Harvey F. Silverman

# One City—Two Giants: Armstrong and Sarnoff: Part 1

## EDITOR'S INTRODUCTION

Our guest in this column is Dr. Harvey F. Silverman. Dr. Silverman received his Ph.D. and Sc.M. degrees from Brown University. He earned his B.S.E. and B.S. degrees from Trinity College in Hartford, Connecticut. He worked at IBM T.J. Watson Research Center in Yorktown Heights, New York, between 1970 and 1980. During these ten years, he worked on a number of projects related to image processing methods applied to earth resources satellite data, analytical methods for computer system performance, speech recognition, and the development of a real-time I/O system as the manager of the Speech Terminal Project. In 1980, he joined Brown University as a professor of engineering. From 1991 to 1998, he was the dean of engineering at Brown University. Dr. Silverman is a coauthor on more than 215 journal and conference papers. Currently, he conducts research on detection of autism from infant cries, microphone arrays, acoustics, and source-location estimation.

Dr. Silverman is an IEEE Life Fellow, was a member of the Executive Committee, Trustees at Trinity College from 2001 to 2003, and a Charter Trustee at Trinity from 1994 to 2003. He was nominated for the 1994 ComputerWorld Smithsonian Award and received the IEEE Centennial Medal Award in 1984. In 1981, he received the IEEE ASSP Society Meritorious Service Award, and he received a number of awards at IBM for his outstanding work on speech recognition and detection algorithms. At Brown, he supervised and graduated 26 doctoral students, and currently he supervises three Ph.D. students.

Dr. Silverman has been an avid vegetable gardener for over 40 years and currently has about 6,000 square feet under cultivation. An outgrowth of this passion is that of using his knowledge and engineering skills to develop intelligent means for deterring the many furry and feathered creatures who very much like to share in the eating, although not the planting and cultivating. So far, the critters are winning!

As our author mentions at the beginning of this article, in 1969 he bought the book *Man of High Fidelity*, which was a 1969 paperback version of a 1956 biography of Edwin Howard Armstrong. The book was so intriguing that Dr. Silverman borrowed an autobiography of David Sarnoff. This was the beginning of a journey where our author learned about these two inventors and how such two strong characters and complex men spent more than 40 years in competition and race to inventions and pioneering. Our author has made it a habit to educate his students at Brown on a weekly basis about history through Sarnoff and Armstrong and the dynamics of inventions including patents, trade secrets, competition, restraint of competition, and politics. Dr. Silverman suggests this story to be an important part of electrical engineering education. Of course, some people have a different view of the two men and their stories, and our author points this out in his article citing a 1956 letter written by Lee de Forest.

Dear readers, Dr. Silverman is taking us on an intriguing journey in the complex lives of Armstrong and Sarnoff. In this column, we publish Part 1 of the journey; in the next issue, we will publish the second and final part of this journey.

*Ghassan AlRegib*

As an avid reader, crazy-gadget-loving engineer, and history enthusiast, I bought a US$1 paperback when I was a graduate student in 1969 titled *Man of High Fidelity*, the 1969 paperback version of the 1956 biography of Edwin Howard Armstrong by Lawrence Lessing. The story told within was so fascinating that I needed to learn more, so I borrowed a copy (it had been given to an outstanding Radio Corporation of America (RCA) researcher by Sarnoff himself) of the commissioned autobiography of David Sarnoff written by his cousin, Eugene Lyons, published in 1966. It was clear that these two giants of their time had lives that intermingled over more than 40 years. I loaned out the paperback and never had it returned—aside from this, I did little to learn more until about 20 years ago, when I thought it would be a good idea for my sophomore electrical circuits students at Brown to hear their story, and thus of the beginning of the electronics era through the history of radio invention. Therefore, each Friday of a semester for about ten minutes each week, I have been telling the story I will try to relate here.

The story is poignant; different authors (and original participants) have had widely different viewpoints, as the men were strong characters and complex, to say the least.

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I shall try to tell it as someone quite inspired by many of the qualities of both men and who has hopefully learned a little by seeing some instances in which some compromising would have led to better outcomes.

I do point out another wonderful source—Ken Burns produced a powerful 2 h documentary called "Empire of the Air" about ten years ago. Also, would you believe that there is a new opinion on the story of FM radio expressed in a 2010 book by Gary L. Frost, *Early FM Radio*?

At a recent International Conference on Acoustics, Speech, and Signal Processing (ICASSP), it became clear that the same situations faced by Armstrong, Sarnoff, and others in the early days of the electronics industry still happen today. Trade secrets, patents, competition, restraint of competition, politics, and just simple fate all coalesce to determine the winners and losers in our vast electronics community just as they did back then. It is for this reason that I suggest that the story should be a part of an electrical engineer's education. With this article, I hope that a few more people will know some history and thus not be doomed to repeat it.

## THE BEGINNING

The turn into the 20th century was indeed a time for beginnings. There were no "electronics," although the electrical age was well along. Morse's telegraph in 1839 had been the first practical invention that harnessed this new force—electricity. A few decades later, electric lighting followed, with electric motors finding great utility soon thereafter. This naturally allowed the development of generators and then power systems for cities. The telephone was an invention contemporary to electric lighting and used early forms of microphones that converted sound to an electronic analog that could be sent along wires—continuous analog signals instead of the (digital?) dots and dashes of the telegraph. However, there was no good way to amplify these electronic analogs. In the United States, large corporations such as General Electric (GE), Westinghouse, and American Telephone and Telegraph became the movers of this new electrical industry with new opportunities in motors, generators, power distribution, telephony, and lighting so large as to turn these electrical corporate giants into the growth industry of their day. GE and AT&T started the two largest research laboratories for this new industry, while Westinghouse made advances using AC ideas, based on advice and counsel of Nikola Tesla.

There were some physicists and engineers of this period who were fascinated by the possibilities of wireless transmission and electronic phenomena. Perhaps Heinrich Hertz is a good place to start when he, in 1888, demonstrated that wireless transmission would occur using a spark generator and a "tuned" C-shaped loop that sparked across its open end across a room when the spark was initiated by the generator. It took a few years, but this principle was demonstrated further by Guglielmo Marconi in 1899, transmitting telegraphic dots and dashes—a device that appeared to have some useful potential! Soon thereafter, the Marconi Company in England was founded with the American subsidiary, American Marconi, coming a few years later.

**IT IS HARD TO BELIEVE THAT THE CAREER OF ONE OF THE MOST INFLUENTIAL MEN OF THE EARLY WIRELESS INDUSTRY WAS DETERMINED BY SUCH KARMA!**

During these years too, some experiments of interest were carried out based on the light bulb. In 1873, Thomas Guthrie reported thermionic emission, but in 1884, Edison, ever the trial-and-error experimenter, added a second filament to his vacuum bulb and saw that electricity would flow from one filament to the other under certain circumstances. While Edison patented what he found (US patent 307031), and this was to be his only true contribution to "science," he was unable to see the value of the invention nor understand the underlying physics. This was dubbed the Edison effect and abandoned by the great inventor. Edison was not going to be a player in the electronics field.

In July 1900, two nine-year-olds of vastly different backgrounds were living in New York City. The older of the two, Edwin Howard Armstrong (18 December 1890) was born into a "genteel Victorian household" [7]. He was the son of John Armstrong, who worked for Oxford Press. John ultimately rose to the position of the manager of the American branch and was a trustee of the old North Presbyterian Church in Manhattan. His mother, Emily Smith Armstrong was a graduate of Hunter College and had been a public school teacher for ten years prior to marrying John Armstrong in 1888. Edwin was the oldest of three, having two younger sisters. At age nine, he contracted St. Vitus' Dance, an early childhood disease now associated with rheumatic fever. While St. Vitus' Dance normally ran its course in a few months, it was a full two years that Edwin remained at home, schooled by his family until his recovery. To get him "into the sun," [7] the family moved to Yonkers at this time to a large house with an attic in which he could do his experiments. While he fully recovered, he was left with a lifelong "tic" in which he would "hitch his shoulder forward and twist his neck and mouth whenever he was excited or under stress" [7]. In 1904 and 1905, his father, returning from annual trips to London, brought Edwin two new books, *The Boys' Book of Inventions* and *Stories of Inventions*. It was thus at age 14 that he decided to be an inventor—his path was set early.

The other nine-year old was David Sarnoff, who, at this time, had literally just stepped off a steerage deck, having emigrated from a shtetl (a small town) called Uzlian in the province of Minsk in Tsarist Russia. He had been born just two months after Armstrong on 27 February 1891, the oldest of three sons. By age five, David showed himself to be handsome and bright and knew how to read and to recite passages from the Bible by heart. In 1896, his father, Abraham Sarnoff, left the family for America to earn the money necessary to bring the family over to join

him. Abraham was pious but sickly, and it took him four years. During this period, David's mother was struggling in Uzlian, so his grandmother arranged for him to leave the family for four years to "become learned" [9]. He was sent 400 miles away to live and study with his great uncle, a rabbi in Korme. He was following the traditional path for the learned, studying 12–14 h a day reading over the Prophets in Hebrew and, later, the Talmud in Aramaic. Perhaps it was in this early period that he truly sharpened his mind, learning the disciplines of patience, concentration, and memory. After four years, his mother sent for him—they were going to America.

America! When David Sarnoff arrived in New York, he spoke no English and moved into a squalid, narrow, fourth-floor railroad flat of a decrepit tenement in the Lower East Side of Manhattan. Abraham Sarnoff's condition grew worse, and he could barely support his family. Ultimately, he died a few years later when David was a young teenager. However, the few years Abraham gave to his family allowed David to attend public school, originally being placed in one of the special classes set aside for new immigrants. He was reading English and speaking with some fluency before the end of the year. At the same time, he had to help support the family as the oldest son. He started by peddling Yiddish newspapers, rushing after school to grab a bundle, making a profit of US$0.25 if he could sell 50 papers in a very competitive selling environment. When his father died, David was no longer able to attend school, so he began working full time. About the time of his bar mitzvah at age 13, he had turned his newspaper peddling into a family newsstand at the corner of 46th Street and Tenth Avenue, the heart of a tough Irish neighborhood called Hell's Kitchen. As it was for several turning points in his life, good fortune played a role; the US$200 needed to purchase the newsstand was given him by an anonymous, mysterious middle-aged woman who came to his tenement! Twenty years later he found out she was a social worker, but he never found out who the real donor of the gift was. The tough Irish kids did not make life easy for Jewish boys in their neighborhood, but David held his own although forced by the circumstance to grow in toughness. He successfully moved his family to the area and a slightly better apartment so that they could all play roles in their new business.

Armstrong did not have the same finishing school of the streets. He went on to high school and college, was the captain of the Yonkers High School tennis team, finished his high school career with an 89.8 average, and was accepted into the Columbia University School of Engineering, Department of Electrical Engineering. During his high school days, he had become fascinated with the art of wireless telegraphy and telephony, had erected a large, 150 ft antenna in his backyard and was making many new acquaintances over the miniscule electrical currents in the air using the crude apparatus of the day. He entered college in 1909, commuting to school on his new Indian motorcycle his father had bought for him as a graduation present, and his first years were undistinguished. He had a one-track mind—wireless—and what he did not like he largely ignored, but passed his courses. He spent much time in his attic communicating with his amateur-radio cadre.

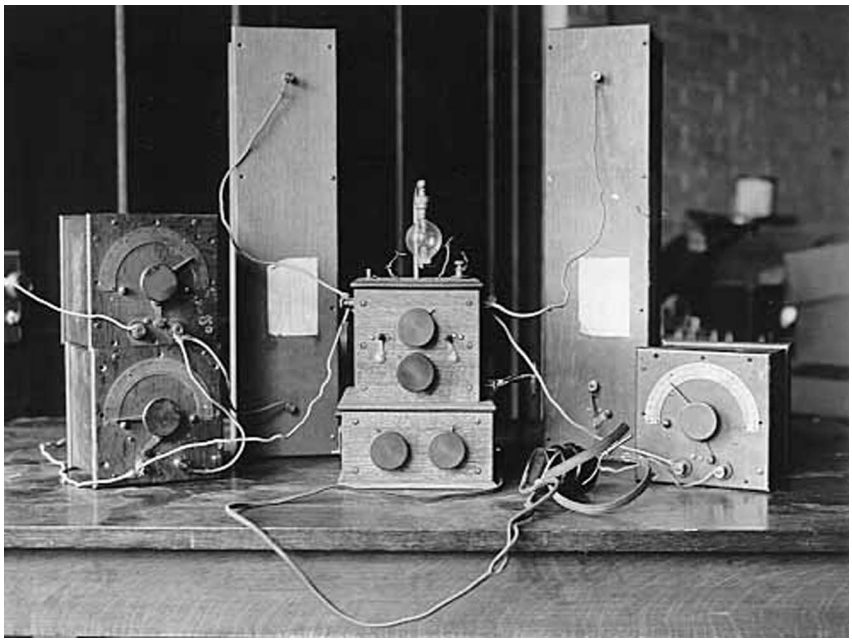
**[FIG1] Junior telegraph operator David Sarnoff, Marconi Wireless Telegraph Co. of America, circa 1907. (Image courtesy of the Hagley Museum and Library [DS_1906].)**

In early 1906, Sarnoff decided to try to get a full-time job (when he was about 15). Having sold newspapers, he decided that being a reporter, ultimately rising to editor or publisher, was his ambition, so he went off to the *New York Herald* to apply. However, he made an error. He asked a man behind a window in the lobby for a job, but that man was with the telegraph office of the Commercial Cable Company. The man advised him of his error and then told him of their need for a messenger boy and David took the job. It is hard to believe that the career of one of the most influential men of the early wireless industry was determined by such karma! Determined not to remain a messenger boy for long, he saw that the telegraphers were an important company asset, so he took two of his precious dollars and purchased a practice telegraph key. He was allowed to learn more by asking lots of questions and by working with some of the company telegraphers during off times. Nevertheless, this job did not last long. Sarnoff also sang in a synagogue choir for the high holidays to make a little extra money in the fall and asked for the days off. He was told to take them—and all the days following as well. He was fired!

Having become quite proficient with a telegraph key, he applied for a job as a junior operator at the seven-year old Marconi Wireless Telegraph Company of America—the American subsidiary of the British Marconi Company that controlled a great portion of wireless telegraphic messaging (Figure 1). He was hired as an office boy in September 1906, beginning his lifelong career with the single commercial entity that was to become RCA.

## THE FATES OF YOUTH

In his junior year, Armstrong came under the influence of one of the founders of the Department of Electrical Engineering at Columbia, Michael Pupin. A Serbian immigrant, Pupin was the head of the Marcellus Hartley Research Laboratory and did his research in the basement of Philosophy Hall. His lab was full of the typical electrical engineering (EE) clutter



[FIG2] **The invention that started it all for Armstrong, the 1912 feedback (regenerative) receiver. This equipment was donated to the Smithsonian Institution following Armstrong's death. (Image from the Houck Collection site, reprinted with Permission from Mike Katzdorn.)**

and drew aspiring electrical engineers like a mecca. Pupin believed that engineers needed to be well grounded in basic science, quite at odds with most EE programs of his time. Pupin was also an inventor, having sold his patent for the Pupin loading coil, important for telephony, to AT&T for a goodly sum. In 1912, at age 21, Armstrong had an idea that would begin his inventing career. He could not wait to return to Philosophy Hall in September to develop it. On 22 September, he started a group of experiments that would lead to the regenerative circuit using the principle of partial feedback in a three-element tube (triode) to give amplification orders-of-magnitude more than what had been seen before (Figure 2). Moreover, when the amount of feedback was made too large, the circuit squealed (oscillated), which turned out to be an even larger discovery, for now there could be an electronic means for generating high-frequency waveforms, a necessity for both transmitters and receivers of wireless.

With his senior year still to finish and as he did more experimental work, he was sure that he had discovered the answer for which so many had been searching. While still pretty naïve about intellectual property and protection of it, he was careful enough to put his apparatus into a "black box" and not reveal what was inside. In the winter, he showed his remarkably clear reception of distant wireless signals to his radio friends from Yonkers but would not reveal the insides. He hinted at his accomplishments to his instructors who advised him to seek a patent. However, a patent cost US$150 to file and his only source, his father, refused to give him the money until he graduated in the spring. Father did not know best here! He sought out support from friends and relatives and even sold his motorcycle, but he could not come up with the full amount. However, an uncle who had some legal knowledge advised him to draw up a sketch of his device and get it dated and notarized, which he did on 31 January 1913. This cost him US$0.25.

**AS A RESULT OF ALL THE NOTORIETY, THE COMPANY RECOGNIZED THAT SARNOFF WAS MORE VALUABLE THAN JUST A TELEGRAPHER AND STATION MANAGER.**

Armstrong became absorbed in his experiments, taking some time to set up a second audion tube to show off its more controlled oscillating abilities, ultimately so important for transmitters and receivers too. While excitedly doing all this, he managed to graduate in June 1913 with a degree in electrical engineering; he was then offered an appointment as a teaching assistant in the department for one year at a salary of US$600—which he accepted. His father, prouder of the new job than his son's invention or graduation, came through with the money for the patent, which was ultimately filed on 29 October 1913. In this, his first experience with patents, he made an error that proved very costly later on. He insisted that any coverage for the oscillator function be sought in a second patent, not as part of the first one, as he wanted to develop the idea a little more in the laboratory. The oscillator patent was filed 18 December 1913.

In early 1907, 17-year-old David Sarnoff had all the duties of an office boy—dusting, cleaning typewriters, and emptying wastebaskets—but he managed to sometimes practice his telegraphy communicating with the four Marconi stations and with Western Union. Soon he was trusted to receive messages. His superiors found it amusing that he read many of the correspondences he was to file—he was learning about the business and at the same time improving his English. He also spent time with the laboratory technician and, after blowing out dozens of fuses, was able to set up experiments and do repairs in the lab. An exciting period was when Marconi himself visited New York and spent some time in his Front Street workshop. David lugged his suitcases, delivered candy and flowers for him, and experienced the aura of the great inventor. Apparently, Marconi saw in David a first-rate mind; the man and the boy engaged in very philosophic discussions. A few months after turning 16, Sarnoff was promoted to "pony operator" (junior telegrapher) at the salary of US$7.50 per week. A move to Nantucket Island to be one of the four operators of that station

earned him his next promotion at age 17 to "assistant operator" at US$60/month and soon thereafter to "full operator" at US$70/month. On Nantucket, he acquired a second-hand bicycle, often pedaled the seven miles to the Nantucket Library, and took correspondence courses in algebra and geometry.

In 1909, Sarnoff was made manager of Marconi's Coney Island station, the company's busiest. While taking a US$10 a month cut in salary (he was back in New York after all) he was becoming well-known worldwide by telegraph operators who could recognize his "fist" (the rhythmic patterns unique to a telegraph operator). In 1911, Sarnoff took an assignment on the sealing ship, *Beothic,* and was involved in the first time radio was used to aid in a medical emergency. He also served as the telegraph operator on the SS *Harvard*. He then was given the task of manager and operator for the 5 kW (most powerful station in New York) station atop Wanamaker's Department store. With a second station located in their store in Philadelphia, Wanamaker's hoped the novelty of radio would attract thousands to the stores. For Sarnoff, finally having regular hours allowed him to take a special night course in electrical engineering at Pratt Institute that compressed three years into one.

Even his diligence and skill, however, could not push his career as well as another event (which was fortuitous for him). The 21-year-old Sarnoff was at the key at Wanamaker's on 14 April 1912 and received weak and static-filled radio messages from the SS *Olympic*, saying that the *Titanic* had hit an iceberg and was sinking fast. For the next 72 hours Sarnoff stayed at his post, acknowledging the messages and relating the details to the public and the assembling crowd that converged on the store. President Taft ordered all other U.S. stations to power down. Not until the complete list of survivors was given to the press did he quit. Sarnoff had been at the key position and had taken proper action, showing all too clearly that many more lives could have been saved had there been more and better radio apparatus aboard vessels. Congress immediately passed the Radio Act making it mandatory for all ships carrying more than 50 persons to have and continuously man a radio system. The Marconi Wireless Telegraph Company of America began to make some money!

As a result of all the notoriety, the company recognized that Sarnoff was more valuable than just a telegrapher and station manager. Near the end of 1912, he was appointed its radio inspector for ships in New York Harbor and, a few months later, the chief inspector for the whole country. He was also given the title of assistant traffic manager, and he served as an instructor at the Marconi Institute, a training school for radio operators. By the summer of 1914, Sarnoff was named the contract manager for the new American director of the Marconi Wireless Telegraph Company of America, Edward J. Nally. There is little doubt that his influence was growing well beyond whatever title he now held.

## THE FIRST MEETING

In December 1913, a demonstration of Armstrong's new apparatus was set up in Prof. Pupin's laboratory for a group from the Marconi Wireless Telegraph Company of America. By this time, David Sarnoff had the position of assistant chief engineer, and on 6 January 1914, he came with two older Marconi engineers. The two 23-year-old principals, each of genius talent, appeared and acted very differently: "Armstrong tall, slow-spoken, extremely reserved, with an analytical mind; Sarnoff short, fluent, aggressive, the entrepreneur" [7, p. 53]. Surprisingly, they hit it off. Sarnoff could see the potential for the commercialization of what Armstrong showed, likely more so than did his older colleagues. The Columbia "wizard," who still kept his apparatus in a covered box, showed clear reception of signals from Marconi's transmitter in Clifden, Ireland. The transcriptions were verified a few days later by the company. Sarnoff's report the next day might be considered a turning-point document, saying, while he would like to see further tests, "the results obtained were, I thought, quite phenomenal" [9, p. 65].

**ALAS, THE CUT-THROAT WORLD BEGAN TO SHOW ITSELF TO ARMSTRONG JUST AFTER HE HAD FILED FOR HIS PATENT IN LATE 1913.**

About two weeks later, Armstrong was asked to demonstrate his apparatus at a new Marconi transmission station in Belmar, New Jersey. Armstrong and Sarnoff went through the night in a drafty wireless shack on a bitter and cold night copying messages from Clifden, Cornwall (England), Nauen (Germany), and Honolulu, which all came in strongly in the early morning hours. Again, all these were verified. Sarnoff's letter based on this experience was stronger, "the most remarkable receiving system in existence" [9, p. 65]. He recommended acquiring the system without delay. When the word of this recommendation reached Sir Godfrey Isaacs, the managing director of the Marconi Company, his temper flared, saying to the effect, that this young upstart should be fired, being so ready to spend the company's money! The Marconi Company did not buy into Armstrong's system at that time and Sarnoff was not fired. What is clear is that the two men always looked back fondly on that night in which so much about the possibilities for wireless became evident.

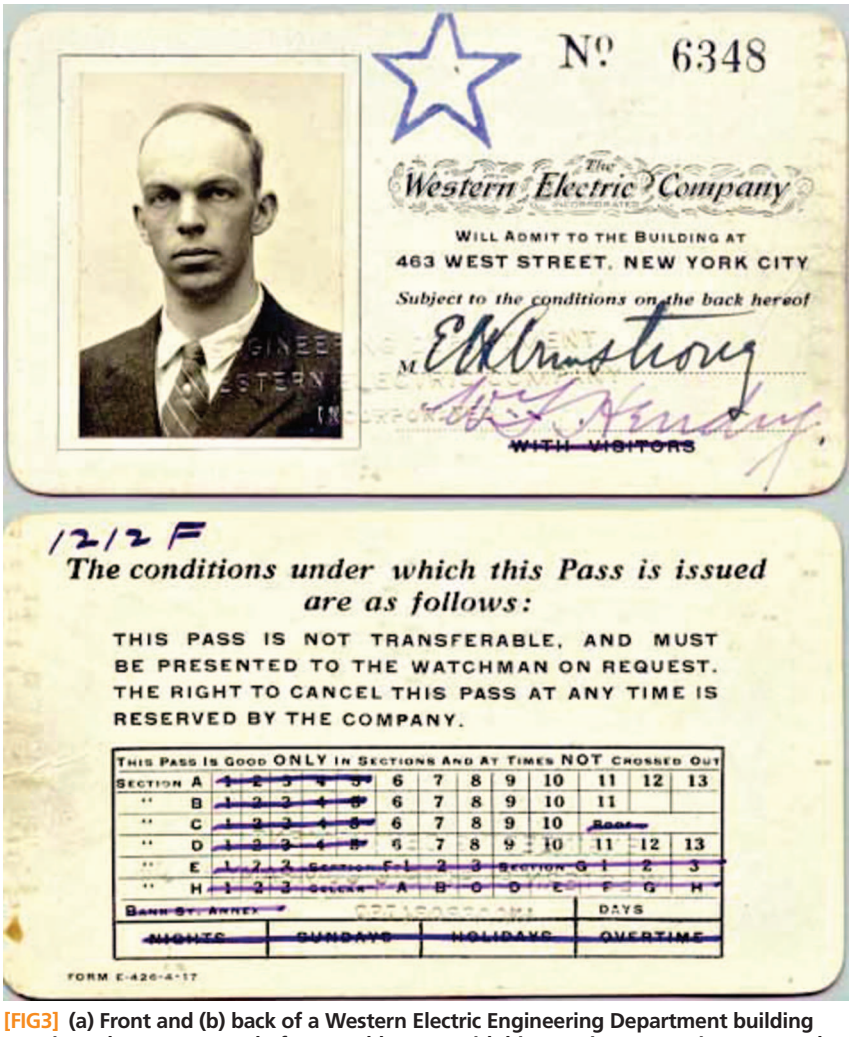
## PREWAR

In February 1914, Prof. Pupin bragged to a group at the University Club in New York City that he had listened to Honolulu. The chief engineer of AT&T, J.J. Carty was there and very skeptical, so a demonstration was arranged for some of their technical personnel. One should note that AT&T by this time had acquired the rights to the de Forest audion for wire and telephone use via some rather devious [6, pp. 108–109] indirect purchase by an attorney and some desperation on the part of de Forest, who had just had one of his companies go bankrupt and was on the verge of being indicted for stock fraud. AT&T was working extensively on the audion and Fritz Lowenstein, an AT&T inventor, had just used the audion to amplify in a telephone circuit without

screeching. How dare this unknown college student do better! After disclosing the workings of his circuit in the spring of 1914, Armstrong did not hear from that company again.

Somewhat more illuminating is Armstrong's first meeting with Lee de Forest at the 1913 meeting of the one-year old Institute of Radio Engineers (IRE, one of the predecessors of IEEE). De Forest lectured at Columbia about his audion and its use in a telephone repeater circuit and really wanted to see if the rumors he had heard about a Columbia student's discoveries were true. Armstrong, however, knew that de Forest had been admonished a few years before for trying to patent, essentially, a detector that he had seen in Fessenden's laboratory, so he was willing only to give a "black box" demonstration. There was little doubt that the two men disliked each other at first sight.

In the summer of 1914, Armstrong's instructorship ran out, but a one-year fellowship was found and he continued work at Columbia with Prof. Pupin attacking, for the first time, the problem of static in wireless systems. On 6 October 1914, his first patent was issued on the regenerative receiver circuit. With the outbreak of the war in Europe, the British cut off all undersea cables to Germany, leaving Germany only with wireless communications to the United States. After a demonstration of his apparatus in October 1914, the German company Telefunken and the German Embassy used Armstrong's receiver and was the first to license his patent, paying fees until the United States entered the war in 1917.




[FIG3] **(a) Front and (b) back of a Western Electric Engineering Department building pass issued to Armstrong before World War I. With his growing reputation among the radio community, and his many professional contacts at the IRE and The Radio Club of America, he must have been a frequent visitor to labs such as this one. (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

In late 1914–early 1915, Armstrong, with the help of Prof. Morecraft at Columbia, published and gave talks about the properties of the three-element tube (triode or audion) that clarified its use as an amplifier and/or oscillator. These were the tools that electrical engineers needed to design these devices into various products. De Forest, at about this time was ridiculing Armstrong's smoothly drawn curves. He strongly argued that the curves needed to have some "wiggles" in them. The discussions, which were reported in the IRE journals, were quite heated; history has shown that it was clear that de Forest even these years later still did not understand how his invention worked!

By 1914, Sarnoff had become the "de facto if not the de jure most effective adviser on technical and commercial policies" [9, p. 68] for the company. He was becoming its spokesman as well. His ideas for tolls, rates, and routing raised some controversy when he presented a paper to the IRE, but ultimately it was his views that prevailed. His opinion as an "out of the box" prognosticator was presented to Vice-President Nally in 1915 when he wrote him a memorandum developing a case for his in infamous "radio music box." Sarnoff realized that one of the problem issues with his company's business was that the radio transmissions were open to the public and not private for the sender and receiver. He thought this could be turned into an asset by using "broadcasting" to send out to thousands, if not millions, of receivers owned by the public. This was five years prior to the first true broadcasting station in the United States. In the memo, Sarnoff reasoned that they could bring the cost of the receiver down to about US$75 and sell a million of them. While the numbers were small compared to what really happened, the idea was proved by history. Marconi management read the memo in "wide-eyed amazement,"

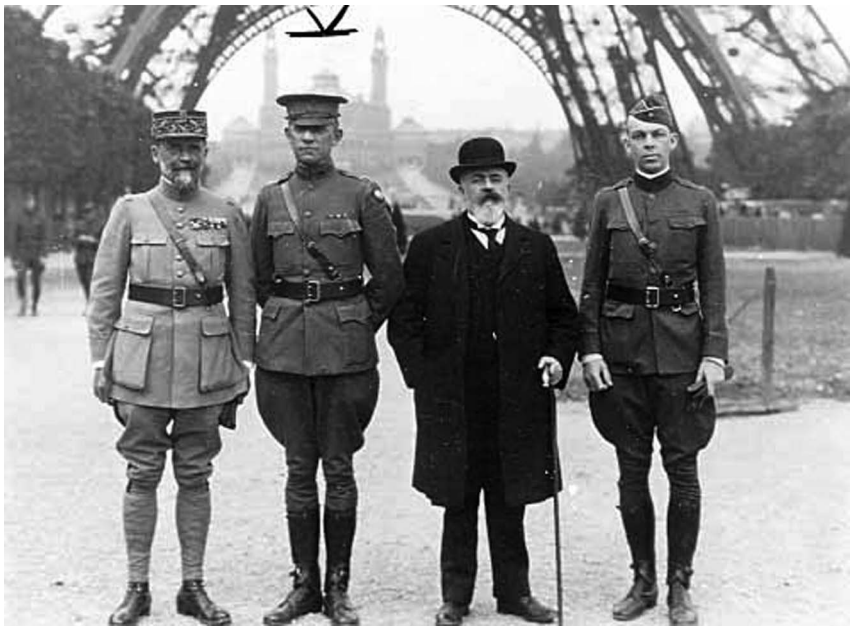
[9, p. 73] considered it harebrained, and it was filed and forgotten.

By 1 January 1917, Sarnoff had been promoted to the commercial manager of the growing company, one that was tripling its manufacturing capabilities. He was widely recognized as a spokesperson for the wireless industry and was made the secretary of the IRE. He had learned to interpret very intricate issues into a few basic tenets and had dealt with patent entanglements, licensing, and commercial rates. While not an inventor himself, he was very current in the technical intricacies of the industry and "his judgments on the enfolding science were not warped by the kind of ego drives and emotional reactions that unavoidably affected the views of men like de Forest, Fessenden, and Armstrong" [9, pp. 74–75]. Also, in February 1917, Sarnoff married Lizette Hermant, a vivacious French-born woman.

Alas, the cut-throat world began to show itself to Armstrong just after he had filed for his patent in late 1913. Three claims were made by others for the same or similar invention. One was from GE's excellent scientist Irving Langmuir, who was known for great improvements to the vacuum tube, but who had arrived at regeneration independently some time after Armstrong. Next was by a German, Alexander Meissner, who filed on 16 March 1914 for a regenerative circuit for a gas discharge tube. The third was Lee de Forest, who filed two patents, the first of which was dated March 1914, about six months after his "interaction" with Armstrong. All these were used for interference proceedings with Armstrong.

## WORLD WAR I

In 1917, Armstrong, a Theodore Roosevelt progressive, Republican, and Protestant Presbyterian, joined into the patriotism of the era. He was quite famous among the radio community and had just been elected the president of the Radio Club of America in 1916 (Figure 3). He decided to join the Army and was commissioned a captain in the U.S. Army Signal Corps, given short training in the summer of 1917 and had the good fortune to be stationed in Paris for the duration. At first he helped build some equipment that was devoid of vacuum tubes and his regenerative circuits. Then he was assigned to work on radio systems for communicating with aircraft. Of course, this gave him ample excuses to fly along with the equipment, which pleased him immensely.



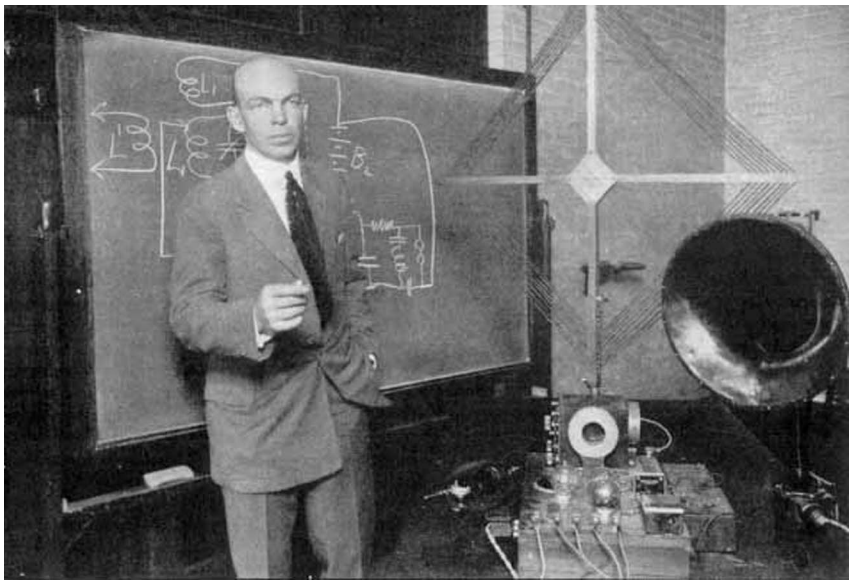
**[FIG4] From left: General Ferrie, an unidentified man thought to be his aide, Prof. Abraham, and Armstrong in front of the Eiffel Tower, 1918. (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

One evening in Paris, at a time when the German air force stepped up its bombing of the city, Armstrong was out watching the "fireworks" from a bridge over the Seine. He wondered whether he could somehow detect the very high-frequency (for that time) ignition noise electromagnetic emissions from the airplanes and use them in a direction finder to guide anti-aircraft fire. He had been dealing with the issue of how to detect these high-frequency waves with the currently available vacuum tubes that could not yet amplify well at these frequencies. At one intersection on his way back to his apartment, the idea hit him for what was to become the superheterodyne system. He immediately hacked together an eight-tube receiver. "Where the regenerative circuit amplified signals up to about one thousand times, the new circuit increased this by several thousandfold, with unprecedented stability, selectivity, and quietness" [7, p. 70]. He was to apply for a patent on this, but the application was dated 30 December 1918, signed in Paris. It reached the U.S. Patent Office on 8 February 1919 and was issued very quickly on 8 June 1920. This may have been his most important contribution, but it was not the patent that caused him to have his many patent legal battles.

In February 1919, he rose to the permanent rank of Major for his distinguished service. He was asked to give two lectures at the Sorbonne: one on regeneration and the other on the superheterodyne, and was awarded the Chevalier de la Legion d'honneur at the Palace of Justice (Figure 4).

He was unable to get home until late in September 1919 and in absentia was awarded his most prized honor. The IRE (the larger of the two societies that became the IEEE in 1963) had awarded its first Medal of Honor to him for his invention of the feedback circuit. This award was to play a role in Armstrong's later situations.

Sarnoff, having had many interactions with the Navy, the premier service for military radio, also immediately went down to the Brooklyn Navy Yard, applying for a commission in their



**[FIG5] Edwin H. Armstrong explaining the principles of his latest invention, "superregeneration" at a meeting of the RCA held at Columbia University, New York City. (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

communications area. However, his commission was blocked by "race prejudice in Washington" [9, p. 77]. He refused to ask his local draft board for a deferment and was thus certified for active service in the Army. However, Admiral R.S. Griffin wrote to the board that Sarnoff was essential in his current position, "in that the Fleet will not suffer delays due to unsatisfactory deliveries in existing contracts" [9, p. 77]. So Sarnoff performed his wartime duty in New York. The Germans and the British had succeeded in cutting each other's transocean cables, so wireless was more vital than it had been prior to wartime. In fact, President Wilson signed an order that all radio facilities, both commercial and amateur, be taken over by the Navy in April of 1917. Nevertheless, under Sarnoff's principal guidance, the Marconi Company had unprecedented sales of over US$5 million in 1917. He had made contacts with virtually all those in the military who dealt with communications (which would later prove important) and received many commendations for his leadership during this period.

## THE POSTWAR PERIOD

In 1919, the British Marconi Company wanted to acquire minimally, unrestricted access to the Alexanderson high-frequency alternator, the rotating machine, high-power transmitter that was developed and controlled by GE. As early as 1916, Sarnoff had written a position paper for the Marconi Company that the entity that had this technology would have a substantive advantage in the wireless communications business. Three months after the armistice, British representatives came to complete the multimillion dollar deal. The Navy, however, had alerted President Wilson that having foreign control over wireless communications in the United States was a bad idea. Assistant Secretary of the Navy, Franklin Roosevelt, then wrote to GE to postpone the sale of the transmitters and a conference was held in New York on 8 April 1919. The head of GE's legal department, Owen D. Young, was then asked to direct a group that was to let GE forcibly "buy out" American Marconi. GE completed the sale of the American Marconi interests on 20 November 1919 for over US$3 million and formed the RCA.

However, there was going to be a problem when the government was to allow wireless to return to private industry; the patent structure was very messy and no one company could build anything without infringing on patents held by another. AT&T held the de Forest patents and had accumulated many important patents, (principally on improvements for vacuum tubes) over the previous ten years, so a few months after RCA was formed, AT&T became one of the principal owners, purchasing about US$2.5 million in RCA stock. AT&T was to concern itself with all radiotelephony associated with telephone service and the manufacturing of transmitter equipment, while GE was to control all wireless telegraphy and receiver equipment construction.

The other large electric corporation, Westinghouse, did not want to be left out of the new arrangement. It had a modest patent portfolio of its own, but soon added to it by purchasing the International Radio Telegraph Company, the nearly bankrupt successor to Reginald Fessenden's National Electrical Signaling Company and later on purchasing the rights to all of Armstrong's patents. When Armstrong returned to the United States in the fall of 1919, his only income from licensing was the US$5,700 that had been paid by the Marconi Company over the previous two years. Thus, while always reticent to sign over patent rights, Armstrong was convinced by his patent attorney to sign over both the feedback and the superheterodyne rights to Westinghouse for US$335,000 payable over ten years, and for an additional US$200,000 payable when his oscillator patent was cleared from de Forest's pending interference suit. With these in hand, Owen Young was able to add Westinghouse to the ownership of RCA effective mid-1921. The deal was that Westinghouse was to do 40% of the manufacturing for RCA while GE was to retain 60% for itself. RCA was to have no manufacturing rights.

Owen D. Young became the first chief executive officer of RCA, Edward G. Nally its first president (he had been the managing director of American Marconi), and GE's Alexanderson the chief engineer. Sarnoff retained his position as commercial manager but was not named to the board of directors. In the beginning, only the memo justifying the idea

of a "radio music box" that Sarnoff had submitted to the Marconi Company had anything to do with RCA being in broadcast radio. However, in early 1920, Dr. Frank Conrad, a researcher at Westinghouse, started some regular broadcasts for amateur (typically crystal-set builders using earphones) listeners from his home in Pittsburgh. He was able to convince his company to build a new transmitter at Westinghouse and to broadcast the election results of 1920. Thus was founded what is accepted as the first radio station, KDKA in Pittsburgh, which received its license on 27 October 1920. It was to broadcast on a clear channel of 360 m (833 kHz). What followed was a stampede like no other before it. By 1 May 1922, about 18 months later, 218 [4, Exhibit G] of what we would today call commercial broadcasting licenses had been granted. However, with no reasonable regulation, most of these were crowded into a few frequencies. Given interferences and receivers that tuned badly, amateurs, and commercial messaging, it was a mess!

Armstrong, while devoting a lot of nervous energy to several litigations regarding all his patents, went back to Prof. Pupin at Columbia, working closely with him trying to solve the problem of radio interference for the standard amplitude modulation (AM) transmissions. He would work on this problem for the next 12 years before the wideband frequency modulation (FM) solution was found, and in the course of the research had many false starts based on inaccurate hypotheses. The wartime experience had impacted Armstrong, and he had returned as a more confident 28-year-old and was established as an expert among the growing group of radio amateurs. In 1920, de Forest had reopened his station in New York, broadcasting gramophone records and even using some live talent, but the Navy closed him down, since he was interfering with their messages. Dozens of amateur stations were also available, and electronics parts shops exploded with radio essentials, mostly for crystal sets. Armstrong had kept the rights to license his patents to amateurs and many wanted to use his regenerative circuits, so that by 1922, he was earning about US$10,000 per month from these licenses alone.

With the terrible crowding in the "normal" radio band, in 1921 the government restricted amateur radio transmissions to the "commercially useless" short wave band of over 1.5 MHz! In the summer of that year *QST*, the magazine of the American Radio Relay League proposed a test for this frequency range, wanting to obtain highly reliable transmissions with Great Britain. Armstrong and his Radio Club, using a transmitter of his own design and a superheterodyne receiver setup in Greenwich, Connecticut, not only made strong contact with the group specifically set up to receive the "high-frequency" commercial transmissions, but also with amateurs from Holland, Germany, and Catalina Island in California. This group of amateurs had done for about US$1,000 what industry might have done with greater ease, should it have been so inclined. Of course, Sarnoff was not one to miss the event. He and a group of RCA aides all came out to see what had been considered "impossible." Still, it took until about 1927 before Congress legislated to use some of these "short-wave" frequencies to get some semblance of order for the crowded airwaves. Stations continued to try to drown out their competitors and, if so inclined, worked out arrangements so that only one was on at a time.

It was also in 1921 when Armstrong, preparing to testify at the interference hearing against de Forest, was going over some of his old regenerative circuitry to refute a fact brought into evidence by an opposing lawyer. Suddenly, he heard reception so clear that it was very much beyond what he would have expected from the regenerative circuit. He immediately concluded that he no longer fully understood all about regeneration and subsequently invented a new system that used a second tube to "quench" the annoying squeal (oscillations) about 20,000 times a second. This allowed an amplification of up to 100,000 times the original signal strength, even more than for the superheterodyne. Now, being experienced with patents, he filed for a patent on superregeneration in 1921 (see Figure 5) and received a patent in July 1922, with six more following on the idea soon thereafter. Armstrong's timing could not have been more perfect, as this was at the beginning of the broadcasting explosion. Sarnoff was among the first to see the new system.

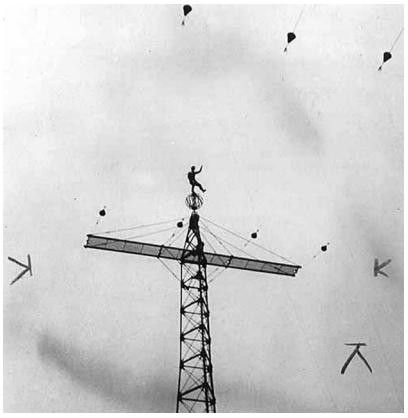
As RCA started to function, Sarnoff had the challenge of working through the maze of licenses and agreements with the large corporate shareholders of RCA all the while developing the wireless communications business and the burgeoning of the radio broadcast industry. As no corporate entity had foreseen broadcasting's spectacular growth, RCA and its corporate owners had to reach for a part of this new business, often in competition with one another. Keeping peace among them was no easy task, and Sarnoff worked endless hours on agreements, litigations, marketing, sales, and planning, having gained great friendship and trust from Owen D. Young.

From their first historic meeting in that Columbia laboratory in 1914, Sarnoff and Armstrong remained friendly. After the war, it was not unusual for Armstrong to drop in to Sarnoff's apartment at breakfast time for "just a cup of coffee" [9, p. 112]. Sarnoff's children called him "the coffee man." They were also often together at the RCA office discussing Armstrong's research and plans. While visiting in 1922, Sarnoff's secretary, Esther Marion McGinnis, a tall "strikingly handsome" [9, p. 112] woman of 22, who was out on her own in New York, abandoning the factory town of Merrimac, Massachusetts, caught Armstrong's eye. Lively and witty, she politely deflected Armstrong early advances. However, after Armstrong took a trip to France in October 1922, bringing back a fancy Hispano-Suiza automobile, she accepted a ride the next spring. The affair was on.

About this time, RCA was constructing its first New York broadcasting station, building twin 100-ft towers on top of the Aeolian Building on 42nd Street. There were crossarms on each tower on which a man could walk and, 15 ft higher, a large iron ball. Armstrong, always a bit of a daredevil, enjoyed being in high

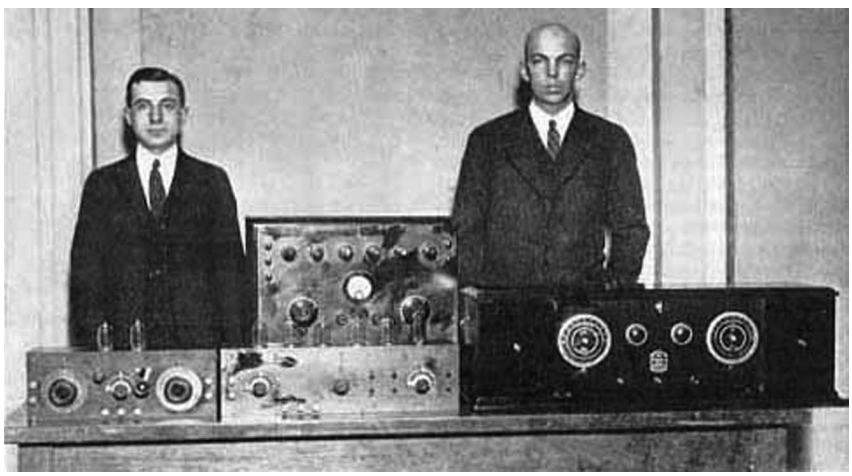
places, so he often came to watch the construction; however he also enjoyed climbing up and dangerously balancing himself atop the iron ball. This came to Sarnoff's attention, and he wrote Armstrong a strong letter to stop doing this. However, on the station's opening day, Armstrong climbed the tower and posed for the well-known picture shown in Figure 6, some 350 ft above the street. While this led to Sarnoff banning Armstrong from the station, it did not affect their friendship. Shortly thereafter, Marion McGinnis accepted Armstrong's proposal for marriage. After a harrowing trip in his new car from New York to the Boston area in December 1923, they were married in Merrimac and tried to take the Hispano-Suiza for their honeymoon to Florida. However, the car (and they) traveled more by train than they had expected! They moved into an apartment on 86th Street and Riverside Drive.

The friendship, inventions, and the need all came together in 1922 and 1923. RCA, unable to manufacture on its own, had a very slow development process that killed sales of RCA radio sets as other companies could offer the latest developments. While crystal sets were at first the most widespread, new designs using vacuum tubes were appearing. One in particular, the Neutrodyne, invented by Alan Hazeltine, a friend of Armstrong and a professor at Stevens Institute of Technology in New Jersey, was widely



**[FIG6] Armstrong atop the new WJZ/WJY Broadcasting Tower in New York City, 15 May 1923. (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

accepted by the public. It successfully avoided the large patent entanglements controlled by RCA, and its design was put up by Hazeltine for licensing to a large number of RCA's competitors. RCA's offerings, often six months behind, had a very poor share of the marketplace. Thus Sarnoff saw an opportunity for RCA, having been so impressed with the abilities of the superregenerative system. Of course, first he needed to do "due diligence" as the corporate manager, so he had his patent department search for a patent with which RCA could challenge Armstrong's invention. They only found one marginally similar English patent granted to a man named John Bolitho. However, Armstrong had done his homework and had purchased the rights to the patent for a few thousand dollars. Ultimately, Sarnoff's attorneys were told if they wanted the Bolitho patent to see a man named Armstrong. Thus, Sarnoff persuaded his board to offer Armstrong US$200,000 and 60,000 shares of RCA stock for the exclusive rights to superregeneration. This was a very large sum for the time. RCA stock was booming, and this transaction made Armstrong an instant millionaire. Unfortunately for Sarnoff, in a short time RCA and Armstrong concluded that the superregenerative system could not be mass produced easily. Superregeneration was used for identification, friend, or foe (IFF) transponders, police radio, ship-to-shore, and other special purposes later on. Despite its magnificent amplification, it could not be made sufficiently frequency selective, dooming it for the radio industry of that time. However, Sarnoff seemed to always have a lucky streak; for, at the same time, he had also obtained exclusive rights to Armstrong's superheterodyne system. Armstrong had demonstrated his latest design at then Vice-President Sarnoff's apartment in early 1923. Sarnoff was very impressed, having been told by his own technical staff that the superheterodyne design was years away. Armstrong also took another set to the apartment of RCA Chairman Owen D. Young, entering with the battery-powered receiver blasting an opera that had clarity beyond anything he had ever heard.



**[FIG7] Houck and Armstrong with three superhets: (a) The Signal Corps. set built in France, (b) the preproduction second harmonic superhet, and (c) the production second harmonic superhet, the Radiola Superheterodyne, 1923. (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

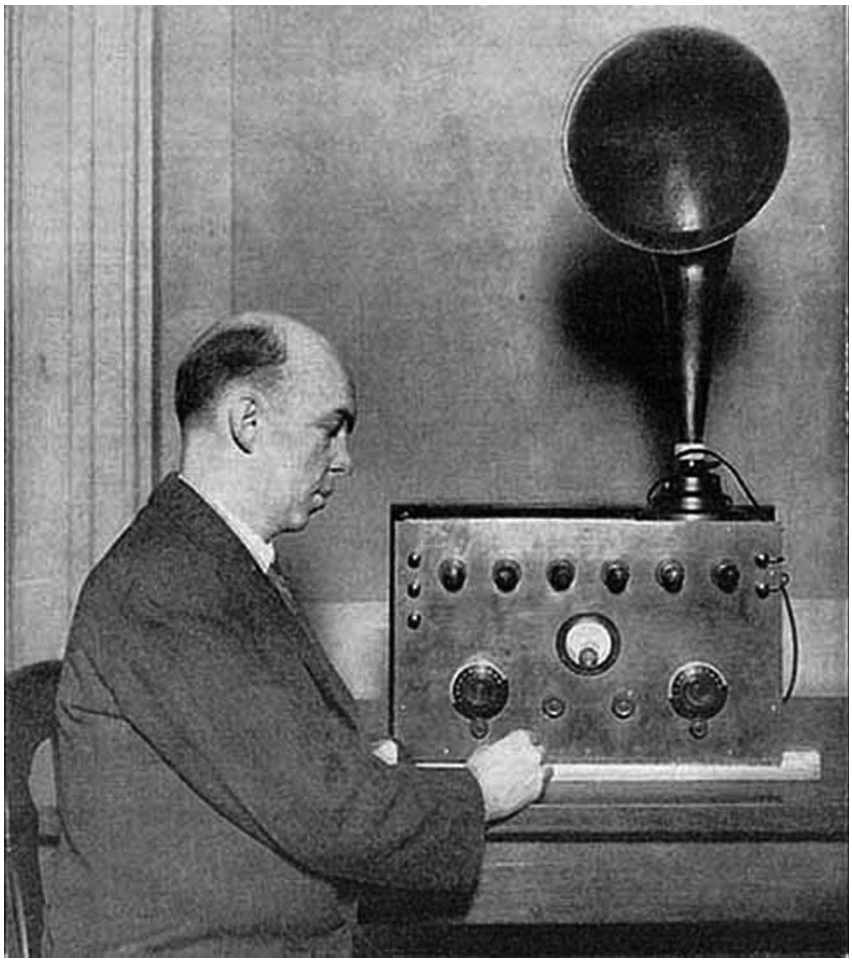
At the time that the licensing arrangement with Armstrong was consummated, RCA was about to conclude its yearly commitment for several million dollars with its two manufacturers for radio sets who were to build an improved design developed by the RCA technical staff. With the superheterodyne now in hand, Sarnoff canceled the next meetings needed to conclude the contract. He was willing to sacrifice a year of sales to restart with the technically superior product. The RCA staff began a crash program to get the superheterodyne system to market in 1924, hopefully leapfrogging its Neutrodyne (et al.) competitors. By midsummer of 1923, Sarnoff heard that AT&T (part of the licensed group) was

preparing to enter the radio receiver business with a superheterodyne receiver of its own and was going to install a set in the White House for President Harding. However, Sarnoff's staff was having a lot of problems developing the superheterodyne for production.

When Dr. Albert Goldsmith, RCA's head of their laboratory came to Sarnoff to advise that the project be abandoned and the original contracts reinstated, Sarnoff was in a tough spot. Seeing the crisis, Marion McGinnis suggested, "Why don't you call Armstrong?" [7, p. 119].

Not only had Armstrong made further developments of the superheterodyne, but, Harry Houck, working with him (see Figure 7), had developed technology sufficient for a patent for using the second harmonic in the superheterodyne receiver and had reduced the complexity of the receiver to two knobs. After a few intensive weeks, and successfully getting the new RCA receiver ready for production, Sarnoff awarded Armstrong an additional 20,000 shares of RCA stock for pulling off this success. This proved to be a good investment, as the new receiver, introduced for sale in early 1924, was a sensation and put RCA far ahead of its competitors (Figure 8). RCA dominated the market for the next three years, also working hard to try to mitigate the Hazeltine patents. Surprisingly, the additional shares made Armstrong the largest single stockholder in RCA. Finally, in 1927, a system of more liberal licensing was put into place that allowed virtually everyone to use the patents, making the "superhet" available to all manufacturers. RCA received modest royalties under the agreement that it had to share with the electric companies. Armstrong was never paid any royalties by RCA.

After the licensing agreement was concluded with Westinghouse in 1920, the company backed his decision to prepare a suit against the de Forest Radio and Telegraph Company, one of about 25 [10, pp. 86–87] companies that de Forest started that ultimately went bankrupt. This suit, to once and for all mitigate de Forest's infringing claims, started hearings in the federal court of the southern district of New York in January 1921. This



**[FIG8] Armstrong and his prototype second harmonic superheterodyne (radio broadcast 24 July 1923). (Image from the Houck Collection site, reprinted with permission from Mike Katzdorn.)**

fight ultimately took 14 years and had a severe impact on Armstrong. This is well expressed by Lessing, who quoted one of Armstrong's patent attorneys:

> ...there were really three Armstrongs, closely related, but distinct, contained in the same character but separated by the increasingly harsh attrition of events. The first of these was the easy, modest man of the private world who could relax swiftly among friends into intercourse of intangible charm and grace. This private man held a legion of friends over the years, with but one notable disaffectation [de Forest]. The second Armstrong was the man of finance and affairs, who could press forward aggressively to achieve his ends. A little apart from these figures stood Armstrong the inventor, proud and lonely and raised on a pedestal, whom the other Armstrongs protected with the jealousy of a brother and whose life went forward in the intensely individual processes of creation, oblivious for long periods of even wife and friends. At the slightest threat to the image of the inventor, all the forces of the whole personality marshaled to repel the attack.

In 1922, Armstrong's patents had been sustained twice, both by the District Court and the Second U.S. Circuit Court of appeals. It was clear from the testimony that the true inventions were Armstrong's, as the IRE had concluded in its first Medal of Honor Award in 1919. It was, however, at this point that these apparent legal victories started to unravel. In a patent case such as this, no

final judgment can be entered until either damages are drawn up or the winner has waived damages. The stubborn Armstrong refused to waive damages, against the advice of his supporting Westinghouse attorneys. Meanwhile, the special master assigned to assess damages died suddenly, there were great delays in appointing a successor, and the de Forest Company went bankrupt. In 1924, out of this maze of litigation, de Forest was able to get a decision from the District of Columbia Court of Appeals ordering the Patent Office to issue him immediately patents on both his two patent submissions (applied for later than Armstrong's and after he had seen Armstrong's apparatus) for the "ultra-audion" and his regenerative system. Quoting from a private conversation with my Brown University office neighbor, Barrett Hazeltine, the son of Armstrong's friend, Alan Hazeltine, "My father always said de Forest never understood his own circuit." Now the battle was on again in an interference suit that turned more to legalisms and word games than true technical evidence. Also, de Forest's interests were defended by all of AT&T's legal department, while Westinghouse, whose advice had been spurned by Armstrong, no longer supplied its legal force. Two men now held the same patents. Several suits were filed in Delaware. De Forest sued to have Armstrong's patent declared null and void in Philadelphia. With the issue thus confused, AT&T and de Forest won in both places and in 1927 these findings were upheld by the Third Circuit Court of Appeals.

The losses to de Forest were taken as a personal affront by Armstrong, so he decided to carry the battle to the Supreme Court. This he did in 1931. Marion Armstrong worked hard for her husband, as did his friends from the Radio Club. This was the topic for many discussions at IRE meetings. After some wins and losses in lower courts the final verdict by the Supreme Court was rendered on 24 May 1934, siding with AT&T and de Forest. By this time, RCA had it in its own interest to back the de Forest suit as well, which was a first crack in the friendship between Armstrong and Sarnoff. While there were petitions from Michael Pupin, Alan Hazeltine, and other of Armstrong's supporters who believed the verdict was a total distortion of the scientific facts, the petition was denied. On 28 March 1934, the IRE held its ninth annual convention at the Hotel Benjamin Franklin in Philadelphia. Armstrong walked into the meeting of some 1,000 engineers who were stunned to see the inventor that had been so poorly treated by the patent system. The Institute had been informed that he would like to give a speech, returning the 1918 Medal of Honor awarded to him for the discovery of regeneration. The speech in his pocket began [7, p. 153]:

> It is a long time since I have attended a gathering of the scientific and engineering world—a world in which I am at home—one in which men deal with realities and where truth is, in fact, the goal. For the past ten years I have been an exile from this world and an explorer in another—a world where men substitute words for realities and then talk about the words. Truth in that world seems merely to be an avowed object….

The speech was never presented. IRE President Charles M. Jansky went to the podium and announced that, by a unanimous decision of the Institute's Board, the medal had been correctly awarded. He reaffirmed the citation for his discoveries of regeneration and oscillations for vacuum tubes. He was given a standing ovation. This is especially poignant in that half of the Board members were employed by AT&T, RCA, or their affiliated companies, and this was the depth of the depression. Nevertheless, the corporate departments responsible for putting out press releases now worked hard to build up de Forest as "the father of radio." While somewhat buoyed by the decision of the IRE, the patent fight took its toll on Armstrong continually, from that point on, narrowing his group of trusted individuals.

In the second part of this article, we shall finish the story, observing that, as the goals of the two giants diverge, so does their relationship. Armstrong, while hurt by losing his long patent battle for the regenerative oscillator, still has another breakthrough to reveal in the 1930s—FM radio. Sarnoff, while having to deal with fiscal problems of the depression of the 1930s, has one of his largest successes, using RCA as the driving force for television and later even wins for his standard for color television. However, all the successes did not necessarily lead to happy endings.

I hope you are looking forward to reading the story's conclusion in the January issue of *IEEE Signal Processing Magazine*.

> For a viewpoint totally out of agreement to what is presented here, one may read the letter written by Lee de Forest in 1956 as a criticism to a positive article on Armstrong published in *Harper's Magazine* in April 1956, which is preserved with author Carl Dreher's response near the end of the Houck Collection.

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