists of several graduated shunt resistances that can be selected by a tap switch on the face of the panel (see Fig. 24). The tap switch is varied until the signal reaching the shunted earphones reaches the level of audibility. The tap switch positions are calibrated and labeled on the front panel of the instrument with numbers such that the ratio of any two numbers corresponding to the respective audibility levels of two configurations represents the ratio of the signals in the

two circuits to be compared. For the instrument shown in the figure, the numbers on the tap switch contact studs range between 1.5 and 2000. The audibility meter works only if the weakest signal is strong enough to be heard in the headphones when the tap switch is set for no shunt resistance. For the instrument shown in the figure, the switch position for no shunt resistance is the one that is not numbered.

Bucher provided a simplified schematic diagram to show how the audibility

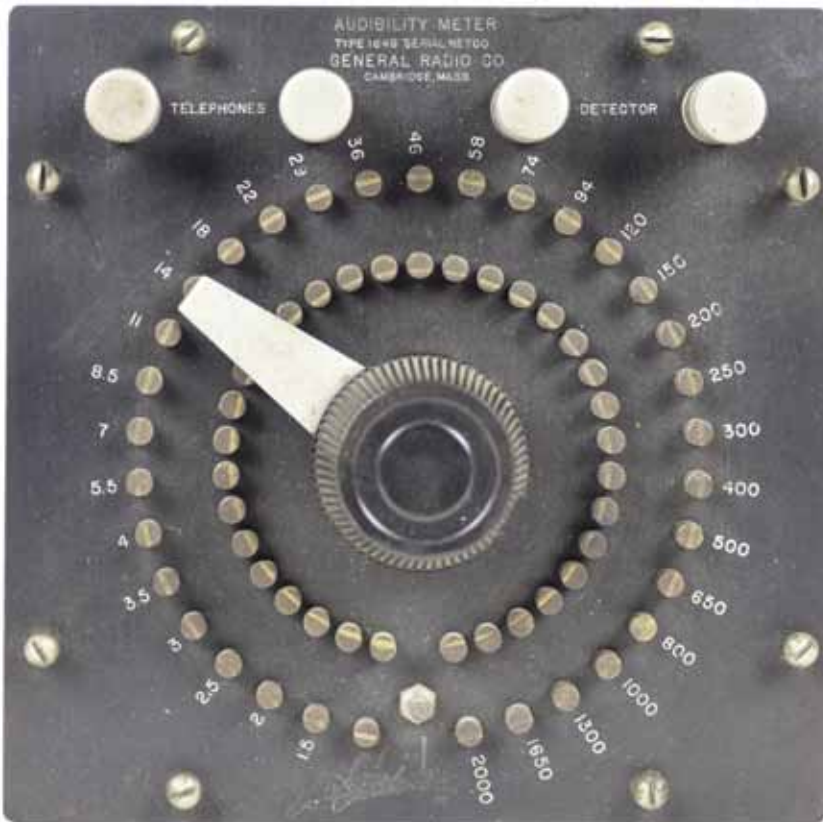


Fig. 24. This example of an audibility meter manufactured by General Radio Company circa 1920 has 33 separate contact positions that can distinguish between 32 audibility levels from 1.5 to 2000. (Author's collection)

meter is connected to the detector circuit (see Fig. 25). The diagram in the book has been slightly modified by converting the inductor into an oscillation transformer to show how the oscillations might be connected to a detector circuit with a stopping capacitor C and a crystal detector requiring no bias voltage. The circuits that Weagant used were often arranged slightly different from this figure; the deviations were dependent on the type of detector and the need to insert a battery in some of the circuits under test.

Bucher stated that he first set the audibility meter switch to the position where there is no shunt and adjusted the

RF signal at the input to the oscillation coil until the signal was at the threshold of audibility. He often used a buzzer circuit for the source of an RF signal. He then adjusted the detector circuit to determine whether the change increased or decreased the audio signal across the stopping capacitor in the detector circuit. If the signal increased, he then quantified the increase by rotating the tap switch to a point where the signal was again at the threshold of audibility. The instrument was calibrated such that the ratio of numbers next to the two studs resulting from the two measurements represented the magnitude of the ratio of voltages across the meter.

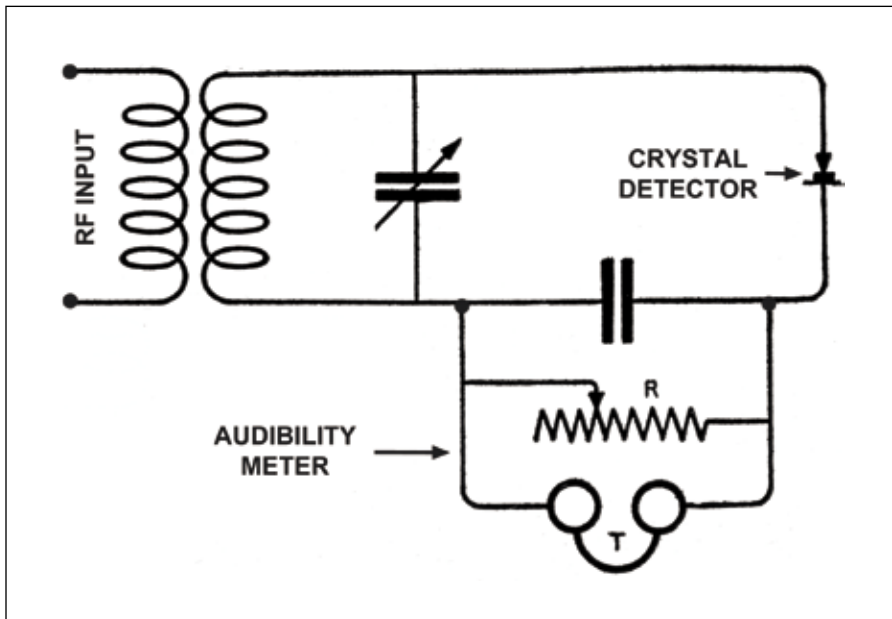


Fig. 25. Elmer Bucher provided a simplified schematic diagram of how an audibility meter is connected to a detector circuit consisting of a crystal detector with no battery; this circuit has been slightly modified by replacing the inductor with an oscillation transformer to show how an RF signal from a buzzer was coupled to the detector circuit. (Bucher, *Practical Radio Measurements*, 1917, p. 217.)

Weagant's Test Results for Flame Detectors of De Forest's U.S. Patent 979,275

Weagant began his testimony by describing the results of his tests on the four flame detectors shown in De Forest's

U.S. Patent 979,275, specifically Figures 1, 3, 4, 5 (see Fig. 26). The remaining two detectors in this patent were arc discharge devices that De Forest had dismissed as being too noisy to use as

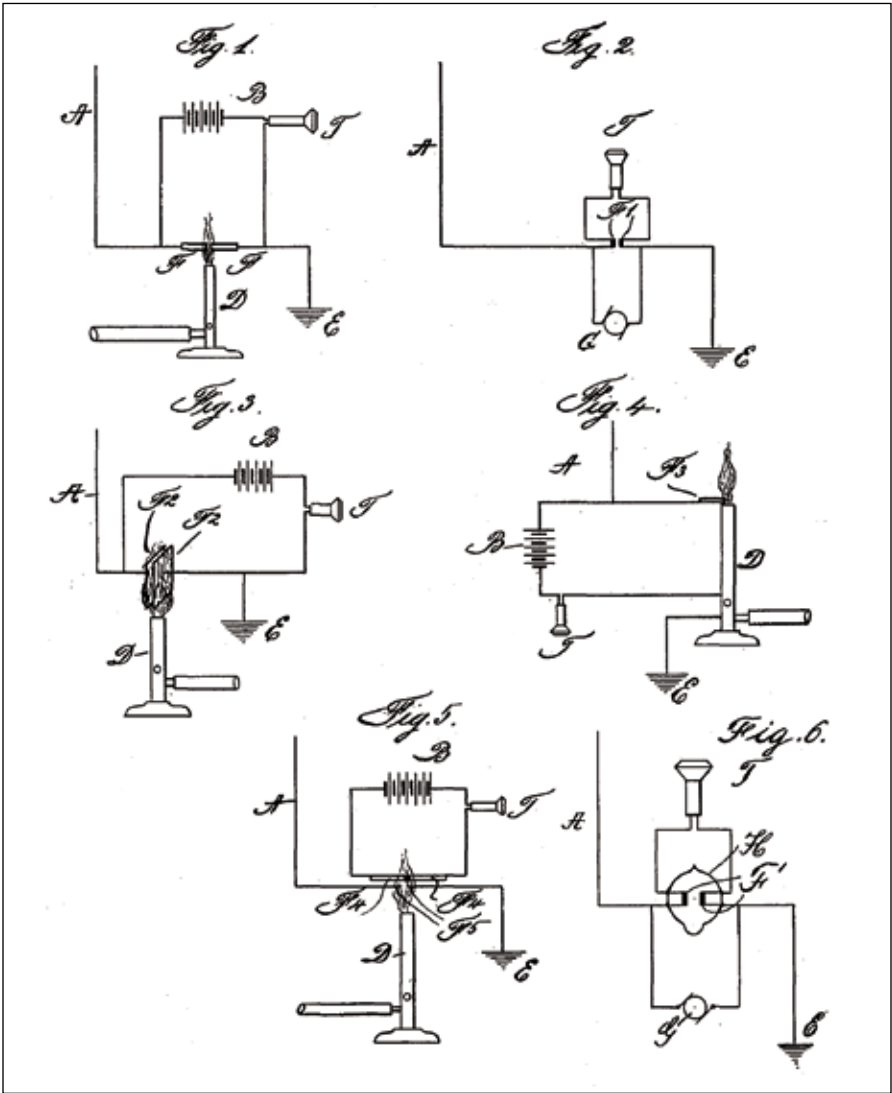


Fig. 26. Weagant performed demonstration tests on the flame configurations here identified as Figures 1, 3, 4, and 5 from De Forest's flame detector patent. (De Forest U.S. Patent 979,275 filed on Feb. 2, 1905)

a detector. The objective of these tests was to quantify the relative sensitivity of De Forest's flame detectors relative to a crystal detector capable of detecting high-frequency oscillations without a battery. The crystal detector chosen for this test was a type P162B No. 121 silicon arsenic combination manufactured by the Wireless Specialty Apparatus Company (WSA), which did not require a battery in the circuit to reach a sensitive operating point. Weagant chose a sensitive crystal detector that functioned without a battery so there would be no doubt that the observed responses from the crystal detector were not a result of amplification by a battery in the circuit.

Weagant reported audibility measurements for a number of parameter variations: the five different flame configurations in the patent: 1) battery voltage, 2) battery polarity, 3) with and without a salt seed that increased sensitivity, 4) electrode size, and 5) electrode composition. Weagant found that the flame configuration of Figure 1 in the patent was as sensitive as or more sensitive than any of the other three flame detectors, so he focused on the results from that configuration in his testimony (see Fig. 27). Incidentally, De Forest identified this configuration in his second published account as being the one in which he claimed he found the audion effect.

Weagant used a buzzer to generate a modulated RF signal for the experiment. This type of buzzer was widely used in receivers of the day using crystal detectors to set the cat's whisker to the most sensitive point on the surface of the crystal. Weagant chose the configuration

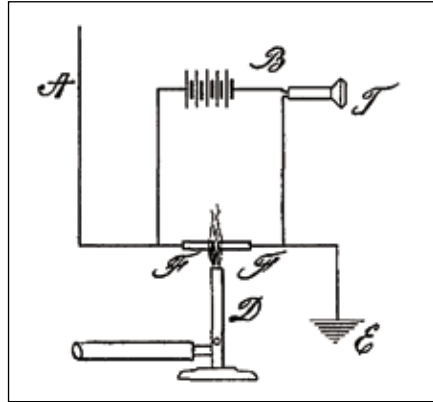


Fig. 27. Weagant found that the flame configuration of Figure 1 in De Forest's U.S. Patent 979,275 was as sensitive or more so than any of his other flame detectors; consequently, he focused on this configuration in his tests and testimony about flame detectors. (Fig. 1, De Forest U.S. Patent 979,275)

of Figure 1 as described in De Forest's patent for the baseline experiment, but with a zero battery voltage and without the addition of any salts—both of which De Forest claimed in the patent would make the detector more sensitive. Weagant arranged the coupling of the buzzer signal to a level that was barely audible in the earphones, which corresponded to the no-shunt-resistance position on the audibility meter (unmarked position on the switch shown in Fig. 24). Most of the sensitivity data he reported for the flame detector variations were referenced to this baseline level.

Battery Voltage: The first experiment was designed to determine the effect of varying the battery voltage of the flame detector. Only a small variation in detector response was noted as the voltage was increased from zero to 450 volts.

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This variation alternated between a slight increase in audibility and a complete lack of audibility. This result is surprising because the electrode configuration in De Forest's flame detector was symmetric, so the addition of a battery would have made it asymmetric and the sensitivity should have increased significantly when the voltage was set at a point where the current became nonlinear due to saturation. It will become evident in due course that the sensitivity of his flame detector was so low that the saturation level was never reached; thus the battery made no difference. The battery polarity was then reversed and there was a definite but not significant difference, which indicated that the flame configuration was not quite symmetric.

Comparison with a Crystal Detector: The next experiment was a comparison of the flame detector with the WSA crystal detector specified above under the same conditions, namely with zero voltage applied to either the flame or crystal detectors. Here is what Weagant reported:

Mr. Weagant: I find that the audibility as measured by the audibility meter is 1 for the flame. I find that the audibility of the crystal as measured with the audibility meter is 500.

Thus, the crystal detector without a battery was 500 times more sensitive than the flame detector. This result was of interest because De Forest claimed that the battery made all the difference in the sensitivity of both his flame and

audion bulb detectors. In fact, it made no difference in the sensitivity of De Forest's flame detector. However, Weagant had not yet reported on the sensitivity of the De Forest flame detector when it was seeded with a halogen salt. This test was the next to come.

Flame Detector Seeded with a Halogen

Salt: Weagant described the test he performed with a halogen salt seeding as follows:

Mr. Weagant: This salt is held with a little loop of asbestos; the loop was pretty thoroughly impregnated with it by dipping it into a thick paste, with salt and water. The first thing that is notable is the characteristic sodium color to the flame, showing that the salt is evaporating and causing some action. I will demonstrate to the Court by moving this in and out of the flame that the sensitiveness of the flame is considerably increased.

The judge listened to the response of the flame detector seeded by salt and reported: *It began to grow faint at 4 and disappeared at 12.* Salting the flame increased the sensitivity by a little more than an order of magnitude, not unlike the results reported by other flame researchers.²⁹ Once again, the applied voltage did not make a significant difference in the sensitivity of the flame detector.

Different Flame Electrode Configurations:

Weagant tested the remaining three flame configurations described in De Forest's flame patent and found

very little difference. Without salt, the response of the flame with the symmetrically placed parallel-plate electrodes was slightly better than the response of the flame with the two symmetrically placed wires. With salt, the maximum response for the parallel plate electrodes was 12, no greater than the response with two wire electrodes. The response of the remaining two configurations with asymmetrically placed electrodes was no greater than the two configurations with symmetrically placed electrodes.

Response of Loose Contacts: Weagant discovered something interesting bearing on the flame detector without salts. Mr. Hoguet introduced this point with a leading question to Mr. Weagant:

Q15. [Mr. Hoguet]: Now, Mr. Weagant, will you please demonstrate what kind of a signal you can get by cutting the detector out of the circuit entirely and using a loose contact, or your fingers, or some similar device for detecting the signals? A. [Mr. Weagant]: If my fingers are in good working order I can probably get as good, or better, a signal than we did with any of these tests with a flame; that is to say, by merely holding my fingers across the two points of connection. For instance in Fig. 1 of patent No. 979,275 [see Fig. 26] if, instead of the flame detector between those two points I put my fingers there, very often I can get as good or better a signal than I can with the flame. ...I will now demonstrate that by simply using my fingers across the two electrodes which were placed in the flame of the test of Fig. 1 of patent 979,275 it

is sufficient to give an indication of at least as good intensity as that obtained with the flame without the use of salts.

The Court: I have listened in and state that Mr. Weagant is correct. The induction was as of as good intensity as that obtained with the flame without the use of salts.

This test has far-reaching implications. It implies that the temperature of the electrodes of the flame detector is of no consequence; instead, it is the high resistance contact between two different materials (electrodes and skin) that matters. It also implies that a flame is superfluous.

Electrode Dimensions and Incandescence:

After Weagant presented the result for the flame configuration shown in Figure 1 of De Forest's U.S. Patent 979,275, he was asked by Greenleaf Whittier Pickard, expert witness for De Forest, why the wire electrodes were so large and whether they exhibited the phenomenon of incandescence:

Mr. Pickard: Why do you use such large copper brass there—to keep them cold, I suppose?

Mr. Weagant: No, those were made, as near as I can judge from the looks of the patent, of substantially the same order. In Fig. 1, the size of the electrodes shown is nearly the diameter of the Bunsen burner. Now, the electrodes which I have here, the rods bear about the same relation to the diameter of the Bunsen Burner as it is shown in Fig. 1.

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Mr. Pickard: Do they keep hot and incandescent?

Mr. Weagant: I do not think they will, normally.

Weagant was justified in selecting large-diameter electrodes because the patent illustrated two electrodes that have much larger diameters than the wires connecting the electrodes to the external circuit, and there were no electrode dimensions specified in the patent. The patent does not even mention incandescence, much less specify a need or desire to have the electrodes heated to incandescence. The patent states that the heat of combustion of gases between the two poles or electrodes is sufficient:

“The separation between them [two poles] may be neutralized sufficiently to enable them to act as a detector of electrical oscillations, if the intervening or surrounding gaseous medium be put into a condition of molecular activity, such for instance as would be caused by heating it in any manner, as by radiation, conduction, or by the combustion of gases in the space that surround the poles.”

Pickard made several more comments about the size of the electrodes, and the court was recessed until the next day. Marconi’s attorney, Mr. Hoguet, began the next day by asking Weagant to elaborate:

Q16. [Mr. Hoguet]: Prior to making the tests with the flame detectors of patent 979,275, for the Court yesterday,

had you made other tests with the same apparatus?

A. [Mr. Weagant]: Yes, I had made a great many tests with the flame detectors.

Q17. [Mr. Hoguet]: State generally what the results obtained were?

A. [Mr. Weagant]: The results obtained were substantially those we obtained yesterday in the demonstration, under our tests.

Judge Mayer then asked Weagant if there was a point to be made on the size of the electrodes:

Q18. [The Court]: We shall probably hear something on the subject later, I gathered from what was indicated yesterday. Is there any point in the matter of those electrodes being not as thin as they might be; I mean, where would that lead you?

A. [Mr. Weagant]: There is some difference due to that. It is not a difference of any consequence, as far as I have observed.

After a few more exchanges, Mr. Hoguet asked Mr. Weagant about the size of the electrodes:

Q21. [Mr. Hoguet]: Would there be any variation in the principle of action, that is what I am getting at?

A. [Mr. Weagant]: That of course I really do not know, that is, just what change in principle might take place with varying construction of the electrodes. I do not really know.

Q22. [Mr. Hoguet]: Please tell us of

your experiments with various other forms of electrodes.

A. [Mr. Weagant]: *The variations which I made during the preliminary tests, from or of the apparatus, and particularly the electrodes which we tested yesterday, were principally in the size and material of these electrodes. I tried several materials, such as copper, brass, silver, and platinum, and with electrodes of the same size and shape. I did not find any difference at all that I recollect, resulting from differences in material. I also tried variations in the size of the electrodes; for instance, in place of the rather thick rods which I used in the test yesterday, I used fine wires. Everything else being the same, the results that I obtained were just the same; I could not detect any difference. Then I took in some instances fine wires and put salts on them, coated them with the salts, and bent them up into little circles so as to hold the salts. These fine wires, of course, got very much hotter than the thick rods, but I did not find any different results from using them.*

Q23. [Mr. Hoguet]: *In order to set this matter at rest, I will ask you, Mr. Weagant, were you not instructed by Mr. Waterman and by me in your tests, preliminary to those made yesterday for the Court, to use every possible means to make a detector, using a Bunsen flame, operate?*

A. [Mr. Weagant]: *Yes, that is correct. I was told to do that, and I did it to the best of my ability. I tried everything that I could think of which would make this flame detector work as well as possible; in fact, I suppose quite a great many days*

were spent in attempts of all kinds to make it work. At the start of the work I could not make it work at all; it was only after a long series of tests that I was able to get anything out of it, and at no time was I able to get results that were materially better than I demonstrated yesterday.

Q24. [Mr. Hoguet]: *Pursuant to those instructions you, as I understand it, used a number of different sizes and kinds of electrodes?*

A. [Mr. Weagant]: *Yes, I did.*

Q25. [Mr. Hoguet]: *And these electrodes ranged in size from what to what?*

A. [Mr. Weagant]: *Why, they ranged in size from a very small wire, perhaps a No. 24 wire, to a large plate. For instance, we made plates for Fig. 3 of patent 979,275, to more or less fill up the whole flame. That was about the largest size.*

Q26. [Mr. Hoguet]: *And some of these electrodes, at least, were in your preliminary tests heated to incandescence?*

A. [Mr. Weagant]: *Oh, yes, very often, the smaller ones.*

The issue of whether or not the electrodes in De Forest's flame detector were incandescent is critical. De Forest did not make a claim in the patent application for his flame detectors that there was a need to heat the electrodes to incandescence. However, he later learned by reading Fleming's papers that at least one incandescent electrode was critical for the operation of his oscillation valve as a detector of Hertzian oscillations, and he

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then falsely claimed that he had specified the electrodes in his early flame detector were heated to incandescence. The degree of incandescence of the electrodes in De Forest's flame detector, if any, is critical to the performance of the flame detector, and Weagant's last statement that he observed the smaller electrodes to be incandescent leaves the issue equivocal. The issue of the incandescence of electrodes in De Forest's flame detectors will be addressed in the next section following the remaining discussion of Weagant's experiments.

Weagant's testimony on De Forest's flame detector experiments ended with a question by Judge Mayer asking Weagant how strong the radio frequency buzzer signal was that he applied to the flame detector circuits in his tests. Judge Mayer's question and Weagant's answer were as follows:

Q28. [The Court]: *Will you please state what the intensity of the signal used in connection with the flame detectors at the tests yesterday was?*

A. [Mr. Weagant]: *This was a very loud signal. As measured on the audibility meter, it ranged from six hundred to a thousand times audibility, when a crystal was used as the detector, without a battery. This, in actual practice, would be an extremely loud signal, such as we would get from a moderate sized transmitting station over a relatively short distance, or a very powerful station over a moderate distance, say a 100 kilowatt transmitter working over a distance of a couple of hundred miles. It was very much stronger than is normally employed*

in the laboratory for tests of detecting elements.

To summarize, Weagant found the largest audibility thresholds for the crystal detector without a battery to be between 600 and 1000, while he found the largest audibility thresholds to be 14 for De Forest's flame detector under optimal conditions of the battery voltage, salt seeding, electrode configuration, and size. Thus, a WSA crystal detector without a battery was almost two orders of magnitude more sensitive than any of the De Forest flame detectors described in his U.S. Patent 979,275 for a flame detector.

Weagant's Test Results for De Forest's First Audion Detectors of U.S. Patent 824,637

Weagant presented the results of his tests on mockups of the first four audion bulb configurations described in De Forest's first audion patent filed on January 18, 1906 (see Fig. 20). He did not test Figure 5 of this patent because the configuration was virtually identical to that of Figure 4, and he did not test configuration Figure 6 because he said it was impossible to fabricate. He claimed that there was no response for the mockup of the configuration of Figure 4, which is no surprise because neither of the electrodes was heated. Finally, he pointed out that the responses of the mockups of Figure 1 and Figure 2 were virtually identical to the response of the configuration of Figure 3. Thus, he presented the results of his tests of the mockups of configuration Figure 3 from De Forest's U.S. Patent 824,637 (see Fig. 28).

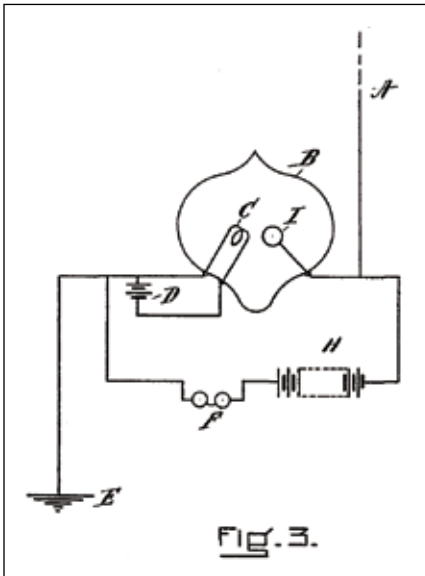


Fig. 28. Weagant found that the response of the evacuated bulb configuration identified as Figure 3 of De Forest's U.S. Patent 824,637 was as good or better as any of the other configurations in this patent, so he presented sensitivity results for this configuration, which happened to be virtually identical to the Fleming valve configuration. (Fig. 3, De Forest U.S. Patent 824,637)

Using this configuration, Weagant varied several parameters until he found the most sensitive response. He varied the pressure in the bulb from atmospheric to that found in an ordinary incandescent lamp of the day with a carbon filament. Then he varied the current in the filament from a level below the onset of incandescence to the level producing the incandescence of an ordinary light bulb, which resulted in a temperature of about the melting point of platinum. Finally, he varied the battery voltage in the plate circuit from 0 to 500 volts. Weagant reported that the configuration did not

detect oscillations when the temperature of the filament was reduced to levels below the temperature of the ordinary incandescent lamp. He also reported that the filament immediately burned out at vacuums much less than that of an incandescent lamp. He concluded that the audion would operate as a detector of radio frequency operations only when the pressure and temperature of the bulb were that of an ordinary light bulb and the battery was adjusted to the optimal voltage, which he did not report.

Weagant did not present a comparison of the sensitivity of the Fleming valve configuration with this audion configuration. Instead, Weagant chose to use one of the audion configurations described in De Forest's second audion patent application for U.S. Patent 841,386 for purposes of comparison. This patent application was filed on August 27, 1906. The results of these tests are described next.

Weagant Compared the Sensitivities of De Forest's Audion and Fleming's Valve as Detectors

Weagant then compared the sensitivity of the Fleming valve detector configuration described in his patent application with De Forest's evacuated bulb audion detector. However, he did not use the earliest audion configuration described in the previous paragraphs. For reasons unknown, Marconi's trial examiner, Mr. Hogan, asked Weagant to make a comparison with the Fleming valve by using the De Forest audion described by Figure 3 of his second audion patent application for U.S. Patent 841,386 dating to August 27, 1906 (see Fig. 29):

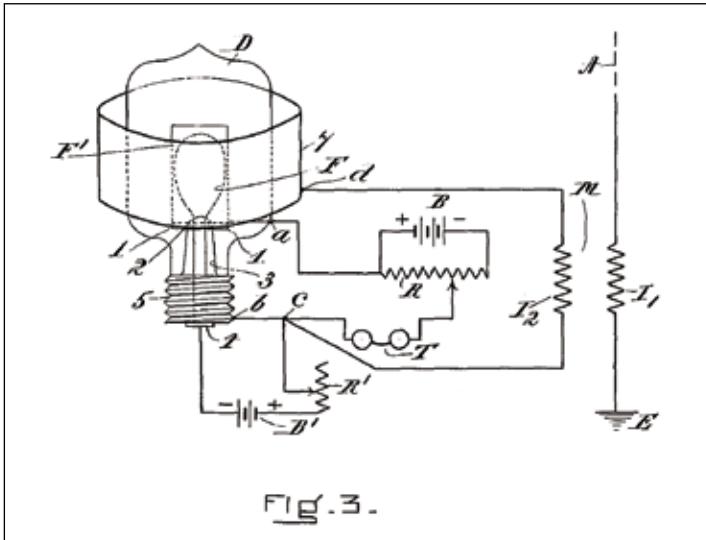


Fig. 29. Weagant found that the sensitivity of this tube with external control tuning was as sensitive as any of De Forest's audion configurations, so he used this configuration to compare with the sensitivity of the Fleming valve. (Fig. 3, De Forest U.S. Patent 841,386)

Q62. [Mr. Hoguet]: *Will you please demonstrate the arrangement of this apparatus to the Court? In this test the witness will demonstrate the arrangement of Fig. 3 of Patent No. 841,386 in comparison with the apparatus of the Fleming valve Patent in suit showing the relative sensitiveness of the two devices.*

It is likely that the device from De Forest's second patent application was selected because De Forest stated in this patent application that he found the response of his audion was more sensitive when the battery of the plate circuit was connected to the positive pole of the filament battery:

"Better results are obtained if the negative pole of the [plate] battery B

be connected to that end of the filament F to which the positive pole of the [filament] battery B' is connected (shown in Figs. 1, 3, and 4 as that end of said filament which is connected to the screw socket)."³⁰

The evacuated bulb in this figure is virtually identical to the bulb configuration in the earlier patent, but the plate circuit is connected to the positive pole of the filament battery, whereas it is connected to the negative pole in the earlier patent application. Regardless of the reason, Weagant's testimony followed Mr. Hoguet's leading question:

A. [Mr. Weagant]: *I have arranged on this board a detector of the type shown in Patent No. 841,386, Fig. 3, and I have*

arranged suitable transfer switches so that this same tube can be connected as shown in this Patent, or can be transferred quickly to the Fleming connection and arrangement shown in Patent No. 803,684.

The demonstration board to which Weagant refers in his opening statement

had suitable transfer switches for rapid comparison of two different detector bulbs (see Fig. 30). The schematic diagram for this board was introduced as Plaintiff's Exhibit 73 (see Fig. 31).

[Mr. Weagant continues]: *I will point out particularly that when the switches are thrown to the position which gives*



Fig. 30. Weagant used this demonstration test board to demonstrate the Fleming valve was as sensitive as the most sensitive De Forest audion configuration shown in the previous figure. (Author's collection, provenance: Edison Museum)

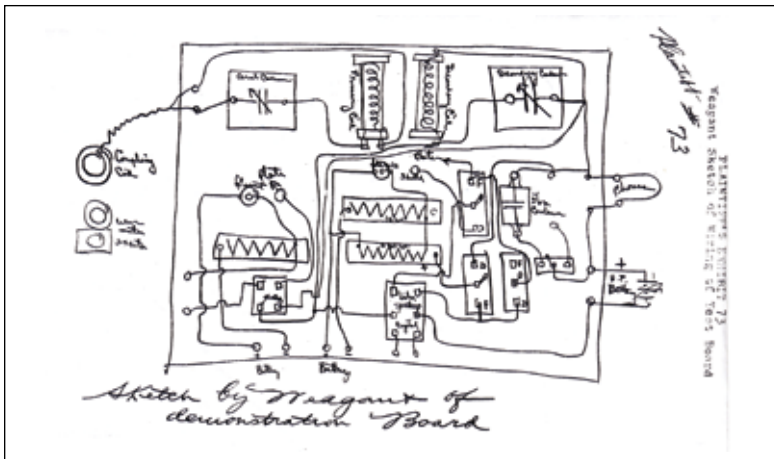


Fig. 31. This schematic diagram of the Weagant demonstration board matches the layout of the board pictured in the previous photograph. (Exhibit 73 from the 1916 trial proceedings, Author's collection)

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this latter connection, the oscillating circuit which connects the filament and the plate of the device [Fleming oscillation valve] is connected to the negative terminal of the filament.

Weagant made a point that the demonstration board was arranged so that the connection of the plate circuit of Fleming's valve was connected to the negative terminal of the filament battery, while the plate circuit of De Forest's audion was connected to the positive terminal of the filament battery.

[Mr. Weagant continues]: *This particular tube is constructed, as nearly as possible, like Fig. 3 and of Patent No. 841,386, and employs a metal filament, tungsten. I am using for excitation the same buzzer apparatus as I used in the tests yesterday with considerably looser coupling, with the signal being of moderate intensity, and this demonstration will show that this same tube when connected as shown in Fig. 3 of Patent No. 841,386 is not substantially different in sensitivity from the same tube connected as shown in Patent No. 803,684 [Fleming valve patent]. In fact, as a rule, the results will be rather better in the latter connection. The results as arranged show that it is a little better connected in the Fleming arrangement.*

Weagant found that the sensitivity threshold of the two detectors was practically identical even though there was a battery in De Forest's plate circuit that was adjusted to 15 volts and there was no battery in Fleming's plate circuit.

This dispelled De Forest's claim that his audion detector was more sensitive than Fleming's valve detector because the battery in the plate circuit acted as an amplifier.

Weagant Tested De Forest's U.S. Patent 841,386 for Tuning "per se"

The U.S. Patent 841,386 that De Forest filed on August 27, 1906, was for an audion that he claimed was self-tuning. By self-tuning he meant that he had developed a detector that was capable of tuning to different frequencies without a tuner circuit, thereby eliminating the need for a separate tuner. His patent stated:

"My invention relates to wireless telegraphy and more particularly to an oscillation-detector which, in addition to performing the usual functions of such detectors, may be used as a tuning device and as a static valve.... In short, said detector *per se* [italics by De Forest] may be made selectively responsive without having recourse to tuned or resonant circuits, so that the use of such circuits may be dispensed with and the detector itself employed to perform the functions heretofore effected by said circuits."

During this lawsuit, this patent became known as the "detector *per se*" patent, and the three devices described in this patent application became known as detectors *per se*. Weagant testified that he was utterly unable to tune any of the three configurations in the patent application by following the instructions for

varying the position of the two hinged wings depicted in Fig. 32 or the position of the outer cylindrical shield relative to the vertical axis depicted in Fig. 29. The configuration of Fig. 32 is the version of the audion that De Forest presented at his lecture to the AIEE in October 1906 when he introduced the audion to the scientific and engineering world.

It was pointed out in Part I that Judge Julius Mayer took note of this demonstration and wrote this statement in his opinion: “The so-called

selective per se patent No. 841,386, is so utterly useless that it might well be declared invalid.” While Judge Mayer did not invalidate De Forest’s selective per se patent, Judge Charles Hough did invalidate this patent during the appeal that De Forest filed after losing the suit in Judge Mayer’s district court:

“The seventh counterclaim patent (841,386) is proved to be inoperative. The patentee declares that by ‘suitably varying the length of interelectrode

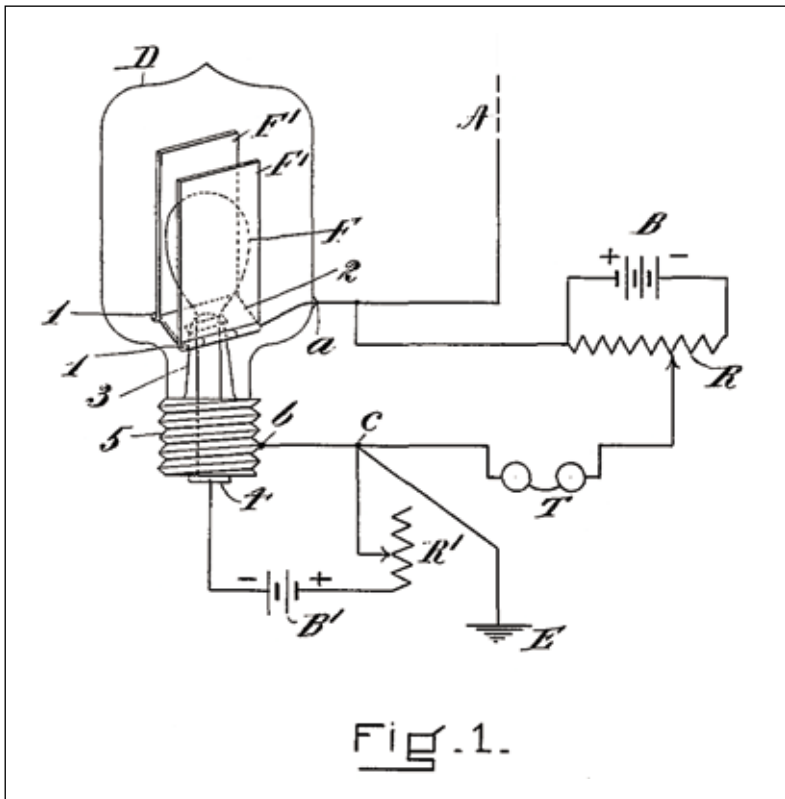


Fig. 32. De Forest claimed that this configuration appearing in his second audion patent was capable of tuning and did not require a separate tuning circuit; it became known as the “detector *per se*” in the 1916 lawsuit. (Fig. 1, De Forest U.S. Patent 841,386 filed on August 27, 1906)

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medium' he can make the audion 'per se selectively responsive.' Assuming this last phrase to mean 'make it work,' defendant at the trial did not do it, and we think refused to try. It follows from the foregoing that we hold patent No. 841,386 void."³¹

Needless to say, De Forest also lost all claims on the appeal.

Incandescence of De Forest's Flame Detector Electrodes

De Forest claimed throughout most of his life that he had discovered the "audion effect" in the flame of a Bunsen burner circa 1903. However, at the time of trial in 1916, it was known that the audion effect was actually rectification caused by nonlinearities in the current that was generated when electrons ejected by thermionic emission from highly incandescent filaments flowed to the plate—with or without a battery in the plate circuit. De Forest had no idea that highly incandescent electrodes were necessary for the audion when he developed his flame detector in 1902–1903, and the conditions for highly incandescent electrodes were not afforded in the flame detectors he described in his U.S. Patent 979,275 for a flame detector.

De Forest's attorneys argued otherwise in the brief they filed on behalf of their client. De Forest had claimed that he used the J. J. Thomson book *Conduction of Electricity Through Gases* as his "bible" during the time he was developing his audions, and the attorneys seized on Thomson's disclosure that electrodes inserted in the flame of Bunsen burner

became incandescent. The attorneys wrote in their brief:

"We have seen *supra* from the prior publications that even in conductivity by flame heating or combustion, it is inevitable that the space-conduction circuit must have its terminals in the flame and that then, as Thomson points out on page 193,³² the terminals thereby become incandescent and so at once have all the electrical phenomena due to incandescent glowing solids.

"In view of the above statement in the 1903 Thomson book, i.e., that the flame conductivity essentially involves conductivity due to incandescent metals, it is not essential to consider at length the enormous temperatures attained in the Bunsen burner flame. It is sufficient to state the fact, as shown at length in the record, that such a flame is used in the arts for the very purpose of obtaining very high temperatures, particularly in cases where the heat is to be localized within a small compass."³³

The claims made in these two paragraphs were problematic for De Forest. Weagant had demonstrated that the audion did not function as a detector of oscillations unless the temperature of the filament was at least as much as the temperature of the filament in an incandescent bulb with a carbon filament. This temperature was known to be about the melting point of platinum, namely 1770 °C. Consequently, the temperatures of the electrodes in De Forest's flame detector were critical to the question of whether or not he could have observed

the “audion effect” in his flame detector, which used electrodes that were inserted in the edges of his Bunsen burner. The attorneys were incorrect in their assertion that it was not essential to consider at length the enormous temperatures attained in the Bunsen burner flame.

It was difficult at that time to accurately measure either the temperature of a selected region of a Bunsen burner flame or the temperature of an electrode inserted in the flame. The usual way of estimating the temperature of a metal electrode inserted into a flame was to observe its color (see Fig. 33).³⁴ The problem with this method is that the color of metal electrodes at temperatures significantly higher than 1300 °C is white with increasing degrees of brightness. However, the degrees of brightness were very subjective.

The real issue is that the electron current emitted from a hot metal surface is not just proportional to temperature; it increases exponentially with temperature. Therefore, it is important to determine more accurately what the temperature is when the color of the incandescence is white. Unfortunately, De Forest had no way of knowing in 1902 that electron emission increased exponentially with temperature. Owen Richardson had not yet published his seminal paper on thermionic emission quantifying the temperature variation of the saturation current from a hot metal filament to a neighboring cylindrical electrode as a function of filament temperature. In this seminal paper published on March 26, 1903,³⁵ he documented by experiment that the measured saturation current for a

Temperature (°C)
550
630
680
740
770
800
850
900
950
1000
1100
1200
1300

Fig. 33. The color of visible light emitted from incandescent metal electrodes depends on the temperature. (Fichier: Example incandescence colors.svg)

platinum filament with an emission surface area of 0.349 cm² increased exponentially by a factor over 4000 when the temperature increased from 1194 °C to 1599 °C (see Table 3). He also demonstrated in this paper that the saturation current for a carbon electrode was two orders of magnitude greater than that for platinum at equal temperatures.

It was shown by Roy Weagant at the trial that the diameter of the electrode in

Table 3. Measured saturation current and current density for platinum versus temperature.

Temperature °C	Total Current × 10 ⁻⁷ amp	Current Density* × 10 ⁻⁷ amp/cm ²
1194	1.04	2.64
1298	13.62	5.34
1419	116	294
1449	578	1470
1490	1370	3477
1533	1730	4391
1599	4180	10609

* Heated wire emission area of 0.394 cm²

his Bunsen burner flame experiment was critical in determining the temperature of the electrode. He testified that he did not observe any visible radiation when the electrode had a diameter of approximately the same size as the barrel of the Bunsen burner—a very large-diameter electrode. He then observed incandescence when he used No. 24 wire with a very small diameter of 0.51 mm as an electrode. However, he was apparently unable to determine the temperature of the No. 24 wire, and that is the problem with using color to determine electrode temperature.

Since De Forest never identified the composition or diameter of the electrodes he inserted into the sides of the flame described in Figure 1 of his flame detector patent, it is difficult to determine whether the electrodes he used in his flame detector were hot enough to generate an adequate thermionic electron emission current. At one point in De Forest's 1906 lecture to the AIEE, he mentioned a flame electrode diameter of

2 mm, which is a more reasonable diameter for an electrode than the one Weagant used in his demonstration experiment as a baseline. Recall that Weagant's electrode had a diameter almost as large as the diameter of the Bunsen burner barrel.

This author performed some tests to reproduce De Forest's flame experiments in an attempt to settle the matter by determining the upper bound to the temperature of any circular wire electrode inserted in the sides of the flame of a Bunsen burner of the type De Forest used. The first experiment consisted of viewing the color of two platinum electrodes inserted in the sides of a flame, one using a No. 12 wire with a diameter of 2 mm, and the other with a No. 26 wire with a diameter of 0.4 mm (see Fig. 34). The larger electrode has a red color indicating the temperature is about 900 °C, far too low to produce the necessary thermionic electron current. However, the smaller electrode is a bright white, which could be any temperature above 1300 °C.



Fig. 34. This demonstration experiment with a 2 mm platinum wire inserted into the side of a Bunsen burner flame on the right and a 0.4 mm platinum wire inserted on the left shows that the temperature of the electrode depends on the diameter of the wire; the smaller diameter wire with a white incandescent glow has a temperature at or above 1300 °C while the larger diameter wire with a dull red glow has a temperature in the range of 800 °C. (Author's experiment and photograph)

The trick is to find the upper bound to the temperature of any electrode of a reasonable size inserted in the flame. This was done by inserting electrodes with a very small diameter using four different metallic elements whose melting temperature varies between that of copper at 1084 °C and platinum at 1770 °C. The first experiment with one small platinum electrode inserted in the side of the flame demonstrated that the Bunsen burner is not capable of melting platinum and therefore the platinum electrode temperature did not exceed 1770 °C. Even when this small-diameter platinum wire was inserted at the hottest part of the flame at the tip of the cone, it did not melt.

The results of inserting four different metal wires with different melting points into the flame of a Bunsen burner at the side of the flame where De Forest inserted his two electrodes and at the tip of the flame where the flame is the hottest are shown in Table 4. Not a single wire listed in the table melted at the point where De Forest inserted his two electrodes in the side of the flame. The conclusion is that the incandescence observed in electrodes inserted into the opposite sides of the flame has a temperature no greater than 930 °C. This temperature is far too low to produce much of a thermionic emission current, and any claim that De Forest observed the audion principle in his flame detectors

Table 4. Melting of fine metal wires placed into the sides and at the tip of the blue cone of a Bunsen burner flame.

Electrode Metal	Melting Point	Thermal Conductivity	Wire Diameter	Melt (Yes/No)	
				Side	Tip
Brass	930 °C	111–120 W/m/K	No. 24	No	Yes
Copper	1084 °C	342–413 W/m/K	No. 24	No	Yes
Nickel	1453 °C	76–106 W/m/K	No. 26	No	No
Platinum	1770 °C	71–82 W/m/K	No. 26	No	No

must be false. The brass and copper wires melted when they were inserted at the tip of the flame but the nickel wire did not. The conclusion is that an electrode inserted at the tip of the flame would not reach a temperature greater than 1435 °C. This temperature is also too low to produce much of a thermionic emission current.

It is interesting to note that the copper wire did not display any incandescence when inserted in the side of the flame but the brass wire did. That result is most likely because the thermal conductivity of copper is three to four times that of brass. The thermal conductivity of a wire is why electrodes of the same metal with a diameter larger than the ones used in this experiment will always have a lower temperature than the wires with smaller diameters. The thermal conductivities of the four different metals, expressed in units of watts per meter per degree Kelvin, are provided to quantify the relative conductivities of the metals.

The takeaway from this discussion is that the onset of incandescence from a blackbody radiator begins at approximately 500 °C with a dull red color and proceeds to a bright white light at about 1300 °C (see Fig. 33). Since the early

thermionic vacuum tubes using elemental metals had to reach a temperature about the melting point of platinum to function (1770 °C), De Forest’s statements that the electrodes of his flame detector and the filaments of his audion bulb were incandescent were irrelevant. Incandescence per se was not sufficient to produce audion action; the temperature had to be near the melting point of platinum, which is far above the threshold temperature for producing incandescence, even bright white incandescence.

De Forest’s Deceptive Audion Detector Demonstration

De Forest claimed to his dying day that his two-electrode audion was much more sensitive than Fleming’s oscillation valve because of the battery in his plate circuit that amplified the signal in his audion, whereas Fleming did not use a B battery in his valve detector:

“The Fleming valve was only a device for rectifying the alternating current generated in a receiving antenna by incoming high-frequency waves. It did not—and could not—do anything to augment the energy of the wireless signals it received. It made therefore a very weak detector.”³⁶

De Forest made this claim despite the demonstration that Weagant made showing that the two devices were equally sensitive when using a battery with the audion and no B battery with the valve. Weagant also demonstrated that the Fleming valve without a battery had a sensitivity that exceeded one of the best crystal detectors, also without a battery, made by the Wireless Specialty Company. Many historians believe that De Forest never understood how the vacuum tube worked. Indeed, De Forest did not know how the audion worked circa 1906–1907, and he readily admitted it in his October 1906 lecture to the AIEE. However, I believe that De Forest did understand how both the two- and three-electrode audions worked after he began to test them. I also believe he developed a deceptive and audacious audion demonstration test configuration in late 1906 or 1907 to demonstrate his claim to all comers that the audion with a B battery was much more sensitive than the Fleming valve without a B battery. This test would have been very convincing to scientists and radio engineers of the day, all of whom had just been introduced to his two-electrode audion for the first time in the course of his lecture to the AIEE on October 26, 1906.

Recall from Part I of this article that De Forest filed his first audion patent with the plate circuit battery of his detector connected to the negative terminal of his filament battery. Also, recall that De Forest found that his audion was more sensitive when the plate circuit battery was connected to the positive terminal of his filament battery. He

documented this finding in his U.S. Patent 841,386 for his second audion invention filed on August 27, 1906:

“It is preferable that the positive pole of the [plate circuit] battery B should be connected to the [filament] electrode F’, and better results are obtained if the negative pole of the [plate circuit] battery B be connected to that end of the filament F to which the positive pole of the [filament] battery B’ is connected, (shown in Figs. 1, 3, and 4 as that end of said filament which is connected to the screw-socket.)”³⁷

In De Forest’s 1906 lecture to the AIEE, he correctly stated he connected the plate circuit of his audion to the positive pole of this filament battery, but he erroneously stated that Fleming had also connected his plate circuit to the positive pole of the filament battery:

“Fleming points out that when the cold plate of the Elster-Geitel tube is connected to the *positive end of the filament* [emphasis added], and the two put in a high-frequency oscillation circuit, only the positive half of the oscillation can pass from the plate to the filament across the gas. He uses this principle to rectify the Hertzian oscillations, and applies the unidirectional currents of the oscillations themselves to operate a sensitive galvanometer, or direct current instrument, for quantitative measurements over very short distances.”³⁸

As late as 1913, De Forest repeated the claim that Fleming connected the

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plate circuit of his valve to the positive pole of the filament battery.³⁹ Oddly, Fleming never refuted De Forest's claims on this point. By claiming that both he and Fleming connected the plate circuit of their respective thermionic detectors to the positive pole of the filament battery, De Forest was well positioned to create his deceptive demonstration.

The basic circuit he would have used in his demonstration is the one he published in his 1920 lecture to the Franklin Institute (see Fig. 35), which shows a connection of the plate circuit to the positive pole of the filament battery. In this case, De Forest indicated the positive pole of his batteries with a short line, so it is evident the plate circuit is connected to the positive pole of the filament battery. He would have added an induction coil like the one in Fleming's valve patent to couple the radio frequency signals into the detector circuit. Recall from Part I that the I-V characteristic of a two-electrode detector bulb depends on the polarity of the filament battery

to which the plate circuit is connected (see Fig. 36). Because the plate circuit is connected to the positive pole of the battery, the characteristic curve for both the audion and valve would be the one labeled "positive connection." Here is how the demonstrations would have taken place.

Phase 1: Test of the Fleming valve without a battery

- Set the plate battery voltage to zero.
- Insert a Fleming valve or mockup thereof into the test socket.
- Increase the RF signal until a tone is heard in the earphones, which will occur when the RF signal is approximately equal to the filament battery voltage of about 4 volts for the Fleming valve.

Phase 2: Test of the De Forest audion with a battery

- Set the plate battery voltage to the saturation current between 16 and 20 volts.

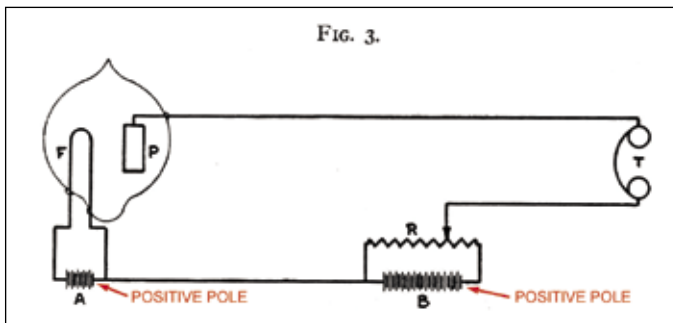


Fig. 35. De Forest's audion configuration from his Franklin Institute lecture in 1920 shows: 1) the positive pole of the B battery (indicated by a short line) is connected to the plate, and 2) the plate circuit is connected to the positive pole of the filament battery (also indicated by a short line). (Fig. 3, *J. Franklin Institute*, 1920, p. 5)

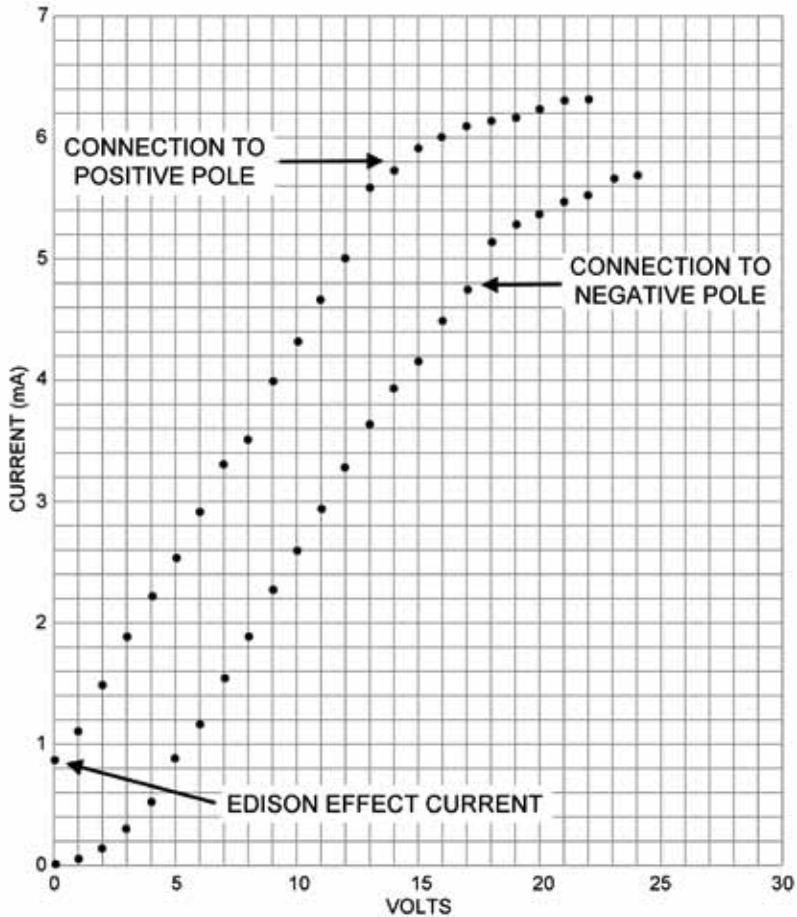


Fig. 36. Two characteristic curves measured for an early two-electrode vacuum tube with a filament voltage of 5 volts; the upper curve shows the plate current for a battery in the plate circuit connected to the positive pole of the filament battery and the lower curve shows the current for the battery in the plate circuit connected to the negative pole. (Author's experimental results)

- Insert a De Forest audion into the test socket.
- Increase the RF signal until a tone is heard, which will occur at an RF voltage level of a few tenths of a volt.
- Adjust the plate battery voltage level to find the point of maximum sensitivity.

These test results are explained as follows. Rectification of high-frequency oscillations is greatest at the point or points on the I-V characteristic curve where there is a knee in the curve, which is the point or points at which the magnitude of the second derivative of the I-V curve has a local maximum. Referring

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to Fig. 36, when the plate circuit is connected to the positive pole of the filament battery, there is only one place where there is a knee, namely at the point near saturation. Thus, the De Forest audion displayed a large response when the voltage was set between 16 and 20 volts. However, because Fleming did not have a battery in the plate circuit, the operating point for a connection to the positive pole of the filament battery would have been in a region of the I-V curve that is linear where no rectification is possible (i.e. for zero applied voltage). Of course, Fleming did not actually connect his plate circuit to the positive pole of the filament battery—and that was the great deception in De Forest’s demonstration. In that case, no significant rectification occurred until the applied oscillations were large enough so the negative swing of the applied oscillations reached the nonlinear portion of the I-V curve, which is not shown in Fig. 36. This happened when the amplitude of the oscillations was a significant fraction of the filament battery voltage, namely a few volts.

The conclusion that would have been drawn from this demonstration is that the De Forest audion in his demonstration responded to oscillations down to a few tenths of a volt while the Fleming valve in his demonstration responded to oscillations when the amplitude reached several volts. Thus, the De Forest audion would have appeared to be about 10 times more sensitive than the Fleming valve. Since a rectifier is a square-law device, meaning the output voltage is proportional to the input power, there would have been a difference of 100 in range of

a radiotelegraph system because the radiated power density from a radio transmitter falls off as the square of range.

In reality, Fleming attached his plate circuit to the negative pole of his filament battery, and the I-V characteristic curve for his valve would have been the one labeled “negative pole” in Fig. 36. Recall that Weagant made a point of stating in his 1916 trial demonstration that he made a connection to the positive pole of the filament battery for the De Forest audion response and a connection to the negative pole of the filament battery for the Fleming valve response. In the case of the Fleming valve, there was a knee in the curve very near the point where the plate voltage was zero with respect to the negative pole of the filament battery. At that point, the Fleming valve acted as a valve because the negative swing of the oscillations produced virtually no current while the positive swing registered a relatively significant current. De Forest’s audion never acted as a valve because, at the operating point of his device, the current generated was the response for a positive swing *minus* the response for the following negative swing (see Fig. 37). In Fleming’s case, there was no response for the negative swing, so the response was the full response produced by the positive swing.

Fleming’s Later Improvement to his External Valve Circuit

By 1909, Fleming had discovered that there were minor differences in the I-V characteristics of his valves that affected their sensitivity as a detector of Hertzian waves. These variations were due to

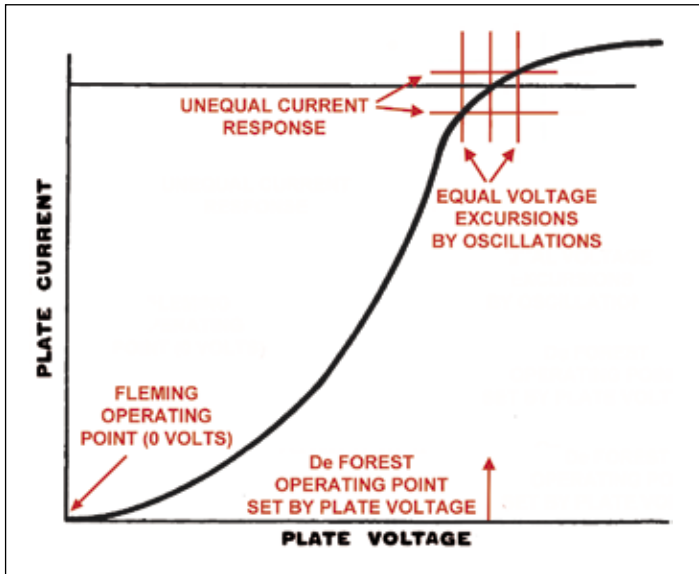


Fig. 37. De Forest's operating point was at the upper knee of the I-V curve located at the saturation point where rectification was the small current produced by the difference between large positive and negative current swings that were nearly equal. Fleming's operating point was at the lower knee of the curve at zero volts where rectification was just the small current for the positive swing because the negative swing was zero (i.e., a unipolar valve effect). (Author's configuration)

a hand-made manufacturing procedure that almost ensured there would be slight variations. While Fleming did not reveal the I-V characteristics that were responsible for the variations, these variations were quantified by the Marconi Company in preparation for the 1916 trial. The expert witness that Marconi hired for the trial, Frank L. Waterman, prepared hand-drawn I-V characteristics for four tubes that were representative of a number of different tubes made for the various demonstrations that were presented during the trial (see Fig. 38).

Each of these four curves had a slightly different I-V characteristic at the operating point with zero bias voltage.

The curve for Tube 1 is an ideal tube in which there is no response for the negative portion of an applied oscillation voltage and a rapid increase in the positive response as the positive portion of the oscillation increases. The discontinuity in the second derivative of current with respect to voltage is not realistic. Tube 3 is more representative of a Fleming valve, and the operating point for this tube without a plate battery is right at the sweet spot where the tube is most sensitive. Tubes 2 and 4 have I-V characteristics that are linear when the operating point without a battery is at zero volts, so they are both less sensitive than Tube 3. However, they could be

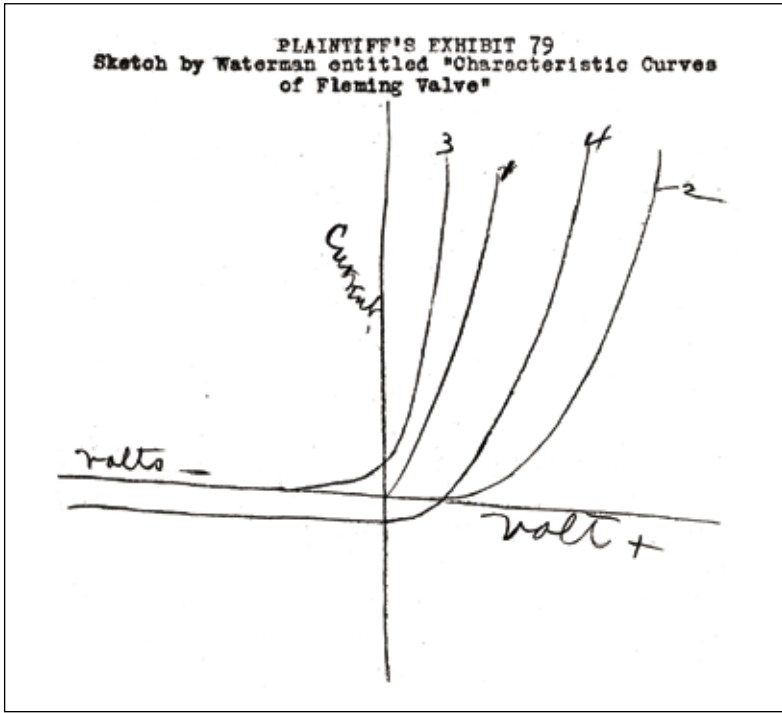


Fig. 38. Expert witness Frank L. Waterman for the Marconi Company sketched these four I-V characteristic curves that he claimed were representative of a number of different Fleming valves made for the various demonstrations at the 1916 trial; these curves represented the variability of the I-V characteristics among Fleming valves. (Exhibit 79 from the 1916 trial proceedings, Author's collection)

made as sensitive as Tube 3 if the bias point were changed by only a few tenths of a volt to a few volts.

In 1900, Fleming published a method of adjusting the bias voltage by the amount required to operate his valve at its most sensitive operating point without adding a B battery to the plate circuit (see Fig. 39).⁴⁰ The circuit shown in this figure used a rheostat across the filament battery to adjust the operating point to a bias point anywhere between zero and a maximum equal to the voltage of the filament battery, typically four volts. This external

circuit was different from De Forest's external circuit and had the distinct advantage of not requiring an additional B battery. Fleming's two-electrode valve with this circuit was used in the commercial systems of American and British Marconi from 1910 to the beginning of WWI (see Fig. 40)—despite claims by De Forest's attorneys in the 1916 litigation that Fleming's valve was useless for wireless telegraphy. A simplified circuit diagram showing this later biasing circuit was prepared by the Marconi Company on May 2, 1913 (see Fig. 41).

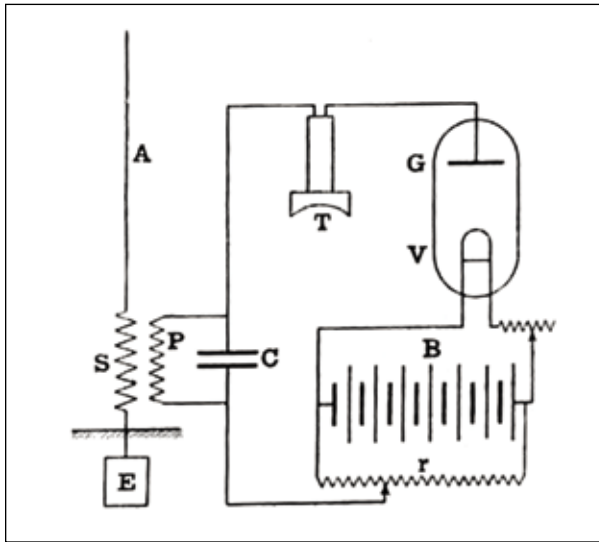


Fig. 39. In 1900, Fleming published a method of adjusting the bias voltage by the amount required to operate his valve at its most sensitive operating point without adding a B battery to the plate circuit. (Fig. 21, *The Electrician*, Vol. 63, July 9, 1909, p. 505)



Fig. 40. Fleming's two-electrode valve with this circuit was used in the commercial systems of the American and British Marconi Companies from 1910 to the beginning of WWI. (Courtesy of Rich Groshong)

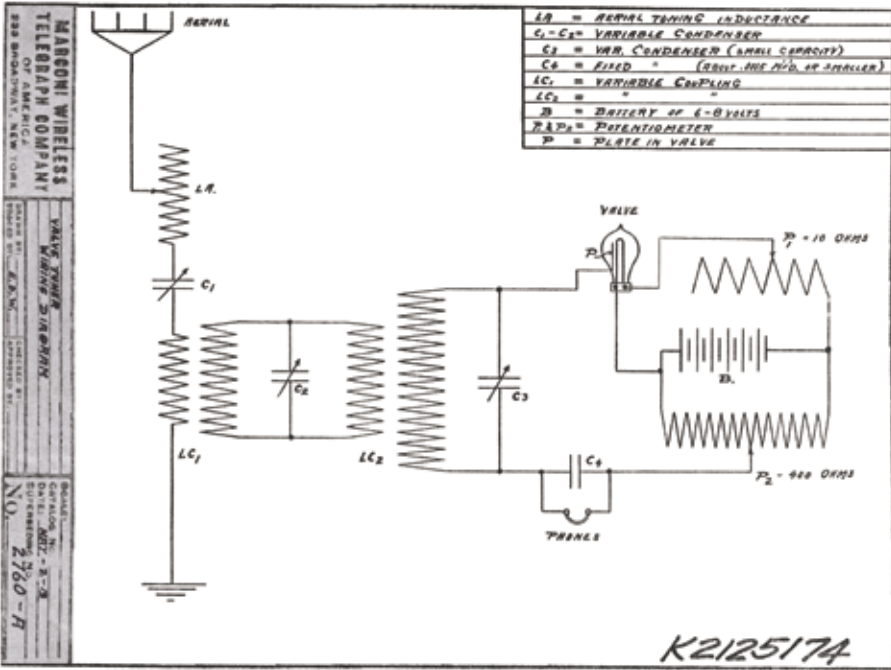


Fig. 41. The Marconi Company prepared this simplified circuit diagram of the Marconi valve tuner dated May 2, 1913, which shows the tuning circuit that appears in the previous figure. (Courtesy of Rich Groshong)

Comparisons of De Forest's Three Accounts

The purpose of this section is to compare and contrast the two main accounts of how De Forest developed the two-electrode audion that he published during his lifetime with the account from the 1916 trial. Based on the sworn testimony and exhibits from the 1916 trial presented here, both of De Forest's published lecture accounts, which were described in Part I, are fatally flawed. De Forest claimed in the documentation of his 1906 lecture that he discovered the audion based on an experiment with an evacuated bulb configuration published by Elster and

Geitel in 1882. De Forest claimed that the configuration was virtually identical to the Edison effect bulb and that he had the idea of inserting a B battery in the plate circuit, which distinguished it from the Fleming valve by making it a very sensitive detector.

De Forest persisted with this story in the literature until American Marconi filed a lawsuit against Lee De Forest and the De Forest Company in October 1914 claiming that De Forest's two- and three-electrode audion infringed Fleming's valve patent with a priority date of his UK patent, November 16, 1904. From that point onward, there was no mention of the Elster and Geitel experiment. Instead,

De Forest's trial attorneys claimed that De Forest had found the audion principle in his flame detector circa 1903 and that there was a continuous line of development from that point to the time he filed his first audion bulb patent application on January 18, 1906.

While De Forest maintained the "continuous-line-of-development" account for the rest of his life, his sworn testimony did not support it. De Forest dropped a bombshell when he admitted under oath that he had filed a patent application for his flame detectors on September 12, 1902, and had allowed it to be abandoned by the U.S. Patent Office for lack of prosecution a year later on September 29, 1903. He also admitted that the patent application he filed in 1902 was identical to the patent application he refiled on Feb. 2, 1905. Finally, he admitted that he had done no further work on a two-electrode flame or evacuated bulb detector between the time he filed the first patent application in 1902 and refiled it in 1905. De Forest attempted to ameliorate the admission of abandonment by claiming that it was due to the negligence of his then-patent attorney, Mr. Reynolds. However, there was overwhelming evidence that he abandoned the application because he admitted that by September 1903 he knew the flame detectors were impractical. Also, De Forest's testimony in another lawsuit made it clear that by September 1903 he had already decided to use Fessenden's Wollaston wire electrolytic detector in the De Forest wireless system in the coming year—even though it was covered by a Fessenden patent.

The Wollaston wire detector was hugely successful in the De Forest system in 1904, and De Forest had no need or interest in developing another type of detector until he lost his patent infringement suit with Fessenden on October 16, 1905, which Fessenden had filed in 1904. De Forest testified that he began to look for a new detector technology only after he was enjoined from using the electrolytic detector. That new detector technology turned out to be an evacuated audion bulb detector with an incandescent filament that was virtually identical to the Fleming valve bulb.

It stretches credulity to believe De Forest when he claimed under oath that he developed his audion bulb detector in the five weeks between October 16, 1905, the date he began his search for a new technology, and November 24, 1905, the date he disclosed his new audion invention in great detail at a meeting with the patent attorney he had just engaged. The detail that he gave to his attorney, such as the requirement for a battery voltage of specifically 10 to 25 volts, would have required experimental test results, which neither he nor his company could make. De Forest stated that he was well aware of Fleming's publications during the period 1903 to 1905. He testified that he had read Fleming's issued patent before giving instructions to his attorney to file his first audion patent.

Judge Mayer found that there was nothing in the U.S. Patent 979,275 for a Bunsen burner flame invention that related its function to the operation of De Forest's audion bulb, which a McCandless employee testified was

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evacuated to the vacuum of an ordinary incandescent lamp with a carbon filament heated to the incandescence of an ordinary incandescent lamp. The judge wrote, “Nowhere [in De Forest’s U.S. Patent 979,275] is there a suggestion of an incandescent electrode.” It should also be noted that nowhere in this flame patent was there a suggestion of an evacuated enclosure. Yet, both a high level of vacuum and incandescence were necessary for the audion to function. The judge found that Fleming’s U.S. Patent 803,684 for his valve invention was valid and did not infringe any of De Forest’s patents but that De Forest’s two-electrode and three-electrode audion bulb detectors infringed claims 1 and 37 of Fleming’s U.S. patent.

De Forest’s attorneys repeated a claim in the 1916 trial that De Forest made in 1907—namely that his B battery in the plate circuit made all the difference in the world between the audion and the Fleming valve because the battery acted as a relay, or amplifier, which made the audion much more sensitive than the valve. Judge Mayer rejected this claim on two grounds. First, the judge pointed out that De Forest’s audion patents were on the bulb, not the external circuit. There is no mention of an external circuit in De Forest’s independent claim.⁴¹ Fleming’s patent is also on the bulb in which there were two electrodes connected by an unspecified external circuit.⁴² Consequently, either inventor could use any external circuit of their choice as long as it was not covered by another patent. Some historians believe that an inventor is restricted to whatever

circuits are shown in a patent, which is not true.

Second, the judge noted that a battery had been used in the external circuit of previous oscillation detectors to set the operating point, specifically identifying the coherer and the electrolytic detector. The judge also noted that Marconi had used a battery in his coherer detector circuit and stated that he was entitled to use it with any other detector including his valve detector. In the end, the judge ruled that De Forest could not distinguish his audion bulb invention from that of the Fleming valve by claiming it was due to the B battery in the external circuit.

The account that De Forest gave in his lecture to the Franklin Institute in 1920 was significantly different from both the 1906 AIEE lecture and the 1916 trial account. De Forest persisted with the continuous-line-of-development theme by dividing the advances into three periods: 1) a successful flame detector demonstration in 1903, 2) the development of a plan to insert two electrodes consisting of carbon filaments into an evacuated bulb heated by external batteries in 1904, and 3) the discovery that the ordinary small incandescent lamp of that epoch supplied admirably the conditions he required for an oscillation detector in 1905. However, the achievements and dates are inconsistent with the testimony and exhibits presented at the 1916 trial. De Forest abandoned the flame detector in September 1903 in favor of Fessenden’s Wollaston wire electrolytic detector in the De Forest system. De Forest disclosed for the first time his plan for inserting two filaments

into an evacuated bulb on November 24, 1905, not 1904. De Forest did not find that the ordinary small incandescent lamp of that epoch supplied admirably the conditions he needed. Fleming is the one who discovered in 1904 that the Edison effect bulb met all the requirements for an oscillation detector, and he published that fact in early 1905. De Forest admitted in the trial that he did not even begin to develop his audion until October 16, 1905, and he claimed he read Fleming's issued patent before he settled on the configuration he claimed he used in 1905.

Summary and Conclusions

This paper began as a study of the five large volumes I received from Jerry Vanicek many years ago that documented the 1916 trial testimony and exhibits associated with the litigation initiated by American Marconi. The Company alleged that the De Forest two- and three-electrode audions infringed the U.S. Fleming patent then owned by American Marconi. It took years to study the thousands of pages and to assemble the testimony and exhibits that tell the story presented here in Part II.

One of the more interesting facts about the trial documents is that most of the testimony, exhibits, and arguments were focused on how De Forest invented his two-electrode audion rather than the three-electrode audion. After all, the three-electrode audion was the main target of the Marconi Company when they initially brought their suit against the De Forest Company and Lee De Forest in 1914. American Marconi's approach at

trial was to show that the Fleming two-electrode patent was valid and was also infringed by De Forest's two-electrode evacuated bulb audions. The attorneys then argued that De Forest's three-electrode audion was a mere extension of De Forest's infringing two-electrode audion, which he had discovered by merely inserting a third electrode into his infringing two-electrode audion. The record will indeed show that is exactly what transpired in the trial.

Virtually all of the accounts that De Forest gave about how he invented the three-electrode audion began with a summary of how he alone invented his two-electrode audion. De Forest did this because he wanted everyone to believe that the Fleming valve was in no way related to his audions. De Forest was aware that Marconi and some historians claimed that he (De Forest) had just added a third electrode to the Fleming valve. De Forest responded to this claim by pointing out that the Fleming valve did not have a B battery in the plate circuit, and without the use of the B battery, the Fleming valve with an added grid "would be nothing but a rectifier with one too many electrodes."⁴³ While De Forest could not deny that Fleming had invented a detector, he chose to distance his audion from Fleming's valve by going to great lengths in his accounts to deny Fleming any credit for his (De Forest's) audion invention.

Something very sinister emerged from these trial documents. It became apparent that De Forest had willfully altered in significant ways the published documents of other scientists including

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Elster and Geitel and John A. Fleming. De Forest also appropriated the issued patents of other inventors, in particular Reginald Fessenden, presuming that he could have them invalidated if he was challenged. He also made many false and conflicting claims about the history of his invention whenever it pleased him. Later in life, De Forest went so far as to claim that he had never heard of the Fleming valve during the time he was developing his two-electrode audion. However, based on De Forest's trial testimony, this claim proved to be absurd.

Six of De Forest's most egregious deceptions are summarized below. These deceptions were all intended to convince De Forest's peers that he alone had invented his two- and three-electrode audions without any contributions from Fleming.

1. De Forest willfully altered the Elster and Geitel Configuration: De Forest's account in his 1906 lecture to the AIEE that he invented the audion based on a configuration that Elster and Geitel published in 1882 was his most egregious deception. This is because he willfully altered the published Elster and Geitel configuration in three different places to make it appear that their configuration was the same as the Edison effect bulb, which De Forest claimed in his 1906 AIEE lecture he used as the basis for his audion bulb configuration (see Fig. 42). In fact, the Elster and Geitel configuration (see Fig. 42(a)) had nothing in common with an Edison effect bulb configuration.⁴⁴ He compounded the deception by maintaining the date of their publication was 1882, long after Fleming informed him in writing that

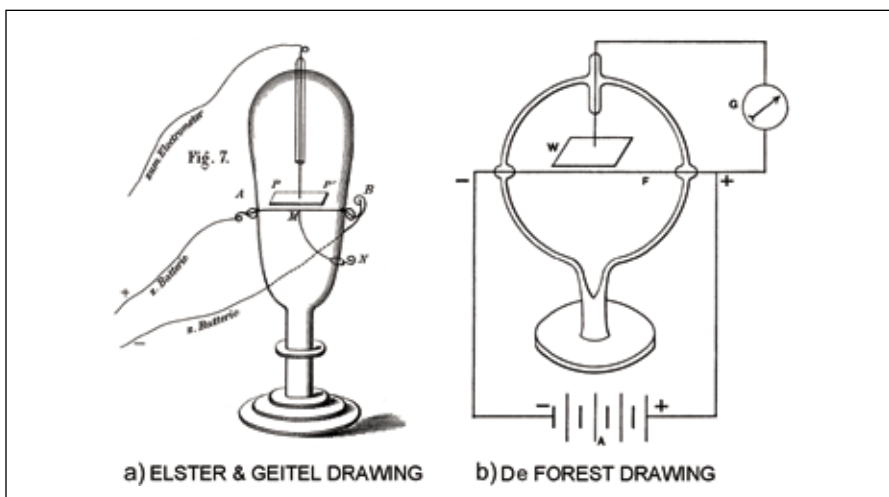


Fig. 42. De Forest altered the image Elster and Geitel published in their paper in 1887 by replacing the high-impedance electrometer (left) with a low-impedance galvanometer (right), thereby placing a positive bias voltage on the plate to make it look like an Edison effect bulb instead of allowing the plate to float, which was a critical feature of the Elster and Geitel experiment. (Plate I, Fig. 7, *Ann. der Physik*, Vol. 31, 1887)

the date of the publication at issue was 1887. It is hard to imagine anything more deceitful and audacious than an inventor who surreptitiously alters critical features in the published circuit diagram of other scientists to reach a false conclusion for the benefit of the errant inventor.

2. De Forest claimed his two-electrode audion was an amplifier: De Forest claimed all his life that his two-electrode audion was an amplifier: “The Audion, even in its crude form, was intrinsically very much more than a simple rectifier of high-frequency current. The addition of the plate battery made a great difference in the intensity of signals receiver [sic], for I was employing high-frequency, not to actuate a telephone diaphragm, as the Fleming valve had done, but to control very much larger quantities of energy from the local battery.”⁴⁵ Some historians have seized on this often-repeated statement to assert that De Forest never knew how the audion worked. He certainly did not know how it worked in 1906 when he first made this claim, but he was not stupid and he must have known how it worked by the early 1920s, a time when many competent authors had published books explaining how the two-electrode thermionic vacuum tube detected oscillations by rectification at the knees of the I-V curve.⁴⁶

3. De Forest claimed a “continuous line of development” beginning in 1902 and ending with the audion in late 1905: To maintain his claim that there was a continuous line of development of his two-electrode

audion, De Forest had to fill the gap in activity between September 1902, when he filed his first flame detector patent application, and October 1905, when he said he began the development of his new evacuated bulb detector. In 1950, he claimed: “In 1904, I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector in place of the open flame.... Two filaments heated from separate batteries would give the desired effect equally as well.”⁴⁷ De Forest was unable to produce any evidence in the 1916 trial that he outlined such a plan in 1904. The first time De Forest revealed this two-electrode configuration was on November 24, 1905, when he met with his attorney (see Fig. 10). This configuration is identical to the configuration Fleming published in the April 1905 issue of *Technics* magazine (see Fig. 11).

4. De Forest read Fleming’s valve patent before he prepared his 1906 audion patent application: De Forest admitted under oath that he had seen Fleming’s patent before he documented the configurations he used in his audion patent application. He testified that he documented these configurations in a letter to his patent attorney dated December 21, 1905. This letter contained a configuration that was identical to Fleming’s valve configuration, which was annotated with the following cautionary statement: “Look out for Fleming’s recent patent in this connection” (see Fig. 17). The following testimony says it all:

XQ107. [The Court]: How did you

come across the Fleming patent? Do you remember how that came to your attention?

A. No. I do not remember distinctly, your Honor. I think Babcock showed it to me.

RDQ113. [Mr. Scull]: When Babcock showed you this Fleming patent now in suit in the fall of 1905 do you recall that he made any remark, and if so, what was it?

A. [Dr. DeForest]: My recollection is that when he showed it to me he said that Fleming was working along the same lines and it behooved me to get busy and file my patent applications.

Nothing could be more damning than his own testimony.

5. De Forest claimed that he and he alone invented the two-electrode audion:

De Forest wrote a letter to his patent attorney dated January 20, 1906, in which he claimed that he alone invented his two-electrode audion: “Keep it absolutely dark but the new receiver is the best yet. Rush all those receiver cases above all else, to fight for any good thing in them. I must get adequate & complete protection on this entire device. It is all absolutely my own from first inception of the principle involved to completed & practical device—and on absolutely new lines—In a class all by itself.” Not only did De Forest claim that the audion was his own discovery, but he also claimed that he had never heard of the Fleming valve during the time he was developing his audion. Read on.

6. De Forest claimed that he had never heard of the Fleming valve while he was developing the audion: “During the time I was developing the two-electrode detector I had never heard of the Fleming valve, and was therefore surprised when I later learned that my invention was being confused with it.”⁴⁸ This was the most incredible statement of all. De Forest had prepared a patent application for the unrelated topic of static suppression on an antenna before he met with his patent attorney on November 24, 1905. In that patent application, De Forest used the Fleming valve to remove charge from an antenna, and he gave a detailed account in the patent of how the valve worked. In this patent application, he also referenced Fleming’s seminal document published in the March 1905 issue of the *Proceedings of the Royal Society of London* that described his valve and how it operated in detail. Thus, De Forest’s own patent application belies this claim.

Before I conclude, I would like to refer to a paragraph that Hugh Aitken wrote on behalf of De Forest in his book, *The Continuous Wave*, which was cited in the introduction of Part I of this paper where he wrote this favorable comment:

“Lee de Forest himself provided a highly plausible and internally consistent account of how the invention was made. In fact, every time he told the story it became more ‘rational,’ in the sense that each step in the process of invention was presented as following reasonably and naturally from what had gone before.”

It is clear from the 1916 trial testimony and exhibits that Aitken was seriously mistaken. Lee De Forest provided a highly implausible and internally inconsistent account of how his invention was made. Every time he recounted the story it became more irrational and more difficult to believe. Worse yet, the De Forest testimony summarized in the six vignettes above shows that De Forest had serious character flaws. The fact that he surreptitiously altered Elster and Geitel's published schematic diagram at three critical points to make their test configuration look like an Edison bulb indicates that he was willing to act dishonestly and unfairly to gain an advantage, indeed, one trait of a narcissist. De Forest's willingness to alter documents provides an additional reason for believing Armstrong's assertion that De Forest had altered his notes to make it appear as though he had developed the regenerative circuit independently.⁴⁹

De Forest claimed that he and he alone invented his audion and knew nothing about Fleming's valve the whole time he developed his audion. His claim that he was surprised when he later learned that his invention was being confused with it is astonishing. This demonstrated his grandiosity, another trait of a narcissist. His propensity to claim that his two-electrode audion was an amplifier when he and the whole world knew that it was not true demonstrated his need to double down on his pronouncements rather than admitting he was in error.

In closing, I conclude that Lee De Forest had no regard for the truth and made up whatever story suited him at the

moment. He expected others to believe whatever he said or wrote. He is not to be believed unless there is documentary evidence to support his assertions, and there is virtually no documentary evidence to support De Forest's multiple published versions of how he invented his two-electrode audion. It is clear from the trial testimony and exhibits that De Forest copied Fleming's valve after reading his U.S. valve patent issued on November 7, 1905. There is no way he could have developed his two-electrode invention within the five-week period between October 16, 1905, and November 24, 1905, as he claimed under oath in the 1916 trial. It is quite clear that Lee De Forest was a master of deception throughout his lifetime.

Addendum: Elster and Geitel's Actual Configuration for Demonstrating Unipolar Responses

Recall from Part I that De Forest originally claimed he based his two-electrode audion on the Elster and Geitel configuration, which consisted of a wire and a flat plate enclosed in a vacuum tube (see Fig. 42(a)). He claimed that the Elster and Geitel configuration appeared in their paper published in volume 16 of *Annalen Der Physik* in 1882, but Fleming corrected him by pointing out that the Elster and Geitel paper containing this figure was published in volume 31 in 1887. Fleming documented this fact in his 1919 book, which also illustrated a version of this figure, although it was missing the ground wire MN.⁵⁰

Many years later, Gerald Tyne published a copy of this image in Part 3 of

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“The Saga of the Vacuum Tube” that appeared in the *Radio News* issue of May 1943. Using this configuration, Tyne described the Elster and Geitel experiment as the one they used to show unilateral conductivity—also known by Elster and Geitel as “unipolar” conductivity. In the following quotation from Tyne’s paper, his Figure 9, which appeared in parentheses in his article, has been replaced by [Fig. 42(a)], which is the figure number used here to identify this configuration.

“The fifth article which appeared in 1887 is entitled ‘On the Electrification of Gases by Glowing Bodies.’ In this article experiments were described involving the use of a glass bulb, which could be exhausted or filled with various gases. Across the inside of this bulb was stretched a platinum wire which could be heated electrically [see Fig. 42(a)]. Opposite this wire, and very close to it, was placed a platinum plate suspended by a leading-out wire. The vacuum was described as ‘the best possible—such as Crookes used in his famous experiments.’ The result of these experiments of Elster and Geitel indicated that ‘*Electrified Particles*’ were thrown off from the glowing wire uniformly in every direction and that the conductivity was unilateral.”⁵¹

Tyne was not the only one who believed that Elster and Geitel had used the evacuated bulb configuration in Fig. 42(a) to demonstrate unilateral conductivity. In 1969, George Shiers published an article in *Scientific American*

featuring Fleming’s first electron tube in which he illustrated the timeline for various discoveries by Hittorf, Goldstein, and Elster and Geitel that had preceded Fleming. The timeline was illustrated with an outline of the configurations they used for various discoveries (see Fig. 43). The bulb shown for Elster and Geitel has the same outline as the one shown in Fig. 42(a), and the text stated that the discovery was unilateral conductivity:

“Julius Elster and Hans Geitel, later well known for their studies of photoconductivity, reported a series of experiments on electrical conductivity in flame and heated gases from 1882 to 1889. One of their devices had a straight platinum filament and flat platinum plate in a highly evacuated bulb. After trying a variety of electrode arrangements they concluded that charged particles were being dispersed uniformly from the glowing electrode; they also reported that conductivity was in one direction.”⁵²

Despite claims by De Forest, Fleming, Tyne, and Shiers to the contrary, the configuration illustrated in Fig. 42(a) of this paper is not the configuration Elster and Geitel used to demonstrate unipolar (i.e., unilateral) response. I became suspicious of this after reading J. J. Thomson’s lengthy description of Elster and Geitel’s experiment using this configuration, which Thomson reproduced in his book.⁵³ The words unipolar or unilateral are not mentioned anywhere in the paragraphs explaining this configuration. To

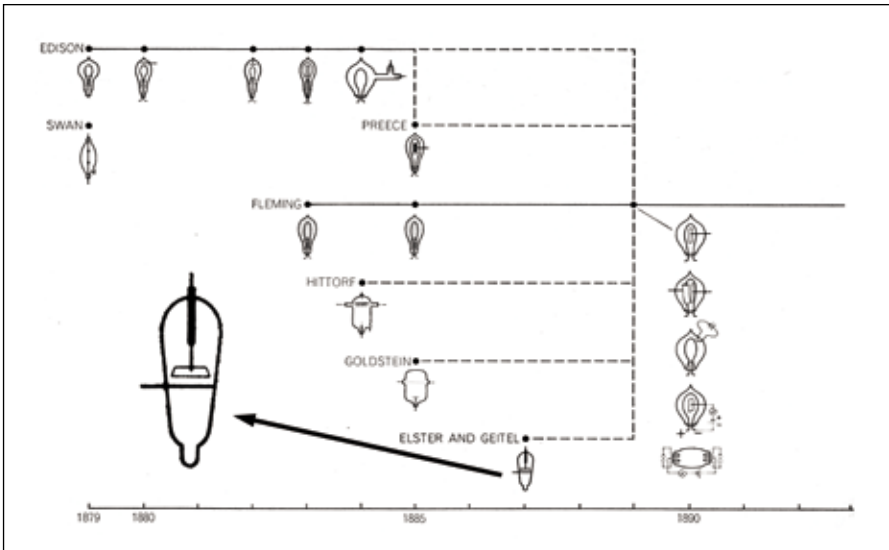


Fig. 43. Historian George Shiers also believed that the configuration reproduced in Figure 43 was the one Elster and Geitel used to demonstrate a unipolar response of a vacuum tube. (Shiers, *Scientific American*, Vol. 220, Mar. 1969, p. 106)

sort this out, I commissioned a translation of the entire article and focused on Section 4 of this paper entitled “Unipolar Behavior of Glowing Wires.” The translation of this section is reproduced in the sidebar. Note that there is only one figure called out from this section entitled “Unipolar Behavior of Glowing Wires,” and it is the configuration that Elster and Geitel actually used for demonstrating the unipolar response of glowing wires. It is designated as “Fig. 6” in the Elster and Geitel paper, which is reproduced here as Fig. 44. In this sidebar, Elster and Geitel clearly stated that Fig. 6 was used to “show unipolar behavior in a very striking manner. This configuration consisted of one glowing wire (designated

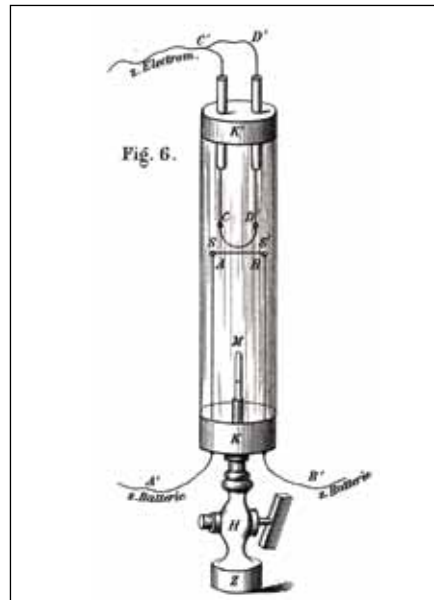


Fig. 44. This configuration, identified as Fig. 6 in Elster and Geitel’s 1887 paper, is the one that they actually claimed to have used to demonstrate unipolar response, which was produced by a single heated wire AB that opposed a single cold wire CD. (Plate I, Fig. 6, *Ann. der Physik*, Vol. 31, 1887)

§4. Unipolar Behavior of Glowing Wires

In an earlier communication,¹ we have found the behavior, which is given by Guthrie, that it is easier to discharge a negative electrical body than a positive electrical body, and the electrification of the air caused by the glowing body, i.e. by the occurrence of the electromotive force that has so far been designated with e . We were in agreement with Herwig², who had previously expressed a similar view in Wiedemann's *Annalen der Physik*, but applied to the inside of the flame.

Glowing wires heated by electricity now show unipolar behavior in a very striking manner. If the wire CD (Fig. 6) attached above the incandescent wire is given a positive charge by temporarily connecting it with the positive pole of a Zamboni column [battery] consisting of pairs of 100 plates, the scale immediately disappears from the field of view of the telescope, and the needle is constantly deflected by a very significant angle. If, on the other hand, when CD is connected to the negative pole of the column, the needle also experiences a deflection, but immediately returns to its former setting. According to our theory, the more energetic the electrification of the surrounding air caused by the glowing body, the sharper this unipolar behavior must be pronounced. In the large number of experiments in which we tested this electric behavior of gliding bodies, it became quite evident that the unipolar conduction becomes all the more prominent the greater the values resulting from the deflections $e + x$ and $e - x$ were for e . In the trials of 9 December, Tab. IV, both $e + x$ and $e - x$ were both positive. Here, the wire CD was almost not discharged at all with a stronger positive charge, and immediately with a negative one.

¹J. Elster and H. Geitel, *Wied. Ann.*, Vol. 26, p.1, 1885.

²Herwig, *Wied. Ann.*, Vol. 1, p. 517, 1877.

AB) heated by a battery and one isolated cold wire (designated CD). Also note that the other Elster and Geitel figure reproduced here as Fig. 42(a) was given the designation "Fig. 7," and it was not referenced in this section. In this experiment, one side of the quadrant electrometer is connected to both ends of the cold isolated wire and it is connected in

turn to the positive pole of the battery used to heat the lower wire and then the negative pole. The responses of the electrometer were observed by a telescope that viewed the position of the mirror produced by connections of one lead of the electrometer to the positive pole of the battery and then to the negative pole. The electrometer cannot measure

the current directly, but according to Thomson, who invented the quadrant electrometer, the current can be “measured by the deflection produced in the electrometer in a given time.”⁵⁴

Another way to understand this is to remember that the voltage produced by the capacitive coupling of a voltage from one wire to another wire is given by $V = C^{-1} \times \int i dt$ where C is the capacitance between the wires and i is the displacement current that induces a voltage on the isolated wire. According to the text in the sidebar, when one terminal of the electrometer was connected to the positive pole of the battery, the scale immediately disappeared from the field of view of the telescope and the needle was constantly deflected by a very significant angle. This would infer that there was a strong current that flowed. However, when the electrometer was connected to the negative pole of the battery, there was a slight movement, and then the scale returned to the null position. This would infer that the net current flow was zero. Therefore, Elster and Geitel concluded that the current flow was strongly dependent on the polarity of the connection—which is the essence of a unipolar response. One thing is clear—they did not directly measure the steady-state current flow itself, nor did they measure the unipolar response of the steady-state current flow between a plate and a wire, such as Edison observed four years before in 1883.

Endnotes

1. Lee De Forest, “The Audion, A New Receiver for Wireless Telegraphy,” *Proc. AIEE*, Vol. 25, Oct. 26, 1906, pp. 719–747.
2. Lee De Forest, “The Audion, Its Action and Some Recent Applications,” *J. of the Franklin Inst.*, Vol. 190, July 1920, pp. 1–38.
3. Lee De Forest, *Father of Radio* (Wilcox & Follett, Chicago, 1950).
4. Eric P. Wenaas, “The Story of How Lee De Forest Developed the Audion, Part 1. The History of De Forest’s Published Accounts,” *AWA Review*, Vol. 36, 2023, pp. 69–133.
5. *Redirect* refers to the examination of one’s own witness after the witness has been cross-examined by the opposing attorney.
6. Lee De Forest, *Father of Radio*, (Wilcox & Follett Co., Chicago, 1950) p. 478.
7. *Ibid.*, p. 479.
8. *Ibid.*, p. 479.
9. *Ibid.*, p. 212.
10. *United States Circuit Court, Southern District of New York, NESCO vs. De Forest Wireless Telegraph Company, et al., Defendants*, (Brief for Complainant on Final Hearing, no publisher or date) p. 4.
11. “The De Forest Wireless Telegraph System,” *Electrician* (London), Vol. 52, Dec. 4, 1903, p. 240–242.
12. *NESCO vs. De Forest Wireless*, Testimony of Melvin G. Lathrop, Marconi v. De Forest litigation, 1916, pp. 284–285.
13. De Forest, *Father of Radio*, p. 212.
14. *Ibid.*, p. 486.
15. *Ibid.*, pp. 478–9.
16. National Electric S. Co. v. De Forest Wireless Tel. Co. et al., *Federal Reporter*, Vol. 140, Oct 16, 1905, pp. 449–455; (A.K.A. 140 Fed 449).
17. “National Electric Signaling Co. v. De Forest Wireless Telegraph Co., et al.,” *Federal Reporter*, Vol. 140, Oct. 16, 1905, pp. 449–455; (A.K.A. 140 Fed 449).
18. J. A. Fleming, “On the Electric Conductivity of a Vacuum,” *Technics*, Vol. 3, Apr. 1905, p. 317.
19. J. A. Fleming, “Problems in the Physics of an Electric Lamp,” *Notices of the Proceedings of the Royal Inst. of Great Brit.*, Vol. 13, Feb. 14, 1890, p. 45.
20. De Forest, *Father of Radio*, p. 478.
21. Fleming, *Proc. Royal Institution*, p. 45.
22. “Marconi Wireless Telegraph Co. of America v. De Forest Radio Telephone & Telegraph Co.,”

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- Federal Reporter*, Vol. 236, Sept. 20, 1916, p. 949.
23. De Forest, "Static Valve for Wireless Telegraphy," U.S. Patent 823,402, filed on Dec. 9, 1905, p. 3, line. 7.
24. J. A. Fleming, "On the Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve," *Proc. Royal Society of London*, Vol. 74, Jan. 24, 1905, pp. 476–487; read on Feb. 9, 1905.
25. Gerald Tyne, "The Saga of the Vacuum Tube," *Radio News*, Vol. 29, May 1943, pp. 27–28.
26. De Forest U.S. Patent 824,637, p. 1, lines 24–31.
27. *Ibid.*, p. 2, lines 66–70.
28. Elmer E. Bucher, *Practical Radio Measurements*, (Wireless Press, New York, 1917) p. 217.
29. Arthur Smithells, H. M. Dawson, and H. A. Wilson, "Electrical Conductivity and Luminosity of Flames Containing Vaporized Salts," *Phil. Trans. Royal Soc.*, Vol. 193, 1899, p. 92.
30. De Forest, U.S. Patent 841,386, filed Aug. 27, 1906, p. 2, lines 73–81.
31. "Marconi Wireless Telegraph Co. of America v. De Forest Radio Telephone & Telegraph Co.," *Federal Reporter*, Vol. 243, May 18, 1917, p. 566; (A.K.A. 243 F 560).
32. J. J. Thomson, *Conduction of Electricity Through Gases*, (Cambridge University Press, London, 1903) p. 193: "It has been known for more than a century that gases from flames are conductors of electricity.... The conditions in these experiments were generally such that the interpretation of the results obtained is always exceedingly difficult and often ambiguous: the reason for this is very obvious—to investigate the electrical conditions of the flame wires are generally introduced, these become incandescent and so at once add to the electrical phenomena in the flame the very complicated effects we have been discussing in the last chapter."
33. *Brief for De Forest Radio Telephone Company as Plaintiff Under Suit, et al.*, pp. 24–25.
34. See: Example incandescence colors (temperature range 550–1300 C).svg
35. O. W. Richardson, "The Electrical Conductivity Imparted to a Vacuum by Hot Conductors," *Phil. Trans. Royal Soc., London*, Vol. 201, 1903, pp. 497–549.
36. See for example De Forest, *Father of Radio*, 1950, p. 213.
37. Lee De Forest, U.S. Patent 841,386, filed Aug. 27, 1906; issued Jan. 15, 1907, p. 2, lines 73–81.
38. De Forest AIEEE lecture, p. 732.
39. De Forest, "The Audion-Detector and Amplifier," *The Electrician*, Vol. 72, Nov. 21, 1913, p. 286.
40. J. A. Fleming, "Researches in Radiotelegraphy," *The Electrician*, Vol. 63, July 9, 1909, pp. 504–506.
41. According to the U.S. Patent Office, the first claim in any patent must be an independent claim that completely describes what is to be covered by the patent. The first claim in De Forest's U.S. first audion bulb patent 824,637 reads: "I claim- 1. An oscillation-responsive device comprising a receptacle inclosing a sensitive gaseous conducting medium containing a halogen salt."
42. What I claim is- 1. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for heating one of the conductors, and a circuit outside the vessel connecting the two conductors.
43. Lee De Forest, "How the Audion Was Invented," *Radio-Craft*, Vol. 18, Jan. 1947, p. 19.
44. See Part I for a detailed discussion on this issue.
45. De Forest, *Father of Radio*, pp. 213–4.
46. In particular, see John Scott-Taggart, *Thermionic Tubes in Radio Telegraphy and Telephony*, (Wireless Press, London, 1921) p. 42.
47. De Forest, *Father of Radio*, p. 478.
48. *Ibid.*, p. 213
49. <https://blogs.cul.columbia.edu/armstrongpapers/2010/04/19/the-regenerative-circuit/>.
50. J. A. Fleming, *The Thermionic Valve and its Developments in Radio Telegraphy and Radio Telephony*, (The Wireless Press, London, 1919) p. 20.
51. Tyne, pp. 27–28.
52. George Shiers, "The First Electron Tube," *Scientific American*, Vol. 220, Mar. 1969, p. 106.
53. Thomson, 1903, pp. 156–159.
54. *Ibid.*, p. 182.

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Eric Wenaas