A History of the Regeneration Circuit:

From Invention to Patent Litigation

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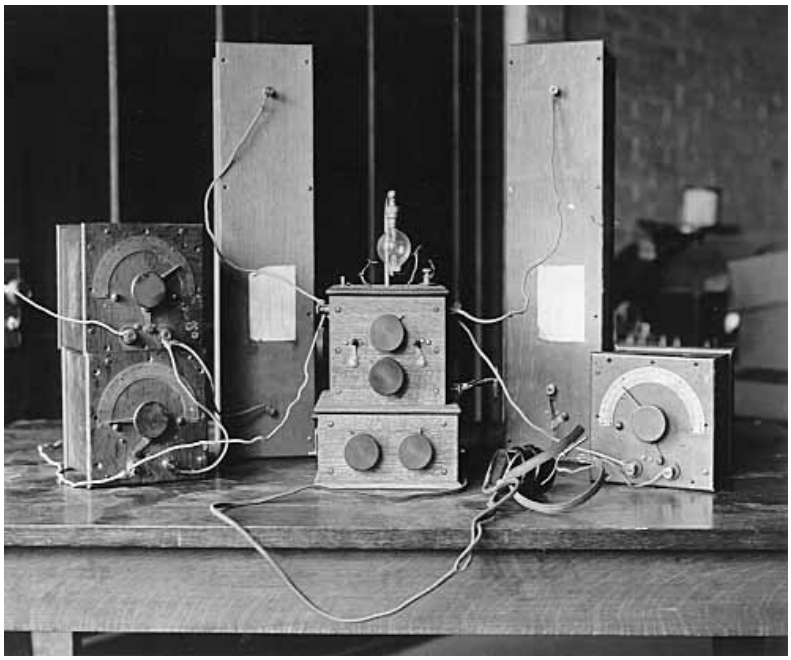
1. Introduction

The regeneration circuit was invented in 1912-13. Priority disputes and patent litigation over who first invented it began in 1914. The US Supreme Court finally decided on 21 May 1934 that Lee de Forest's patents on this invention be sustained, which meant in a legal sense that de Forest was the inventor of the regeneration circuit. During twenty years between 1914 and 1934, Lee de Forest and Edwin Howard Armstrong fought 13 times in the court.



<figure 1. A model of Armstrong's first regenerative circuit. Smithsonian Institution>

According to the radio historian W. Rupert Maclaurin, this is the most complicated patent litigation in the history of radio. One legal expert commented that this long series of patent litigation between de Forest and Armstrong was so complicated that "no mortals could comprehend it completely."[1] Why was it so difficult to reach the final verdict? Was the final verdict of the Supreme Court just and fair? What were the issues in dispute in litigation? My paper aims to examine these issues critically, and provide some answers to these questions.

2. Lee de Forest and His Invention of the Audion Amplification Circuit in 1912

[1] W. Rupert Maclaurin, *Invention and Innovation in the Radio Industry* (Macmillan, 1949). For patent litigation between de Forest and Armstrong, see Alfred McCormack, "The Regenerative Circuit Litigation," *Air Law Review* 5 (1934), 282-295; James R. Gaffey, "Certain Aspects of the Armstrong Regeneration, Superregeneration, and Superheterodyne Controversies," *Patent, Trade-mark and Copyright Journal of Research and Education* 4 (1960), 173-185.

Lee de Forest was a flamboyant American inventor. His father Henry De Forest was a pastor and a teacher who taught black people in a local college in Southern America. Lee de Forest was interested in inventions since he was a boy. At the age of seventeen, he wrote his father that "I want to leave footprints on the sands of time. I can do so best by taking the scientific course." He entered the Sheffield Scientific School of Yale University, and received a PhD degree at Yale in 1899 with his research on the reflection of Hertzian waves. De Forest then moved into the business of wireless telegraphy.[2]

Throughout his life, de Forest looked for money, fame, and power, but above all he quested for new inventions. Since he was a college student, he admired Nikola Tesla, and wanted to equal and excel him. As an inventor, de Forest was not very successful. He began to broadcast music and news perhaps before anyone else, but he missed the boom of broadcasting in the 1920s and a chance to make a fortune from it. He also invented movies with sound, but his system was rejected by Hollywood. The title of a series of detailed biographical articles on Lee de Forest published in the *Saturday Evening Post* in 1942 was "Magnificent Failure." One of his friends described him as "a dynamo without much insulation."[3]

At several points throughout his life, de Forest was a millionaire. He once had a house with an artificial waterfall. At several points, however, he was penniless. It is well known that de Forest filed a British patent for his audion, but since he did not secure $125 dollars for its fee, he had to allow it to lapse. But his name is eternal in the history of technology for the invention of the audion,

[2] For the life and works of Lee de Forest, see Lee de Forest, *Father of Radio: The Autobiography of Lee de Forest* (Wilcox & Follett, 1950); James Hijiya, *Lee de Forest and the Fatherhood of Radio* (A Lehigh University Press, 1993).

the three-electrode vacuum tube. It is not easy to find three-electrode vacuum tubes these days, but they were the antecedent of transistors. The transistors is used as a rectifier, amplifier and oscillator. Transistors embedded the effects of the vacuum tube in the junction of semiconductors, since vacuum tubes also rectified, amplified, and oscillated.

Lee de Forest invented the audion in 1906-7. In 1901, he competed with Marconi over the reception of messages during an international yacht race, which made him famous. In 1902, he became the vice-president and director of the American De Forest Wireless Telegraph Company, which built stations, sold stocks, but hardly sent any messages. De Forest's role in this company was to boost the sale of stocks by continuously creating a public sensation. The company closed operations in 1906. The co-founder of the company betrayed de Forest while he was hiding himself in Canada, and fired him from the company. Around the same time, de Forest's first wife divorced him. Jobless and penniless, he returned to his small laboratory, and in the next six months, invented the audion. Considering several pieces of evidence, he did not fully understand why or how the audion worked. But it did not matter much, not only because no one fully understood why or how the device worked, but because his concern was to rebuild his business with the audion. This small lamp, he believed, was to revive his wealth and fame.[4]

De Forest quickly formed the De Forest Radio Telephone Company, which sold his audions and other wireless devices like wireless telephone sets. None of the company's products were ever purchased. The company could secure money by selling more stocks, but it finally went bankrupt in 1911. The Department of Justice charged de Forest and his associates for fraud over methods

[3] Samuel Lubell, "Magnificant Failure," *Saturday Evening Post* (January 17, 24, 31, 1941).
[4] For the invention of the audion, see Robert A. Chipman, "De Forest and the Triode Detector," *Scientific American* 212 (3) (1965), 93-100; Sungook Hong, *Wireless: From Marconi's Black-box to the Audion* (Cambridge, MA: MIT

they used to promote the company. The angry prosecutor said that the company's only "assets were de Forest's patents on a strange looking device like an incandescent lamp which he called an audion and which had proven worthless." The prosecutor even insulted de Forest by saying that the audion was not even a good lamp.[5]

His second marriage with Nora Blatch, who was then a well-known feminist, came to an end around the same time. De Forest described in 1908 that Nora was "the new woman -- noble and self-knowing, independent yet all-womanly, never the Doll of the Doll's House." At that time Nora told de Forest that "I know I'd never tire of living with you, nay not for 1000 years." But Nora left the house in 1909. When de Forest was charged for fraud in New York, he was staying in California. He decided not to return to New York, because, according to his own words, he liked the weather in California. One can easily see, however, that there were other reasons.[6]

De Forest found a job in the Federal Telegraph Company in California. By that time, the corporate laboratories such as the General Electric laboratory had been born and big corporations began to hire engineers with a college degree. However, many famous engineers were still doing their practices as an independent engineer. Yet, these independent engineers were not isolated, because corporate engineers and leaders paid attention to their works, maintained a strong connection with independent engineers, made use of their inventions, and bought their patents.

Here is an example. The American engineer Fritz Lowenstein worked in 1911 on a radio guidance system in the laboratory of John Hammond in Gloucester, Massachusetts. At the end of 1911, by using de Forest's audions, he developed a primitive amplifier and oscillator. Lowenstein

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Press, 2001), pp. 169-181.

[5] De Forest, *The Father of Radio*; Hugh G.J. Aitken, *The Continuous Wave: Technology and American Radio, 1900-1932* (Princeton: Princeton University Press, 1985).

neither paid much attention to his invention nor did he apply for a patent for it. But his research was not unnoticed. The GE engineer Ernst Alexanderson, who happened to see Hammond's invention, informed this to Irving Langmuir, and Langmuir eventually developed amplifying and oscillating audions in 1913. Another person who noticed the potential importance of Lowenstein's audion amplifier was Beach Thompson, the chairman of the Federal Telegraph Company.[7]

It was a perfect coincidence that Thompson had just hired de Forest. After having been informed of Lowenstein's use of de Forest's audion for amplification and oscillation, Thompson asked de Forest to pursue this line of research, and assigned two assistants – Charles V. Logwood and Herbert van Etten – to de Forest. De Forest had been very depressed and desperate in California in 1911, but had begun to regain his health and energy in 1912. One day in February in 1912, he noted: "each down brings hope; while a new health, an unknown physical strength, a renewed youth grows within me. It is California & I am only 38!"[8]

De Forest's note of 22 April shows that he experimented with two Fleming valves in the wireless receiver. In July of 1912, by connecting two audions in such a "cascade" way that the output of one audion became the input of the other, he obtained some good amplification. In Auguest (6 Aug 1912), he connected the output circuit of one audion to its own input circuit, and according to his own description, he obtained regeneration or feedback amplification, as well as sustained oscillation.[9]

Before we discuss Armstrong's invention, we need to examine one crucial question. What did de Forest actually invent in the summer of 1912? There is no doubt that de Forest invented a

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[6] Hijiya, *Lee de Forest and the Fatherhood of Radio.*
[7] For Lowenstein, see Hong, *Wireless*, pp. 182-183.
[8] Lee de Forest's diary, February 12, 1912, Papers of Lee de Forest, Library of Congress, Washington DC.

telephone amplifier or repeater by connecting the output of the audion into its input. There are two issues to clarify. 1) Did this invention include the amplification of "high-frequency" oscillations? Apparently not, but this issues becomes more tricky, since it had been known that the vacuum-tube worked both with low and high-frequency oscillations. If it worked for low-frequency, there was no technical reason why it should not work for high-frequency. 2) Did it include the generation of sustained oscillations? Telephone engineers had known that amplification by repeaters was not separable from the production of sustained oscillations. But de Forest, like other engineers, tried to abolish, not maintain, the sustained oscillations that caused the unwanted howling sound. What he invented was a device which properly worked if the sustained oscillation was eliminated.[10]

De Forest took his device to New York in October 1912 to show it to John Stone Stone, an eminent engineer who had a good connection with AT&T. When he demonstrated the amplifier to Stone, it still made the unwanted sound. In spite of its instability, De Forest's audion amplifier impressed Stone as well as other engineers and managers of AT&T. AT&T soon bought exclusive rights to de Forest's audion for use in (telephone & telegraphic) communication. By improving de Forest's audion amplifier, AT&T successfully made a telephonic communication between New York and California in 1915. John Stone Stone later gave testimony that in October 1912 he asked de Forest whether he had known if the oscillations extended into the radio-frequency range, and that de Forest answered that he had known about it and had thought about the use of his circuit as a generator of such oscillations. Stone's testimony was crucial for establishing de Forest's priority over Armstrong in court. However, there is no other evidence to support Stone's claim. As

[9] Lee de Forest's entry in his notebook, April 22, 1912 & August 6, 1912, ibid.
[10] If a telephone amplifier made a howling sound, this meant that it was useless as an amplifier. De Forest tried to abolish the howling by changing circuit variables, but found that it's not easy to completely eliminate it.

historians have noted, Stone was not free from AT&T's corporate interest in de Forest's priority. In any case, de Forest aimed to avoid sustained oscillations, either of low- or of high-frequency.[11]

3. Edwin Howard Armstrong and the Invention of the Feedback Amplification Circuit

Edwin Howard Armstrong was an amateur radio operator from his high school days. His father was the American representative of Oxford University Press, and his mother was a school teacher. When he was a boy, he was deeply impressed by reading some popular books on Marconi and wireless, and joined the amateur radio club. He erected a 30-meter antenna in his yard, and liked climbing it, which frequently astonished his neighbors. In 1909, he became a college student at the electrical engineering department of Columbia University. In the electrical engineering department, the legendary Michael Pupin was teaching electrical engineering courses. Armstrong respected Pupin very much, and Pupin liked him as well. Pupin was a master of both theory and practice in electrical engineering. Pupin was a man of scientific mind, but he was also the inventor of the loading-coil, which he sold to AT&T for half-million dollars.[12]

Armstrong obtained an audion from his friend in 1911. Since the expensive audion receiver was not particularly more sensitive than cheap crystal detectors, it had not been widely used. Although he connected the audion to the receiving circuit in many different ways, Armstrong could not get it to work as a good amplifier. Amateur operators preferred to use a crystal detector, in which a telephone was employed to hear the signals. Using crystal detectors, amateur operators

[11] Aitken, *Continuous Wave*, pp. 240-241.
[12] For the life and works of Edwin Howard Armstrong, see Lawrence Lesing, *Man of High Fidelity: Edwin Howard Armstrong* (Philadelphia: J.B. Lippincott Co., 1956).

usually connected a condenser across the telephone to make the telephone readily respond to incoming signals. In the case of crystal detectors, however, the condenser did not affect the strength of the signal.

One day, while experimenting on the audion receiver, Armstrong connected a condenser plate across the telephone as he had done with a crystal detector before. However, he obtained a stronger signal this time – not just some increase, but "a very definite increase." Why did the condenser plate in the telephone circuit of the audion receiver definitely increase the strength of signals? According to de Forest's theory, the audion was a sort of relay device. In the audion's plate circuit connected to a telephone, an oscillation of 1000 Hz (an audible frequency) was supposed to be created, and it was not possible that a small condenser could affect the strength of 1000 Hz signals. One remote possibility was that a high-frequency oscillation was induced in the plate circuit, but this was contrary to the accepted theory of the operation of the audion. To Armstrong, however, this appeared to be the only plausible explanation.

There was an axiom among amateur operators known as "the fundamental axiom of radio." It was: "wherever there are high frequency oscillations, tune the circuit." So, one day in the summer of 1912, Armstrong added an inductance to the circuit to see if any resonance phenomena would happen in this LC (L-R-C) circuit. For this, he added a variable inductance to the audion circuit. Increasing the inductance boosted the signals to an intensity unbelievable at that time. The more inductance the louder the signal. The signal seemed to be hundred times stronger than usual. He could not figure out the reason for this increase, but his belief that there was a high-frequency oscillation on the plate circuit proved to be correct.[13]

[13] Lessing, *Man of High Fidelity*; Armstrong's own testimony in *Radio Corporation of America, American Telephone*

On the same day, he also found another strange effect. As he increased the inductance beyond a certain point, the signals suddenly disappeared, and then a hissing sound of high tone was produced. When he lowered the inductance, strong signals reappeared. When he moved his hand close to the receiver, signals disappeared and a hissing sound was heard. The signal amplification could be explained by the feedback of plate output into the grid circuit as an input. By using the oscilloscope at the engineering department of Columbia University, he could later show that the output was in phase with the input. But why did the signal disappear beyond a certain point? He suspected that the receiver produced high-frequency local oscillations, and also that the hissing was a result of the beat produced by the superposition of these high-frequency local oscillations with incoming high-frequency signals. In other words, his feedback amplification circuit produced high-frequency oscillations. In an undated handwritten note, Armstrong recalled his discovery as follows.

> The invention [of the regeneration circuit] was luck but the production of a workable apparatus was the work of a few hours -- the unravelling of the phenomena involved in the system was a matter of months. Briefly the ~~invention~~ discovery came out of a desire to find out how the audion worked -- not an easy thing to do in the dark age of 11 and 12 when the very scanty literature on the subject spoke learnedly of "gas ionization" etc and the audion was known to the art simply as a detector of high frequency oscillations.[14]

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and Telegraph Company and De Forest Radio Company, Petitioners vs. Radio Engineering Laboratories, INC. Supreme Court of the United States, 1934, pp. 830-886.

[14] An early (undated) note of Armstrong in Armstrong Papers, Columbia University.

With this regeneration receiver, Armstrong captured in New York a message between San Francisco and Honolulu. He also captured a signal coming from Ireland, which was hard to capture even in Marconi's huge wireless stations. In September 1912, Armstrong demonstrated his receiver to his friend Thomas Styles. In early 1913, he gave a demonstration to the general public at Columbia University. This demonstration was attended by an engineer from the Marconi Company. Marconi was also informed of Armstrong's new receiver in early 1914. The vice-president of the Marconi Company examined Armstrong's receiver, and concluded that it was a "wonderful piece." But he was not sure whether it would infringe John Ambrose Fleming's, de Forest's, or Oliver Lodge's patent. The vice-president also told Marconi that Armstrong's lawyer declined to give him any definite idea as to what young Armstrong would want.[15] AT&T engineers also heard the news about Armstrong's invention through Michael Pupin. J.J. Carty, the chief engineer of AT&T, initially thought that what Pupin told him was impossible, but Armstrong's demonstration impressed Carty enormously.

It is not certain why neither Marconi Company nor AT&T showed further interest. Anyone could have easily bought the exclusive right of Armstrong's patent for $10,000. Maybe it was because they were suspicious of the validity of Armstrong's patent which used the audion in a certain way. Marconi Company was planning to sue de Forest for infringing Fleming's valve patent, and AT&T had just bought from de Forest the right to use de Forest's audion for communication. Armstrong's invention came into the world when patents on the vacuum tube were intensely contested.

[15] J. Bottomely to G. Marconi, February 3, 1914, Armstrong Papers at Columbia University.

Armstrong did not immediately file a patent for his invention, because his father would not give him $150 dollars for patent fee until his graduation. But his uncle told him to notarize the invention, an advice that Armstrong followed. The circuit diagram that he notarized on 13 January 1913 became the earliest documentary proof of Armstrong's invention. He applied for a patent on 29 October 1913 just after he had graduated Columbia University.

Armstrong did not include the generation of sustained oscillation in his patent. His patent attorney William Davis told Armstrong that "you ought to keep your eyes wide open to see any indications that may point to the importance of features other than those covered in your application." Two months later, in December 1913, Armstrong filed a separate patent on the audion as an oscillator. The fate of this failed patent is not widely known. A patent examiner, who thought that this oscillator patent was inappropriate because it was the same invention as covered in Armstrong's amplifier patent, told Armstrong to withdraw his new patent. Armstrong was apparently persuaded by the examiner's argument that it was the same invention, and withdrew it. This fundamentally weakened his position in later litigation, because it implied that Armstrong had thought that the amplifying receiver and the oscillator were one and the same thing, although he claimed in court that they were essentially different.[16]

Armstrong's patent was issued on 6 October 1914 (US Patent No. 1,113,149). After his patent was granted, Armstrong published an article in *Electrical World* which detailed the regeneration circuit and its operational mechanism. He also gave a speech at the Institute of Radio Engineers. As a response, de Forest sent a written comment to argue that what Armstrong did had already

[16] E. H. Armstrong to William H. Davis, November 9, 1913. Aitken, *Continuous Wave*.

been in his invention of the audion.[17]

3. Legal Battles between de Forest and Armstrong

There was an engineer who had applied for a patent on the regeneration circuit prior to Armstrong. He was the German engineer Alexander Meissner, who filed a US patent on a regenerative circuit in March 1913. Langmuir, a well-known scientist-engineer at GE, applied for a patent on 29 October 1913, the same day when Armstrong filed his patent. De Forest applied for a patent on the ultra-audion (a regeneration circuit) in 1914, but his patent was not accepted by the Patent Office, because of Armstrong's previous patent. Therefore, De Forest and others filed an "interference proceeding" to the Patent Office, and a proceeding for the four parties involved – Armstrong, de Forest, Meissner, Langmuir – began.[18]

Then WWI started, and the German Meissner was excluded in any patent considerations in the United States. The four-party interference proceeding was continued without Meissner, but moved slowly due to the war. Armstrong even volunteered to join the Army, and after the end of the war, he discussed the patent issue with his lawyer and decided on another way. Since Armstrong was the only party to hold a patent granted, he sued de Forest for infringement of his patent. De Forest defended his right by asserting that his observation of the howling sound in his amplifying circuit in August 1912 was the same as Armstrong's invention.

In 1921, the judge in New York district court Julius Mayer ruled in favor of Armstrong on

[17] Edwin Howard Armstrong, "Operating Features of the Audion," *Electrical World* 64 (1914), 1149-1151.
[18] McCormack, "The Regenerative Circuit Litigation,"; Gaffey, "Certain Aspects of the Armstrong Regeneration, Superregeneration, and Superheterodyne Controversies"; Tom Lewis, *Empire of the Air: The Men Who Made Radio*

two grounds: 1) If de Forest had known the true meaning of his invention, he would have filed a patent for it immediately, because, during that period, he filed several patents rather quickly; 2) De Forest's 1914 notebook on the ultra-audion, as well as his patents on it in 1914-1915, showed that even at this time de Forest did not fully understand the principles involved in the feedback regeneration circuit. The notebook shows that de Forest was stumbling between ignorance and ineffective circuits. The court concluded that de Forest began to have a correct understanding of regeneration only after he read Armstrong's patent and scientific articles on the topic. On these grounds, the judge ruled that de Forest's claim that he had known about the full-fledged feedback circuit before March 1913 was not convincing. De Forest appealed, but the appeal court also ruled in favor of Armstrong, and the Supreme court denied de Forest's petition.

However, there had been another dispute going on: the "four-party" interference proceedings involving Armstrong, de Forest, Langmuir, and Meissner. Meissner was excluded after WWI, and Armstrong secured priority over Langmuir with the former's notarized document on 13 January 1913. Between Armstrong and de Forest, the patent office had initially decided in favor of Armstrong. Since one could bring this case to the court, de Forest appealed to the Court of Appeals of the District of Columbia, and the decision was reversed there for the first time. De Forest's experiments in the summer of 1912 were considered to constitute an invention of the "means for producing sustained electrical oscillations."

Here was a subtle, but significant, change. The litigation was originally about the invention of a radio equipment, that is "means for producing sustained high-frequency oscillations", but de Forest's lawyer succeeded in changing it into the "means for producing sustained electrical

(New York: HarperCollins, 1991), pp. 186-219.

oscillations." The court then decided that what de Forest invented in the summer of 1912 could be interpreted as the "means for producing sustained electrical oscillations."

After this success, de Forest's two patents on the ultra-audion and the regenerative circuit were granted by the Patent Office. He then sued Armstrong for infringement of his ultra-audion patents. The Pennsylvania court decided in favor of de Forest. Armstrong appealed, but the Appeals Court simply affirmed the lower courts' decision. In 1928, the Supreme Court denied a petition. The result of this lawsuit was an agreement which invalidated most of Armstrong's patent claims.

Why did De Forest win the later litigation? There were two reasons for his victory. First, his notebook of 1912 was submitted as evidence. In the previous New York infringement suit, the judge rejected De Forest's oral testimony on the invention of the regeneration circuit in 1912 as being unconvincing. In later litigation, however, de Forest's notebook, in which he recorded his experiments on audion amplifier that he performed with his two assistants Logwood and van Etten in 1912, was recovered and submitted as evidence. This notebook had been used as evidence for some other infringement lawsuit, and since then, De Forest seemed to forget its existence.

Second, De Forest and his lawyers deployed a smart strategy. It is true that the notebook shows that De Forest obtained an audio frequency oscillation in the summer of 1912 (which he wanted to eliminate though). But is this the same as the invention of high frequency oscillator? In his paper published in *Electrical World* (1914) and his paper read at the Institute of Radio Engineers (1915), Armstrong had exhibited several oscillograms of an oscillating triode. In order to take these oscillographs, Armstrong had used a very low-frequency (60Hz) alternating current. The lawyer asked him why he used such a low-frequency. Armstrong answered that it was because

there was no essential difference between high- and low-frequency oscillations in this case. Then, de Forest's lawyer used this testimony of Armstrong to support De Forest, arguing that there was no difference in observing low-fequency oscillations (de Forest's howling in 1912) and high-frequency oscillations.[19]

After the Supreme court's decision in favor of de Forest, a friend of Armstrong told him that "You can make other inventions just as important." Armstrong: paused, and said: "There will never be another oscillating audion." Another friend told him that "All engineers know that you invented the regenerative circuit." But Armstrong wanted to reopen the case. In 1934, AT&T, the owner of de Forest's patent, sued a small manufacturing company for infringement. Armstrong decided to pay the expenses of litigation for the company. The district court decided that de Forest's patent was invalid, and admitted Armstrong's priority. Appeals Court, however, reversed the decision. The Supreme Court ruled for de Forest. After this defeat, Armstrong returned the Institute of Radio Engineers' (IRE) 1917 Medal of Honor for the feedback circuit to the Institute. But the IRE's Board of directors unanimously reaffirmed their original decision.

4. Conclusion

Patent litigation between de Forest and Armstrong was complicated and prolonged for two major reasons. First, an artifactural boundary between low-frequency and high-frequency was not clear. In the summer of 1912, de Forest invented an amplifier for low-frequency oscillations (human voice through telephone lines). In theory, it had been known that same vacuum-tube

[19] *Radio Corporation of America, American Telephone and Telegraph Company and De Forest Radio Company,*

circuit could be used both for low- and high-frequencies. In light of patent, however, whether this invention should be considered to cover high-frequency range was not clear at all. De Forest claimed that he had invented an amplifier for electrical oscillations, whereas Armstrong thought that de Forest had invented a “telephone howling.”

Second, an artifactural boundary between amplification and oscillation was not clear either. When de Forest heard a howling sound with his amplifier, it did not seem so difficult for him to identify its source from sustained oscillation since the notion that amplification tended to accompany sustained oscillation was a commonsense for telephone engineers. Armstrong later clarified that the regenerative circuit also produced a high-frequency oscillations, and that it could therefore be used as an continuous-wave generator. Can we say that de Forest invented an oscillatory circuit by using his amplification circuit? His circuit certainly oscillated, but he tried to eliminate the oscillatory effect.

With the existing patent system, in which one single patent was to be granted to a single invention, it is hardly possible to decide who the inventor of the regeneration circuit truly was. Because what was in dispute here was not only the very definition of what a “single” invention was, but also the very definition of what an “invention” was.

Petitioners vs. Radio Engineering Laboratories, INC. Supreme Court of the United States, 1934.