Reginald Aubrey Fessenden and the Birth of Wireless Telephony

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Abstract

The year 2000 was the 100th anniversary of the transmission of the first voice over radio. On December 23, 1900, Prof. Reginald Aubrey Fessenden (Figure 1) – after a number of unsuccessful tries – transmitted "words without wires" over a distance of 1600 m, between twin aerial systems employing 15 m masts, located on Cobb Island, Maryland. The quality of the received wireless-telephony transmission was reported to be perfectly intelligible, but the speech was accompanied by an extremely loud, disagreeable noise, due to the irregularity of the spark. Spark? Yes. Fessenden had not yet developed a method to generate continuous waves. The sender was a spark transmitter, operating at 10,000 sparks/second, with an asbestos-covered carbon microphone inserted in the antenna lead. In spite of the primitive apparatus used, the poor quality of the transmission, and the short distance, intelligible speech had been transmitted by electromagnetic waves for the first time in the history of wireless.

Who was Fessenden? The purpose of this paper is to touch upon his life's history, and to give some detail of his accomplishments. However, the paper begins with a brief account of the birth of radio, so that the reader can appreciate Fessenden's place in history.

Keywords: History; radio communication; telephony; R. A. Fessenden

1. A Brief History of the Birth of Radio

The very possibility of wireless communications was founded on the research of James Clerk Maxwell. His assumption that a changing displacement density (that is, a changing electric field) was equivalent to an electric-current density, and, as such, would produce a magnetic field, has had most far-reaching effects. Combined with Faraday's law, which indicates that a changing magnetic field will produce an electric field, it leads directly to the "wave equations." It should be observed that this assumption was made as a result of the recognition of an error that was pointed up by mathematics. This is an interesting example of one of those rare cases where mathematical reasoning preceded and pointed the way for experiment. The correctness of the wave equations was established by Heinrich Hertz, when, in 1887, he discovered electromagnetic (EM) radiation at UHF frequencies, as predicted by Maxwell. Since the pioneering work of Maxwell, beginning in the middle 1850s, and of his followers (a small group that became known as Maxwellians, which included the UK's John Henry Poynting, Oliver Lodge, Oliver Heaviside, and the Irish professor George Francis FitzGerald), his equations have been studied for over a century. They have proven to be one of the most successful theories in the history of electromagnetic waves and radiating systems. For example, when Albert Einstein found that Newtonian dynamics had to be modified to be compatible with his special theory of relativity, he found that Maxwell's equations were already relativistically correct. EM-field effects are produced by the acceleration of charges, and so Maxwell had automatically built relativity into his equations.

But the history of wireless can be traced back much earlier. It should be pointed out that in the experimental verification of the results foretold by Maxwell's wave equations, use was made of the results of experiments in pure physics that William Thompson Kelvin had made forty years previously [1]. Kelvin had set himself the task of investigating the way in which a Leyden Jar discharged, and found that under certain conditions, the discharge gave rise to alternating currents of very high frequency.

Joseph Henry, an early experimenter with wireless telegraphy, was not only the first to produce such high-frequency electrical oscillations for communication purposes, he was the first to detect them at a distance – albeit, a very short distance – from an upper floor to the basement, using what was later known as a magnetic detector [2, 3]. Thomas Edison, and Elihu Thompson and Edwin Houston, made many experiments on these transmitted waves, and reports on their experiments can be found in [4], and in Edison's papers in technical journals of that time.

The first wireless telegraphy patent in the US was issued on July 20, 1872, to Mahlon Loomis, fifteen years before Hertz. His Patent No. 129,971 was for "Improvement in Telegraphing," and covered "aerial telegraphy by employing an 'aerial' used to radiate or receive pulsations caused by producing a disturbance in the electrical equilibrium of the atmosphere." In October, 1866, in the presence of US Senators from Kansas and Ohio, Loomis set up a demonstration experiment on two mountain peaks in the Blue Ridge Mountains of Virginia, 22 km apart (see Figure 2). He flew kite-supported wire aerials 183 m long, connected at their support ends to a galvanometer, which itself was connected to a plate buried in the Earth. Each kite had a piece of wire gauze, about 38 cm square, attached to the underside. With a prearranged time schedule, signals were sent from one peak to the other by making and breaking the aerial connection of one galvanometer, and noting the response of the other galvanometer on the other peak. The operation at each station was reversed. Loomis's simple antenna-galvanometer-ground arrangement was duplicated by military engineers, and its workability was substantiated.

Between 1870 and 1888, von Bezold, FitzGerald, and Hertz had clarified the nature of the phenomena being observed to a considerable extent, and Hertz's work had shown that the experimenters were, in fact, dealing with EM waves. Dolbear and Edison had been using vertical grounded antennas for wireless telegraphy, although the effects they obtained were mainly electrostatic, and not propagating EM waves. Crookes, in the *Fortnightly Review* for February, 1892, proposed that resonant circuits should be used to select out messages from different stations. Nicola Tesla, who had been doing a great deal of work in producing HF oscillations, proposed, in 1892, a system for transmitting wirelessly using the vertical antenna of Dolbear, and tuned transformer circuits at the sending and receiving ends [5]. Tesla described his wireless system to the Franklin Institute, in Philadelphia, Pennsylvania, in March, 1893, and later in the same year in St. Louis, Missouri, before the National Electric Light Association. During the St. Louis presentation, he demonstrated sending wireless waves through space, complete with a spark transmitter, grounded antenna, tuned circuits, a Morse key, and a receiver with a Geissler tube as an indicator [6, 7].

Tesla's stroke of genius was to use two tuned circuits in the transmitter (and two in the receiver), inductively coupled, and to so move the energy-storage capacitance (or "discharge condenser") to the primary side. Tesla was the first to inductively couple the secondary side, the antenna side where the capacitances are small, the capacity of the grounded antenna, to a primary tuned circuit where the energy-storage capacitance could be huge by comparison. This made possible the generation of RF signals immensely more powerful than the Hertz type of apparatus, which others were using at that time.

Historians have generally attributed the invention of tuning to Marconi: his so-called master tuning patent. Certainly, Marconi filed and held (in early years) several patents on tuning. His original patent, filed in 1896, described sending and receiving stations with no tuning at all. Marconi's second patent, reissued US Patent No. 11,913 (originally, No. 586,193 granted on June 4, 1901), was for a two-circuit system: one circuit in the transmitter, and one circuit in the receiver. Again, this was a very inefficient system. Marconi's "famous" four-sevens patent (No. 763,722), a four-circuit system, was applied for (some references say, granted) in April, 1900. But this Marconi patent was rejected on June 28, 1904, by reason of the prior art set forth in a patent by Lodge (No. 609,154), but principally in Tesla's US Patent No. 645,576, applied for on September 2, 1897. New applications and petitions for revival were filed by the Marconi company, resulting in a legal battle that continued for years. It took the courts several decades to figure out the facts. Eventually, the US Supreme Court struck down the Marconi patent ruling in Tesla's favor in 1943 (for details, see, in particular, the preface in [8]). *The Tesla patent is the key to early long-distance wireless communications.*

Continuing, Lodge [9] and Popoff [10] – who had used a vertical grounded antenna, coherer and tapper back – pointed out that their apparatus might "be adapted to the transmission of signals to a distance" in 1894/95. Sir Oliver Lodge demonstrated the possibility of Morse signaling by sending wireless signals, i.e., wireless communications, at the British Association meeting in Oxford on August 14, 1894. On the suggestion of telegrapher, Muirhead, he sent dots and dashes over a distance of 60 m, from his induction coil and spark-gap transmitter to the receiver. The receiver consisted of a coherer, a Lodge invention, which was connected to a Morse recorder that printed on paper tape. It could also be connected to a Kelvin marine galvanometer: the deflected light spot made viewing by the audience easier. This demonstration was viewed by several notable scientists in their own right, including Sir J. A. Fleming. Lodge made no attempt to protect the use of his apparatus by others by a patent at that time; he did so three years later, in 1897. He also made no attempt to publicize and promote the idea of wireless telegraphy. Although (apparently) he described the experiment at the time as "a very infantile form of radio telegraphy." This was a statement reflecting his modesty, but an undoubtedly significant one, because it established what he had actually done when the induction coil was actuated by a Morse key by his assistant, E. E. Robinson [11].

On the basis of historical research, there is also indirect evidence (however, not disclosed until 30 years after the event) that Aleksandr Popoff, a contemporary of Lodge and Marconi, gave a demonstration of a wireless telegraph link to a meeting of the St. Petersburg Physical Society on March 12, 1896. It was said that he transmitted the words "Heinrich Hertz," and that as the code characteristics were received, the chairman translated them into letters and chalked them on the blackboard. A description of the equipment used had been published prior to the demonstration, but no verbatim record of the demonstration survives (see Part IV, p. 69 in [12]).

At the University of Bologna, Italy, Augusto Righi incorporated the work of Hertz in his lectures, and constructed a transmitter in 1894. Lodges's 1894 lecture, and the lectures of Righi, caught the young Marconi's attention. With a keen eye for commercial opportunity, Marconi realized that there was a market for such telegraphic systems. In July, 1896, Marconi gave a demonstration to the English Post Office at Salisbury Plain using apparatus similar to that used by Lodge. There, he succeeded in increasing the range from its previous 800 m, obtained by other experimenters, to a distance of about 3 km [13]. But more importantly, as a result of this demonstration, history has (apparently) accredited Marconi with the invention of an early form of wireless telegraphy. However, others were before him.

In the same year (1896), Captain (later, Admiral) Jackson, of the British Navy, found that considerably greater distances could be obtained using the Dolbear-Edison-Tesla arrangement of vertical antennas and tuned sending and receiving transformers at both transmitting and receiving ends.

Clearly, Marconi was not the first to send intelligible signals by Hertzian waves, nor can we say that he devised many of the circuits and devices that he patented. Marconi was an experimenter but not an inventor, and a promoter of the business side of wireless. Marconi spent his entire life attempting to develop wireless communications into a "practical" reality. One can safely say that he was the first to establish a wireless company, The Wireless Telegraph Company Ltd., which was founded in 1897. Its name was changed to Marconi's Wireless Telegraphy Co. Ltd. in 1900.

Such was the state of the art at the beginning of the 20th century. Hertz was not interested in the commercial exploitation of Maxwell's equations. Application of Hertz's work was left to Lodge, who also did little to exploit practical application, and to Fessenden, Marconi, and many others.

2. The Concept of Continuous Waves is Born

Marconi, those working with him, and most experimenters in the new field of wireless communications at the turn of the century, were unanimous in their view that a spark was essential for wireless. Marconi actively pursued this technology, from the beginning of his early experiments in Italy in 1895, until about 1912. In fact, he fought to quell any divergence from that mode – because he wanted wireless communicators, particularly shore-to-ship and ship-to-shore operators, to use Marconi apparatus, and to employ operators trained to use Marconi equipment. In order to (attempt to) control this field, he decided to lease apparatus, rather than to sell it outright. This strategy did not work. Competition developed in Germany (Telefunken Corporation) and in the United States (American De Forest and National Electric Signaling Company), and Marconi was forced to sell rather than lease apparatus to navies of the world. He nevertheless retained numerous restrictions. This lead to further friction. At the height of this debacle, English stations worldwide refused to communicate with ships without Marconi equipment. This absurd and dangerous situation had to change, and coastal stations opened up to all senders in 1908.

Fessenden had been lecturing and experimenting on the production and detection of Hertzian waves for a number of years prior to the turn of the 20th century. He was convinced that there was no essential distinction between the high-frequency oscillations from an arc and a continuous current, discovered by Elihu Thompson in 1892 (US Patent No. 500,630, July 18, 1892), and the damped oscillations produced by spark-generated transmission systems. He was convinced that there was no mysterious "whip crack" of the ether involved in the generation of wireless signals [14]. He was also convinced that practical, operating, wireless systems should be based on sustained oscillations: continuous-wave transmission and reception. When asked how to generate continuous waves, Fessenden boldly said: "Take a high frequency alternator of 100,000 cycles per second, connect one terminal to the antenna and the other terminal to ground, and then tune to resonance".

To exemplify current thinking at that time, Prof. Cross stated that "alternating currents in the vertical wire will not produce Hertzian waves in the ether, as such waves are produced only by disruptive discharge" [15]. In the first edition of his book on *Electromagnetic Waves*, published in 1906, Fleming made reference to Fessenden's 1901 patent (No. 706,737) describing the generation of CW wireless signals by use of a HF alternator. Fleming stated that there was no suitable high-frequency alternator of the kind described by Fessenden, and that it was doubtful if any appreciable radiation would result if such a machine were available and were used as Fessenden proposed. Quoting directly, he further stated, "...unless some form of a condenser is discharged to cross the spark gap there can be no production of Hertzian waves – the disruptive discharge is the one essential condition for the production of Hertzian waves." This statement did not appear in subsequent editions of Fleming's book, since 1906 was the year in which Fessenden succeeded in getting his HF alternator to work, and used it in conjunction with an aerial to generate EM waves. But this belief, and an earlier belief that the terminals of an antenna had to be bridged by a spark, show how wrong some of the early views were.

Subsequently, Judge Mayer, in his opinion upholding Fessenden's patent on this invention, said, "It has been established that the prior art practiced, spark or damped wave transmission, from which Fessenden departed and introduced a new or continuous-wave transmission, for the practice of which he provided a suitable mechanism – which has since come into extensive use."

The above references are cited to aid the reader in properly evaluating the great contribution of Fessenden's: *the concept and the method of generating continuous waves.*

3. The First Voice Over Radio

Marconi saw no need for voice transmission. He felt that Morse code was adequate for communication between ships and across oceans. He was a pragmatist, and uninterested in scientific inquiry in a field where commercial viability was unknown. He, among others, did not foresee the development of the radio and broadcasting industry. For these reasons, Marconi left the early experiments with wireless telephony to others: Fessenden and, later, Lee De Forest.

Reginald Aubrey Fessenden was born in Canada, in Knowlton, Brome County, Canada East (now Quebec), on October 6, 1866. Working in the United States, he recognized (his early work dates to about 1892 [14, 16]) that continuous-wave transmission was required for speech. He continued the work of Tesla, John

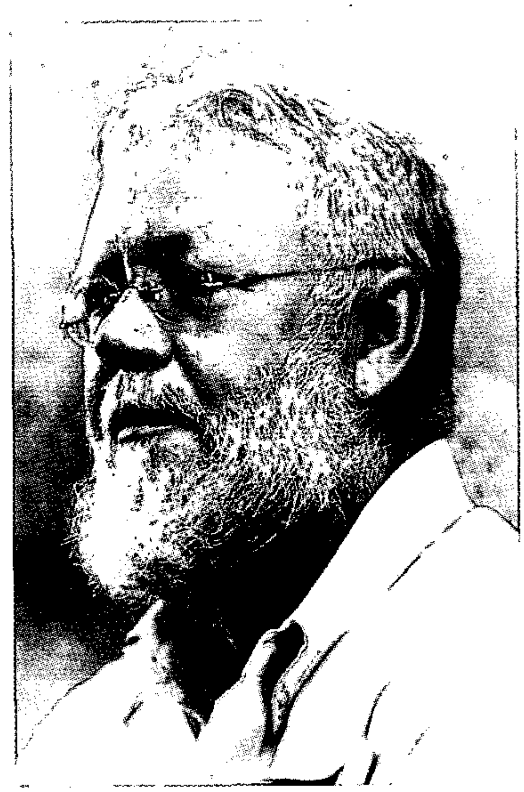

Figure 1. Professor Reginald Aubrey Fessenden (1866-1932).

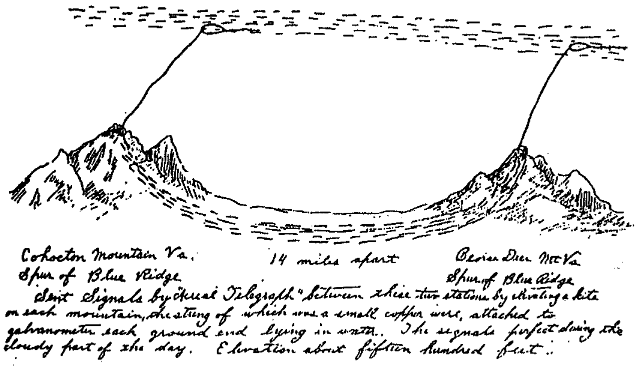

Figure 2. A reproduction of Mahlon Loomis' sketch of his 1866 demonstration of wireless aerial telegraphy between Cohocton Mountain and Bear's Den, Virginia.

Stone, and Elihu Thompson on this subject. Fessenden also felt that he could transmit and receive Morse code better by the continuous-wave method than with spark apparatus. Quite alone in this direction at the turn of the century, his CW patents had little impact on the users of wireless technology [17, 18]. Methods to generàte and receive CW transmission were yet to be developed.

From the very beginning of wireless communications, Fessenden realized that to improve upon the Hertz-Henry damped-wave spark-generated transmission systems – with the Branley-Lodge-Edison bad-contact (Fessenden's words) coherer detector system, used by Marconi and others for receiving wireless telegraphy signals – one needed a continuous-wave signal [19]. He also realized that for wireless telephony, a CW signal was a necessity. There was no satisfactory means of generating a CW signal prior to circa 1903. There fore, his early work – which began circa 1896, when he was a professor at the University of Pittsburgh, Pennsylvania – was to develop a more suitable receiver for Hertzian waves (CW or spark).

He knew that he needed a "continuously acting, proportional indicating receiver" (Fessenden's words). He tried dozens of methods in the period 1896-1902: methods proposed by others, as well as methods devised by himself. In 1900 and in earlier years, his liquid Barretter (US Patent No. 727,331, April 9, 1903, for the basic detector; and No. 793,684, December, 1904, for a sealed detector for shipboard use) had not yet been devised. The word *barretter* was coined by Fessenden from his classical background. The term is a derivation from the French word *exchanger*, implying the change from alternating current to direct current. Nowadays and even then, this detector is referred to as an electrolytic detector. But Fessenden did not like this name, because he believed, at that time, that its operation depended upon a resistance change associated with heating at the point of contact with the sulfuric acid.

Circa 1898, Fessenden was using his modified version (US Patents Nos. 706,736 and 706,737, December 15, 1899) of Elihu Thompson's alternating-current galvanometer (US Patent No. 363,185, January 20, 1887). In the words of Fessenden, he described how "the ring of a short period Elihu Thompson oscillating current galvanometer rested on three supports, two pivots and a carbon block. A telephone receiver with a battery in series was used in the circuit with the carbon block." This primitive device must have produced resistance changes associated with amplitude changes of the received RF signal, which were detected by the telephone receiver.

In November, 1899, while experimenting with this receiver – listening to a spark-generated telegraphy signal, produced by a transmitter with a Wehnelt interrupter for operating the induction coil used for sending – he noted that when the sending key was held down for a long dash, he could distinctly hear the peculiar wailing sound of the Wehnelt interrupter. This immediately suggested to him that by using a spark rate above audibility, and with some means to modulate or change the amplitude of the transmitted signal by speech, that wireless telephony could be accomplished. Recall that a method to generate CW was yet to be devised. So, proceeding along these lines of thought, Fessenden decided to up the spark rate by a large factor, to better simulate a CW-like signal. Professor Kintner – one of Fessenden's earlier students, who at that time was assisting Fessenden with his experiments – designed an interrupter to give 10,000 breaks/s. Mr. Brashear, a celebrated optician, constructed the apparatus, which was completed in January or February, 1900. But it was not before the fall of 1900 that this interrupter was used. The reason was that Fessenden was engaged in transferring his laboratory from Allegheny, Pennsylvania, to Rock Point, Massachusetts, and in setting up stations at Rock Point and on Cobb Island, Maryland.

It is clear that for his initial wireless-telephony experiments, in December, 1900, that he was using a spark transmitter with the Kintner-Brashear interrupter. However, the author has found no mention of the type of receiver used. The detector must certainly have been Fessenden's version of the oscillating-current galvanometer, because, as noted above, he had no time to devise a better detector. Nor was the frequency for this first experiment mentioned. However, since the transmission took place between two twin-tower antenna systems on 15 m masts, 1600 m apart, the frequency could have been 5 MHz, or probably much lower. The modulator for the spark transmitter was an asbestos-covered Edison-carbon microphone, inserted in the antenna lead (see Figure 3a; US Patent No. 706,747, August 12, 1902). This figure also shows a later version of a Fessenden receiver (Figure 3b), in use after 1902.

After a number of unsuccessful attempts, Fessenden was finally rewarded by success. Speaking very clearly and loudly into the microphone, he said: "Hello test, one two, three, four. Is it snowing where you are Mr. Thiessen? If it is telegraph back and let me know." Barely had he finished speaking and put on the headphones when he heard the crackle of the return telegraphic message. It was indeed snowing, since Mr. Thiessen and Prof. Fessenden were only 1600 m apart. But intelligible speech by EM waves had been transmitted for the first time in the history of radio. The received telephony transmission was described as words perfectly understandable, excepting the speech was accompanied by an extremely loud, disagreeable noise due to the irregularity of the spark [16, 19]. Because the voice-induced resistance change (which modulated the antenna current) was small, the percentage modulation must also have been small; nonetheless, it was enough to demonstrate wireless transmission of sound. But, "words perfectly intelligible" with such a primitive apparatus?. The author, using equipment similar to that used by Fessenden excepting for the detector, has, however, simulated the authenticity of that transmission [20].

4. Transatlantic Communication

Since methods to generate CW were yet to be developed, as noted above, Fessenden's early experiments had to make do with spark transmitters, the only means known to generate appreciable

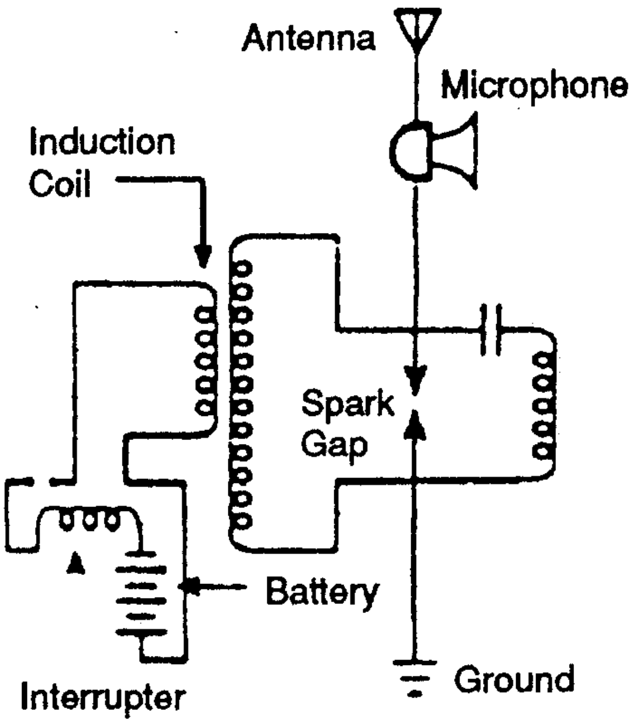

Figure 3a. An early version of Fessenden's spark-gap telephony transmitter.

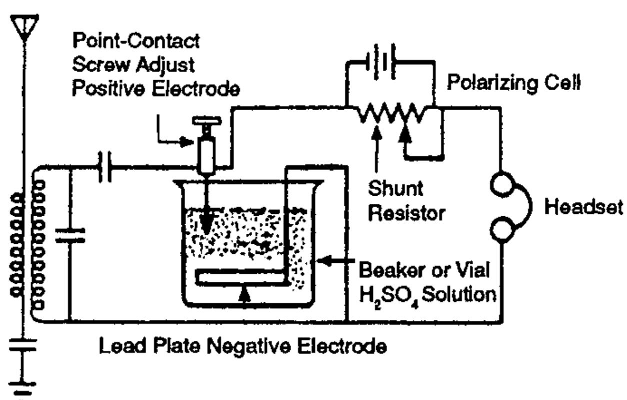

Figure 3b. A version of receiver employing an electrolytic detector, used somewhat later than the transmitter of Figure 3a.

power. So, he set his mind to make this type of transmitter more CW-like. This lead to his development of the synchronous rotary spark-gap transmitter. In effect, this was a type of quenched spark gap that was much more efficient, less noisy, and narrowband, compared with the unquenched gap in use at that time. Also, because of the regularity of the spark – and since the spark rate was right for aural reception (750 sparks/s) – the signal heard using his receiver, employing his electrolytic detector, was quite musical (a 750 Hz tone). This was easily distinguished from atmospheric noise, and from the interference caused by other spark-generated transmitters.

In the mean time, Marconi was still struggling to achieve transatlantic communications, and to establish a wireless telegraphy service (which he did, in the autumn of 1907). In spite of the fact that he had not yet realized reliable transatlantic communications, he was receiving much media publicity. Clearly, Fessenden's technology was superior. So, Fessenden and his associates turned their attention to transatlantic wireless. Identical stations were set up at Brant Rock, Massachusetts, and Machrihanish, Scotland, in 1905. Each had Fessenden's synchronous spark-gap transmitter (Figure 4), with a 122 m umbrella top-loaded tower monopole antenna (US Patent No. 793,651, July 4, 1905; Figure 5), and with his two-circuit receiver with electrolytic detector (Figure 3b). These stations were completed late in 1905, and experiments began early in January. On January 10, 1906, the world's first communications-quality transatlantic – in fact, the first-ever *two-way wireless transmissions* – were made. During January, February, and March, two-way telegraphy communications were established on a regular basis, exchanging messages about the working of machines. Each day, improvements were made. The signals were too weak to be received during daytime (a frequency of about 80 kHz was used), and in summer.

Early in December, 1906, a fierce storm tore down the Machrihanish tower. It was never rebuilt. The Brant Rock tower was collapsed intentionally during World War I. It was deemed too visible by enemy ships; otherwise, it might still be still standing today.

5. Follow-on Wireless Telephony Experiments

It is important to note that while Marconi was struggling to achieve reliable *one-way* wireless spark-generated transatlantic communications, Fessenden had already developed a technique for sending multiple Morse code messages over a single radio-frequency carrier. He did this (at least in concept) by applying tones of different frequencies to a CW-like carrier, and keying the individual tones with the Morse code. This technique, for which Fessenden was awarded a US patent in 1903, was the logical predecessor to applying the human voice to the RF carrier [21].

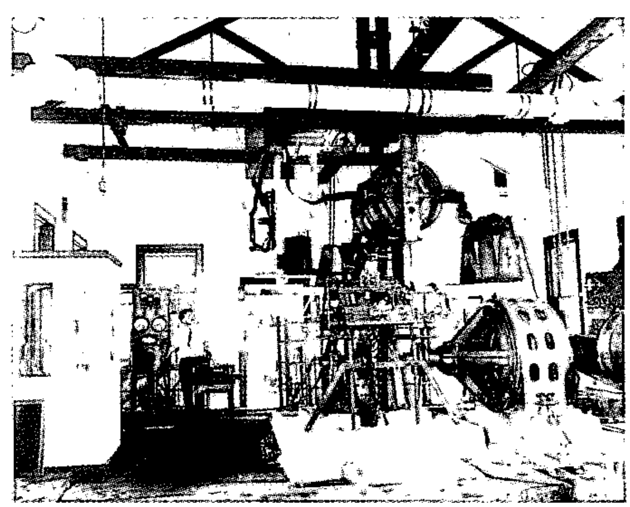

Figure 4. Fessenden's synchronous spark-gap transmitter, Brant Rock, Massachusetts. The operator is Guy Hill (from the National Museum of American History, Smithsonian Institution, Washington, DC).

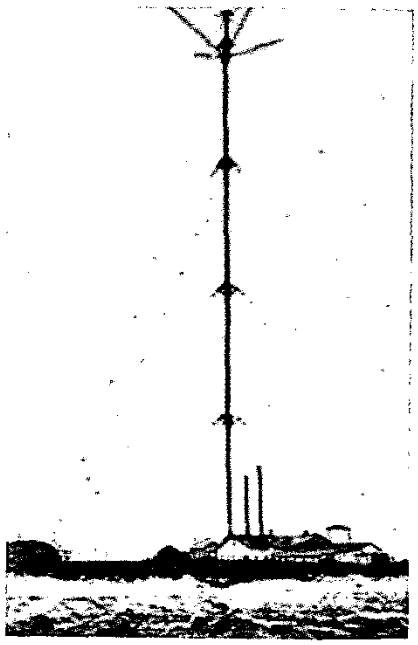

Figure 5. The Brant Rock, Massachusetts, tower. The tall pipes extending above the transmitter building are smoke stacks for the steam engine, used to drive the AC generator for Fessenden's synchronous rotary spark-gap transmitter, and later his alternator for wireless telegraphy and telephony.

By the end of 1903, fairly satisfactory speech had been obtained by the more-continuous arc method (more-CW-like, compared with spark). The method of producing high-frequency oscillations from an arc and continuous currents was discovered by Elihu Tompson in 1892 (US Patent No. 500,630). The receiver in use at that time was much improved, since it used Fessenden's electrolytic detector, a method used until the much later development of the thermal-electric diode, circa 1912. But reception was still plagued by a disagreeable noise.

Fessenden was trying to develop an HF alternator giving an output frequency high enough to be useful with practical antenna systems used at that time, and high compared with voice frequencies. Work on the HF alternator (Fessenden called this device a dynamo) was begun in 1900. However, his instructions (in Fessenden's words) were not followed by the manufacturer, and when delivered in 1903, its highest operating frequency was 10 kHz. A second alternator was delivered in 1905. A letter from the GE Company that built the machine stated that, in the opinion of the company, it was not possible to operate it above 10 kHz. In 1890, Tesla had built high-frequency alternating-current generators, one of which had 384 poles and produced a 10 kHz output frequency. He later produced frequencies as high as 20 kHz. It is not clear, therefore what the GE Company had accomplished after five years of development.

So, Fessenden scrapped the GE Company alternator, except for the pole pieces, and rebuilt the armature in accordance with his design, in his Washington, DC, shop. By the autumn of 1906, he had succeeded in developing a machine that gave him an operating frequency of 50 kHz, and a power output of half a kilowatt (Figure 6). Later machines gave output frequencies as high as 200 kHz (c.f. Figure 7), and powers up to 250 kW. The problem had been solved. Fessenden could now transmit a pure CW wave.

But Fessenden's rectifier-type of detector was useless for reception of telegraphy by the on-off keying (amplitude-shift keying) of a CW carrier. A spark-generated signal was, in effect, a modulated carrier: the damped-wave RF signal component was modulated by the spark rate. If the spark rate was very regular (Fessenden's synchronous spark-gap transmitter), and optimum for aural reception (say, 750 sparks/s), the received signal was heard as a quite musical note (a 750 Hz tone). For (unmodulated) intermittent continuous-wave transmission, however, all that would be heard would be clicks as the Morse key was closed and opened.

Again, Fessenden's fertile mind worked around this problem. He devised the methodology of combining two frequencies to derive their sum and difference frequencies, and coined the word *heterodyne*, derived from the joining of two Greek words: *hetro*, meaning difference, with *dyne*, meaning force. Today, heterodyning is fundamental to the technology of radio communications. His initial heterodyne circuit was described in US Patent No. 706,740, dated August, 12, 1902, and his advanced heterodyne circuit, Patents Nos. 1,050,441 and 1,050,728, is dated January 14, 1913. In this time period, however, heterodyning was way ahead of its time. It would take the addition of de Forest's triode vacuum tube – which was integrated with Fessenden's heterodyne principle in

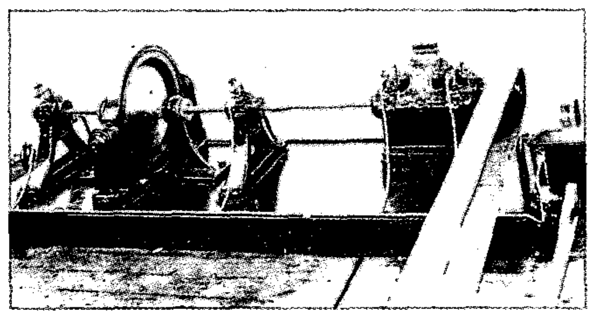

Figure 6. An early version of Fessenden's HF alternator. A simple belt drive was used, with a long self-centering shaft that eliminated excessive vibration and pressure on the bearings (the alternator speed was 139 rev/s for 50 kHz).

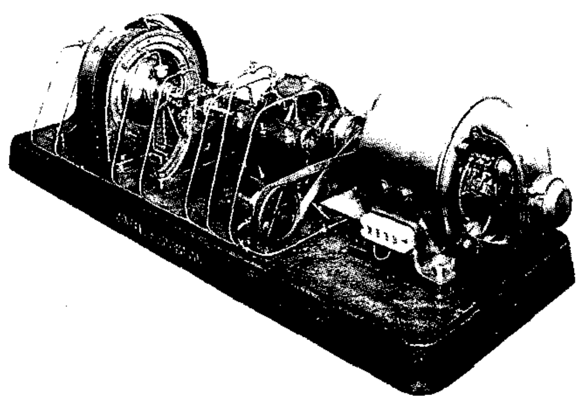

Figure 7. A 2 kW 110 V 100,000 Hz alternator, driven by a 2000 rpm direct-current motor, gear connected, to provide an alternator shaft speed of 20,000 rpm. Note that the tubing shown and the belt-driven pump provided the oil circulation to lubricate the high-speed bearings (from North Carolina Division of Archives and History).

Edwin H. Armstrong's "superheterodyne" receiver of circa 1912 – to make Morse-code-keyed CW telegraphy reception practical. Some historians [22] consider Fessenden's heterodyne principle to be his greatest contribution to radio. Edwin Howard Armstrong's superheterodyne receiver is based on the heterodyne principle. Except for method improvements, Armstrong's superheterodyne receiver remains the standard radio-receiving method today.

John Hogan's classic 1913 paper, in which he described radio equipment used in the US Navy's Arlington-Salem tests, explained the principle of heterodyning. He claimed that an equipment employing this principle had greatly improved the sensitivity of wireless-telegraphy receivers. This paper has recently been republished [23]. In the closing words of Hogan's paper, "The maximum of credit is due to Prof. Fessenden, for his fundamental invention compared to which the improvements brought out by such as us as have continued the work are indeed small."

Fessenden's method of modulating his CW device, a HF alternator, was, as before, an asbestos-covered carbon microphone, inserted in the antenna lead. But with this apparatus, he achieved important communication successes. In November, 1906, on a night when transatlantic propagation was very good, Fessenden and his colleagues were conducting experimental wireless telephony transmissions between stations at Brant Rock and Plymouth, Massachusetts. Mr. Stein, the operator at Brant Rock, was telling the operator at Plymouth how to run the dynamo. His voice was heard by Mr. Armour at the Machrihanish, Scotland, station with such clarity that there was no doubt about the speaker, and the station log confirmed the report.

Fessenden's greatest triumph was soon to come. On December, 24, 1906, Fessenden and his assistants presented the world's first radio broadcast. The transmission included a speech by Fessenden, and selected music for Christmas. Fessenden played Handel's Largo on the violin. That first broadcast – from his transmitter at Brant Rock, Massachusetts – was heard by radio operators onboard US Navy and United Fruit Company ships, equipped with Fessenden wireless receivers, at various distances over the South and North Atlantic, as far away as the West Indies. The wireless broadcast was repeated on New Year's Eve. *This was the first radio broadcast.* One can imagine the feelings of surprise to the lonely ship operators – accustomed to the cold, colorless dot and dash of the Morse code – when music suddenly burst upon their ears, to be followed by understandable speech. Fessenden received many letters from operators on ships over the North and South Atlantic, asking how it was done. Figures 8 and 9 show Fessenden at Brant Rock in January, 1906.

Figure 8. Fessenden with his staff and son, at Brant Rock, Massachusetts, January, 1906 (from North Carolina Division of Archives and History).

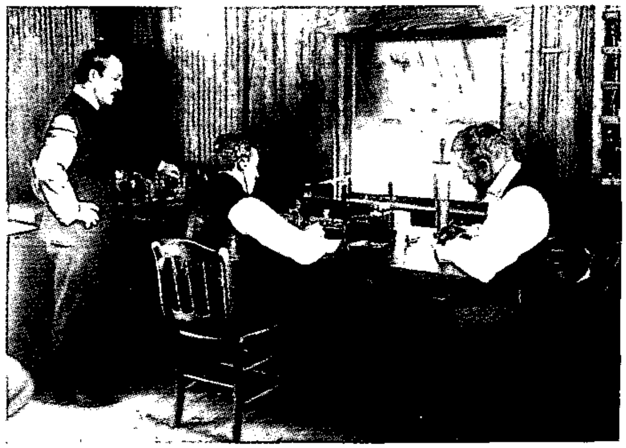

Figure 9. Fessenden (on the right) with staff members Passmill and Wescoe, Brant Rock, Massachusetts, January, 1906 (from North Carolina Division of Archives and History).

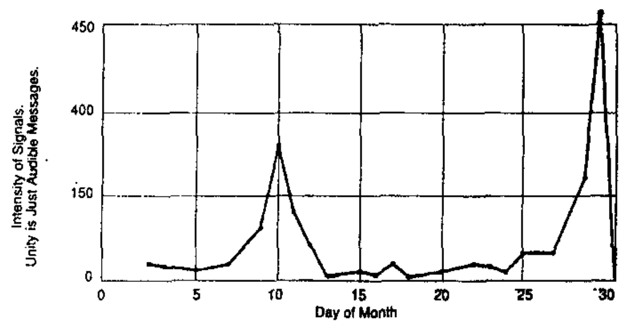

Figure 10. A curve showing the variation of the intensity of transatlantic signals (on a path from Machrihanish to Brant Rock; frequency about 80 kHz) for the month of January, 1906. Unity corresponds to a just-audible message. Such a curve is certainly the first recording of LF propagation.

6. The First Radio Propagation Experiments

There is no evidence that Marconi made any attempt to systematically investigate the characteristics of propagation at the frequencies he was using. Fessenden, on the other hand, carried out many propagation experiments, beginning in 1899. The first record showing the day-to-day variation of the relative intensity of transatlantic nighttime messages, transmitted between Brant Rock, Massachusetts, and Machrihanish, Scotland, during the month of January, 1906, is reproduced in Figure 10 [24]. During that year, Fessenden found that the absorption (attenuation) of signals at a given instant was a function of direction as well as distance. On a given night, the signals received by stations in one direction would be greatly weakened, while there would be less weakening of signals received by stations lying in another direction, and a few hours or minutes later, the reverse would be the case. Measurements of signal strength on the path from Brant Rock to Machrihanish were found to have a definite correlation with variations of the geomagnetic field.

Experiments were made between Brant Rock and the West Indies, a distance of 2735 km, during the spring and summer of 1907. Frequencies in the band from 50 kHz to 200 kHz were used.

It was found that the absorption at 200 kHz was very much greater than at 50 kHz, and that messages could be successfully received over this path in daytime at the latter frequency. No messages were received in daytime with the higher frequency, although nighttime messages transmitted from Brant Rock at this frequency were officially reported as having been received at Alexandria, Egypt, a distance of 6436 km.

The facts that the experiments between Brant Rock and the West Indies were made during summer, that the receiving station was in the Tropics (with high atmospheric-noise levels), and that the distance of 2735 km was practically the same as between Ireland and Nova Scotia, were reported by Fessenden. After publication of the above results, in early October, 1907, Marconi abandoned his previously used frequencies, and moved to an even lower frequency, 45 kHz. He immediately succeeded in operating between Glace Bay, Nova Scotia, and Clifden, Ireland, a distance of more than 3000 km. The same messages were received at Brant Rock, Massachusetts, a distance of nearly 4825 km.

Certainly, in the time period when these early propagation experiments were being conducted, little was known about the mechanism of propagation. For short-to-medium distances, propagation was considered to be over the surface of the curved Earth. In 1899, with the assistance of Prof. Kintner, a considerable number of propagation experiments were conducted and published [25]. In these, a sliding-wave theory, referred to by Elihu Thompson, was explained and illustrated. Fessenden later (1900) developed his mathematical model for such waves, guided over the surface of the ground, and showed that for transatlantic distances, this (ground-wave) signal would be negligible. The reception of signals across the Atlantic must therefore (in Fessenden's opinion) have been due to a reflection from some conducting layer in the upper atmosphere. It should be noted that Kennelly and Heaviside were colleagues of Fessenden (Kennelly was a friend and colleague, and Fessenden corresponded regularly with Heaviside). Certainly, Fessenden was very familiar with their independent suggestions (in 1902) off the existence of such a conducting layer [26, 27]. While Heaviside (in 1902) made the suggestion for a conducting layer "in the upper air," and that transatlantic propagation would in effect be due to a guidance by the sea on one side and the conducting layer on the other side, it seems that he thought (at that time) that transatlantic propagation was predominantly due to guidance by the conducting sea. Kennelly, however, (in 1902) was more specific. He gave a height for his conducting layer (about 80 km), and he suggested, in some detail, that long-distance propagation was due to wave reflection in the upper atmosphere.

Evidence for the existence of such a reflecting layer was provided by the discovery by Fessenden in 1906 of what were called "echo signals:" "On certain nights there appeared to be indications at the Brant Rock station that a double set of impulses from the Machrihanish station were received, one about a fifth of a second later than the other." Fessenden correctly interpreted that this delayed signal had traveled the other way around the great-circle path [24]. Though this conclusion was severely commented upon at the time, we know now of the existence of around-the-world echo signals, and that such a conducting layer (the ionosphere) does exist.

7. Fessenden the Man

The writer has briefly outlined Fessenden's life history, and has touched on his accomplishments [17]. For the interested reader, it should be pointed out that a recent paper by William S. Zuill [28] – whose grandfather married Fessenden's wife's elder sister – has just recently been published. This paper gives considerable personal detail about Fessenden the man.

Figure 11. Fessenden about the time when he was working for the Submarine Signaling Company (after Erne DeCoste, private communications, 1992).

Reginald Aubrey Fessenden was a most interesting radio pioneer, a man with a dynamic, inspiring imagination. Chomping on his ever-present cigar (see Figure 11), he would argue with anyone on any subject. With his razor-sharp mind, his attempts to try to command all situations, his use of his classical scholarship, and his lack of patience with slow minds, he certainly did not agree with all who came face-to-face with him, or worked with him, but he could be charming. While he never graduated from university, his capacity for self-education was a remarkably successful substitute. Described by his contemporaries as "choleric, demanding, vain, pompous, egotistic, arrogant, bombastic, irascible, combative, domineering, etc.," when coupled with a notorious lack of patience, he could not help making waves constantly, in every direction. When these characteristics emanated from a ginger-colored-hair-and-bearded person, well over six feet tall, of large girth and wearing a flowing cape on his shoulders, topped with a seafarer's cap on his head, he must have commanded attention in any crowd [30].

Fessenden was clearly an outspoken skeptic of Marconi's claim to have received signals in Newfoundland, from his sender in Poldhu, Cornwall, on December 12, 1901. And, with reference to Marconi's wireless transmission of the message from President Roosevelt to King Edward in January, 1903 – claimed to be the first message sent from the USA to England – Fessenden pointed out that it was found necessary to first send the message by cable, and, after the wireless *one-way* transmission, to send a second message by cable, directing release of the message initially sent via cable [31]. 2001 was the 100th anniversary of Marconi's December, 1901, first transatlantic experiment. The claimed reception of signals (the Morse letter "S") on Signal Hill, Newfoundland, transmitted by a sender at Poldhu, Cornwall, has been debated by radio scientists (including Tesla and Fessenden) for one hundred years [32, 33].

8. Closing Remarks

Fessenden made many contributions to the art and science of radio, including the first-ever quantitative, scientific investigation of electromagnetic phenomena, wave propagation, and antenna design. His Brant Rock and Machrihanish umbrella top-loaded vertical-monopole antennas look like antennas used nowadays (he held a US patent, No. 793,651, July 4, 1905, on base-loaded base-fed monopole antennas). His continuous waves, his invention of a new type of detector – which he called a liquid Barretter (an electrolytic detector) – and his invention of the method as well as the coining of the word heterodyne, did not by any means constitute a satisfactory wireless telegraphy or telephony system, judged by today's standards. They were, however, the first real departure from Marconi's damped-wave-coherer system for telegraphy, which other experimenters were merely imitating or modifying. These were the first pioneering steps toward modern wireless communications and radio broadcasting.

Fessenden was at home in his laboratory, but out of his element when dealing with the business and political aspects of inventing. Until late in his life, he never reaped any financial reward for his many wireless inventions, and he was compelled to spend much time and energy in litigation. His work with the US Weather Bureau (1900-1902) came to an abrupt end in August, 1902, over ownership of his patents. His partnership with two Pittsburgh millionaires, T. H. Given and Hay Walker – which began in September, 1902, with the formation of the National Electric Signaling Company (NESCO) – collapsed in 1912. This was the result of arguments about the direction the company should take, and, again, ownership of patents. Fessenden resented the financiers' efforts to meddle in his work, while they grew increasingly anxious for a return, as their investment mounted. In May, 1912, Fessenden won a judgment of $400,000 from what remained of NECSO, but the company went into receivership before he could collect. Fessenden's patents were eventually purchased by Westinghouse in 1920, and then by RCA in 1921, prompting Fessenden to sue again. The legal suits that consumed much of his life finally came to an end on March 31, 1928, in an out-of-court settlement in which he received $500,000 from RCA, with $200,000 of this sum going to his lawyers.

Leaving Brant Rock (in 1912) did not impair Fessenden's creativity, but he made few major contributions to the science and technology of wireless after that date. During the period 1912-ca. 1921, he worked with The Submarine Signaling Company, where he developed the fathometer. During the 1920s, as radio exploded in popularity and new generations of inventors took on the task of improving it, the world's first broadcaster turned from the laboratory and devoted himself to research in ancient history. The products of these investigations were published privately, under such titles as *The Deluged Civilization of the Caucasus* and *Finding a Key to the Sacred Writings of the Egyptians* [28]. However, he continued writing for the popular press on his radio inventions, on the quality and reliability of his early communication systems compared with those of others, and, as well, on his own views concerning propagation. This was in a series of articles entitled "The Inventions of Reginald A. Fessenden [29] and "How Ether Waves Really Move" [15].

It is a wonder that Fessenden was able to mentally and physically withstand the barrage of negative events that befell him, and to yet continue to invent. The long-term grinding dissention, however, took its toll. But for the constant support of Helen, his wife, he might not have reached the year of 1932, when he passed away in Bermuda from a heart attach, on July 22.

In summary, Fessenden was clearly the father of AM radio. As an inventor, he held some 229 US patents [34]. Fessenden did not confine his expertise to one discipline, but worked with equal facility in chemical, electrical, radio, metallurgical, and mechanical fields. He was the inventor of sonic-frequency echo sounding for the measurement of the depth of oceans and iceberg detection, a technology which later became known as SONAR (sound navigation and ranging). His work involved with safety at sea won him the *Scientific American* Gold Medal in 1929. Other awards included the Medal of Honor of the Institute of Radio Engineers in 1921, for his effort in that field, and the John Scott Medal of the City of Philadelphia, for his invention of continuous waves. Fessenden, a genius, and a mathematician, was the father of AM radio, and a primary pioneer of radio *as we know it today*.

9. Acknowledgements

The author acknowledges discussions with many historians interested in the history of radio, particularly George Elliott, who for many years was Editor of an *Amateur Radio Fessenden Society Bulletin*; with Orn Arnason, then with The Brome County Historical Society; with Robert S. Harding, with the Archives Center, National Museum of American History, Smithsonian Institution, City of Washington; with Fred Hammond (now deceased), who established an important personal radio museum; with Ernie DeCoste, Curator (now deceased) with The Canada National Science and Technology Museum, Ottawa, Ontario; and with Bruce Kelly, Curator (now deceased) of the Museum of the Antique Wireless Association, Bloomfield, New York.

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11. Bibliographic Notes

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