REGINALD AUBREY FESSENDEN AND THE BIRTH OF WIRELESS TELEPHONY*

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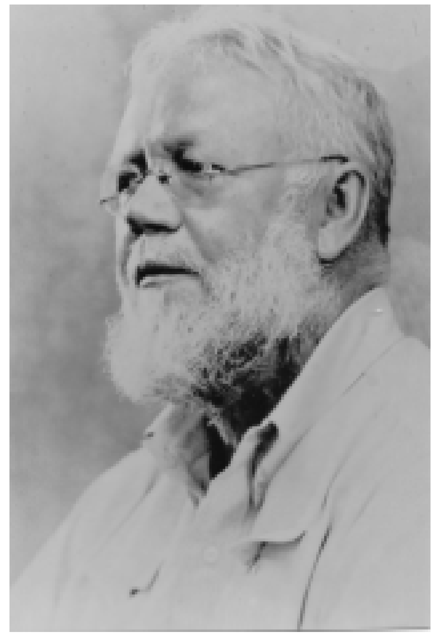
The year 2000 was the 100th anniversary of the transmission of the first voice over radio. On the 23rd of December 1900, Prof. Reginald Aubrey Fessenden, after a number of unsuccessful tries, transmitted 'words without wires' over a distance of 1600 meters, between twin aerial systems, employing 15 m masts, located on Cobb Island, MD. 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 history, and to give some detail of his accomplishments, but the paper begins with a brief account of the birth of radio, so that the reader can appreciate Fessenden's place in history.



Professor Reginald Aubrey Fessenden
(1866-1932)

A Brief History of the Birth of Radio

The very possibility of wireless communications is founded on the research of James Clerk Maxwell, since his equations form the basis of computational electromagnetics. Their correctness 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 UK's Poynting and Heaviside), his equations have been studied for over a century, and have proven to be one of the most successful theories in the history of radioscience. 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 theory use was made of the results of experiments in pure physics which 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 [4] made many experiments on these transmitted waves, and reports on their experiments can be found in Edison's papers in technical journals of that time.

The first wireless telegraphy patent in the US was issued on 20 July 1872 to Mahlon Loomis, fifteen years before Hertz. His Patent No. 129,971 was for "Improvement in

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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

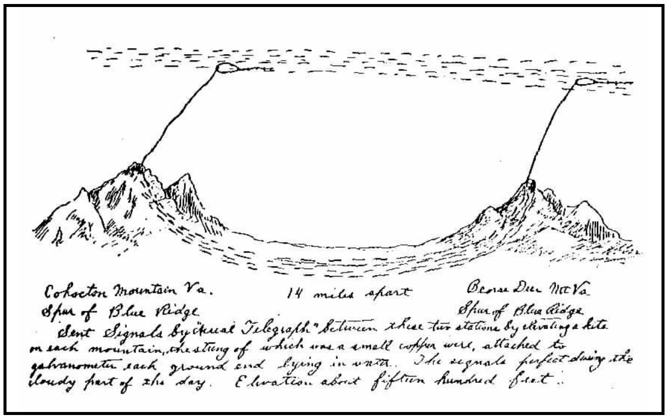

Figure 1 Reproduction of Mahlon Loomis' sketch of his 1866 demonstration of wireless aerial telegraphy between Cohocton Mountain and Bear's Den, VA.

Blue Ridge Mountains of Virginia, 22 kilometers apart, see **Figure 1**. He flew kite supported wire aerials, 183 meters 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 centimeters 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 substantiated.

Between 1870 and 1888 von Bezold, Fitzgerald and Hertz had clarified to a considerable extent the nature of the phenomena being observed, 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 telegraphing wirelessly, though 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 in 1893 described his wireless system to the Franklin Institute, in Philadelphia, PA, in March, and later in the same year in St. Louis, MO, 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 so move the energy storage capacitance (or 'discharge condenser') to the primary side, and add a ground connection. Tesla was the first to inductively couple the secondary side, the antenna side where the capacitances must be small, 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, US reissued patent 11,913 (original 586,193 granted on 4 June 1901), was for a 2-circuit system, one circuit in the transmitter and one circuit in the receiver. Again a very inefficient system. Marconi's "famous" 4-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 28 June 1904, by reason of the prior art set forth in a patent by Lodge (No. 609,154), but principally Tesla's US patent 645,576 applied for on 2 September 1897. New applications and petitions for revival were filed by the Marconi company, resulting in a legal battle which continued for years. It took the courts several decades to figure out the facts . Eventually the US Supreme Court in 1943 struck down the Marconi patent ruling in Tesla's favor (for detail see in particular the preface to reference [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 in 1894/95 that their apparatus might "be adapted to the transmission of signals to a distance".

In fact some historians consider Oliver Lodge to be the first to transmit Morse code letters before a learned audience, from his induction coil and a spark gap transmitter over a distance of some 60 m on 14 August 1894 (Austin [11]). The receiver consisted of a coherer, a Lodge invention, which was connected to either a Morse recorder which printed onto paper tape, or a Kelvin marine galvanometer, the deflected light spot made viewing by the audience easier. This demonstration, at a meeting of the British Association in Oxford, England 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; or 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", 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.

There is also on the basis of historical research, 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 12 March 1896. It is said that he transmitted the words "Heinrich Hertz" and that 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 (IEEE Spectrum, August 1969, p. 69, see Süsskind [12]).

Marconi, who had worked under Righi, had, with a keen eye for commercial opportunity, realized that there was a market for such telegraphic systems, and in July 1896, gave a demonstration to the English Post Office at Salisbury Plain, where he succeeded in increasing the range from its previous 800 meters obtained by other experimenters to a distance of about 3 km [13]. But more importantly, as a result of this demonstration, history has accredited him with the invention of an early form of wireless telegraphy.

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

Such was the state of the art at the beginning of the 20-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.

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, and 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.

Fessenden who 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 was convinced that there was no essential distinction between the high frequency oscillations from an arc and continuous current, discovered by Elihu Thompson in 1892 (US patent 500,630, 18 July, 1892), and the damped oscillations produced by spark generated transmission systems, and that there was no mysterious "whip crack" of the ether involved in the generation of wireless signals [14]. He was also convinced that practical operative 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 --- ". Fleming, in the first edition of his book on *Electromagnetic Waves* published in 1906, in reference to Fessenden's 1901 patent (No. 706,737) describing the generation of CW wireless signals by use of a HF alternator, stated that there is no suitable high-frequency alternator of the kind described by Fessenden and it is doubtful if any appreciable radiation would result if such a machine were available and were used as Fessenden proposes. 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 to use 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.

Judge Mayer subsequently, in his opinion upholding Fessenden's patent on this invention, said, in effect, "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 three references are cited to aid the reader in properly evaluating the great contribution of Fessenden's, the concept of and the method of generating continuous waves.

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, Reginald Aubrey Fessenden and later Lee De Forest.

Fessenden, born in Canada, in Knowlton, Brome County, Canada East (now Quebec) on 6 October, 1866, but working in the United States, recognized (his early work dates to about 1892 [14, 15]) that continuous wave transmission was required for speech, and he continued the work of Tesla, John Stone 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 [16, 17], and methods to generate and receive CW transmission were yet to be developed.

Fessenden realized from the very beginning of wireless communications 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 the receiving wireless telegraphy signals, one needed a continuous wave signal [18]. And, that for wireless telephony a CW signal was a necessity. Since there was no satisfactory means of generating a CW signal prior to c1903, his early work, which began in c1896, when was he was a professor at the University of Pittsburgh, PA, 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 727,331, dated 9 April 1903 for the basic detector; and 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 up a resistance change associated with heating at the point of contact with the sulfuric acid.

In c1898 he was using his modified version (US patent 706,736 and 706,737, dated 15 December 1899) of Elihu Thompson's alternating current galvanometer (US patent 363,185, dated 20 January 1887). In the words of Fessenden, he describes 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, that 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, 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 being that Fessenden was engaged in transferring his laboratory from Allegheny, PA, to Rock Point, MA, and in setting up stations at Rock Point and on Cobb Island, MD.

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, but author Belrose 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, but 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, probably much lower. The modulator for the spark transmitter was an asbestos covered carbon microphone inserted in the antenna lead, see **Figure 2a** (US Patent No. 706,747, of 12 August 1902). This figure also shows a later version of a Fessenden receiver (**Figure 2b**), in use after 1902.

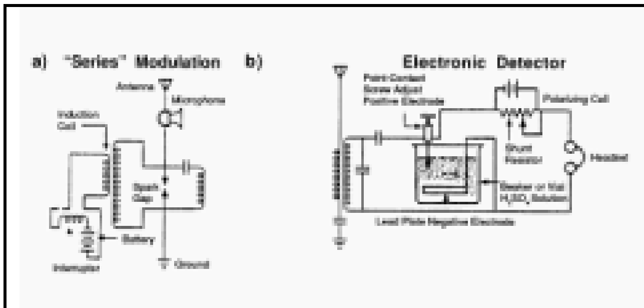

Figure 2 An early version of Fessenden's spark gap telegraphy transmitter a); and a somewhat later receiver, employing an electrolytic detector b).

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

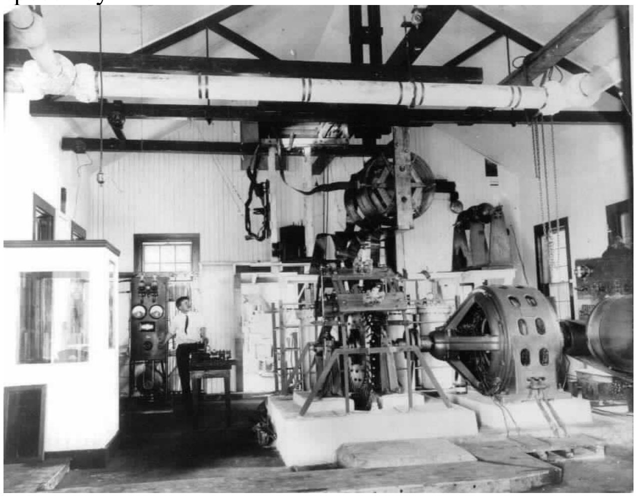

Figure 3 Fessenden's synchronous spark gap transmitter, Brant Rock, MA. The operator is Guy Hill (credit National Museum of American History, Smithsonian Institution, Washington, DC).

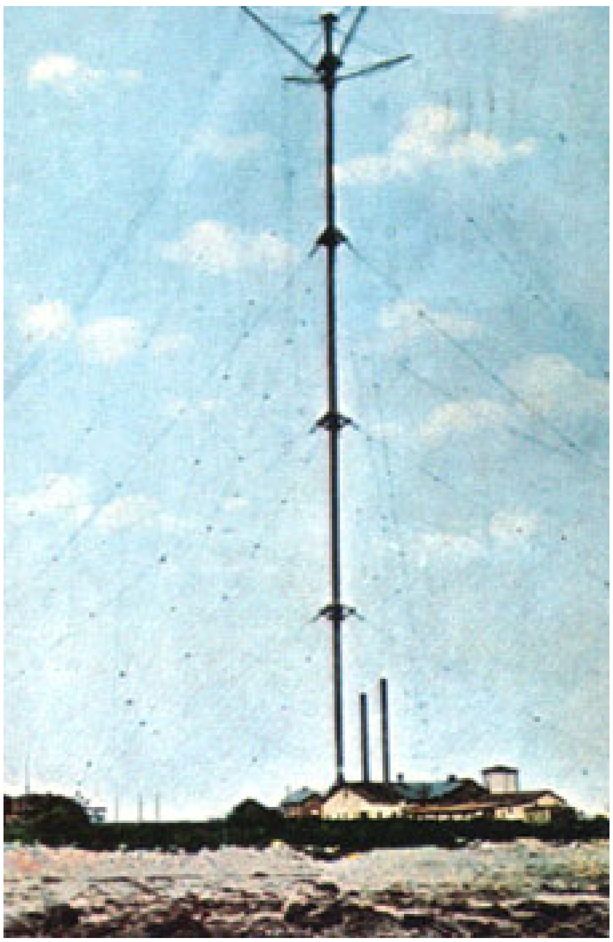

Figure 4 The Brant Rock, MA tower. The tall pipes extending above the transmitter building are smoke stacks for the steam engine used to drive the AC generator for his synchronous rotary spark gap transmitter, and later his alternator for wireless telegraphy and telephony.

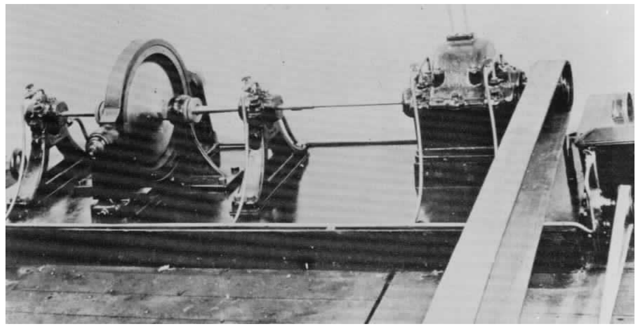

Figure 5 Early version of Fessenden's HF alternator. A simple belt drive was used, and a long self-centering shaft that eliminated excessive vibration and pressure on the bearings (alternator speed 139 rev/sec for 50 kHz).

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.

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 (Belrose [19]).

Transatlantic Communication

Since methods to generate CW were yet to be developed, as noted above, Fessenden's early experiments had to make due with spark transmitters, the only means known to generate appreciable 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, which in effect was a type of quenched spark gap, that was much more efficient, less noisy and narrow band 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 aurally heard using his receiver employing his electrolytic detector was quite musical (a 750 Hz tone), easily distinguished from atmospheric noise and from the interference caused by other spark generated transmitters.

Marconi in the mean time 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, MA, and Machrihanish, Scotland, in 1905, each with Fessenden's synchronous spark gap transmitter, see **Figure 3**); with a 122 m umbrella top loaded tower monopole antenna (US patent 793,651, dated 4 July 1905), see **Figure 4**; and with his 2-circuit receiver with electrolytic detector,

Fessenden with staff, son, and cat at Brant Rock, MA, January 1906 (Credit North Carolina Division of Archives and History).

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

see **Figure 2b**. These stations were completed late in 1905, and experiments began early in January. On 10 January 1906 the world's first communications quality transatlantic, in fact first ever, **two-way wireless transmissions** were made. During January, February and March, two-way telegraphy communications was established on a regular basis exchanging messages about the working of machines, and 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, deemed too visible by enemy ships, otherwise it might still be still standing today.

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.

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 500,630). The receiver in use at this time was much improved, since it used Fessenden's electrolytic detector, a method used until the much later development of the thermal electric diode c1912. 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 voice frequencies. Work on the HF alternator (Fessenden called this device a dynamo) was begun in 1900, but 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. Tesla in 1890 had built high-frequency alternating current generators, one which had 384 poles produced a 10 kHz output frequency. He later produced frequencies as high as 20 kHz. It is not clear therefore, that after 5-years of development, what the GE Company had accomplished?

So Fessenden scrapped the GE Company alternator, excepting for the pole pieces, and rebuilt the armature in accord 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 75 kHz and a power output of half a kilowatt (**Figure 5**). Later machines gave output frequencies as high as 200 kHz, 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 quite a musical (750 Hz tone). For intermittent continuous wave transmission 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 is described in US Pat. No. 706,740, dated 12 August, 1902 and his advanced heterodyne circuit, Pat. No. 1,050,441 and 1,050,728, is dated 14 January, 1913.

In this time period, however, heterodyning was away 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 Edwin H. Armstrong's "superheterodyne" receiver of c1912, to make Morse code keyed CW telegraphy reception practical. Some historians [20] consider Fessenden's heterodyne principle to be his greatest contribution to radio. Edwin Howard Armstrong's super-heterodyne receiver is based on the heterodyne principle. Except for method improvement, Armstrong's superheterodyne receiver remains the standard radio receiving method today.

John Hogan's 1913 Classic Paper, in which he described radio equipment used in the US Navy's Arlington-Salem tests, explained the principle of heterodyning, and claimed that an equipment employing this principle had greatly improved the sensitivity of wireless telegraphy receivers, has recently been republished [21]. 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, MA. 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 the 24th December, 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, MA, was heard by radio operators on board 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.

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 qualitatively the day-to-day variation of the intensity of transatlantic nighttime messages transmitted between Brant Rock, MA, and Machrihanish, Scotland, during the month of January 1906 is reproduced in **Figure 6** [22].

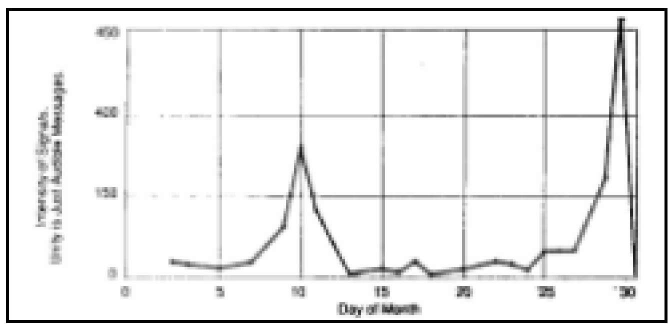

Figure 6 Curve showing variation of the intensity of transatlantic signals (path Machrihanish-Brant Rock, frequency about 80 kHz) for the month of January 1906,

During that year Fessenden found that the absorption (attenuation) of signals at a given instant was a function of direction as well as distance, since 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. Measurement of signal strength on the path 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 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, though 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 fact that the experiments between Brant Rock and the West Indies were made during summer, and the receiving station was in the Tropics (high atmospheric noise levels), and the fact that the distance, 2735 km was practically the same as between Ireland and Nova Scotia was reported by Fessenden. After publication of the above results, Marconi in early October, 1907 abondoned his previously used frequencies and moved to even a lower frequency, 45 kHz, and immediately succeeded in operating between Glace Bay, NS and Clifden, Ireland, a distance of more than 3000 km. The same messages were received at Brant Rock, MA, 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 [23], in which 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 neglible. The reception of signals across the Atlantic must therefore (in Fessenen's opinion) be 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), and certainly Fessenden was very familiar with their independent suggestions (in 1902) for the existence of such a conducting layer [24, 25]. 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 [22]. 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.

Fessenden the Man

The writer has briefly outlined Fessenden's life history, and touched on his accomplishments [16]. For the interested reader it should be pointed out that a recent paper by William S. Zuill [26], whose grandfather married Fessenden's wife's elder sister, has just recently been

Figure 7 Fessenden about the time when he was working for The Submarine Signaling Company (after Erne DeCoste, private communications, 1992).

published. This paper gives considerable personal detail of Fessenden.

Reginald Aubrey Fessenden was a most interesting radio pioneer, a man with a dynamic inspiring imagination. Chomping on his ever-present cigar (see **Figure 7**), 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, 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 [27].

Fessenden was clearly an outspoken skeptic of Marconi's claim to have received signals in Newfoundland from his sender in Poldhu, Cornwall, on 12 December 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 USA to England, Fessenden pointed out that it was found necessary to first send the message by cable, and after the wireless transmission, to send a second message by cable directing release of the message initially sent via cable [28].

This year 2001 is 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 radioscientists (including Tesla and Fessenden) for one hundred years [29, 30].

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 load vertical monopole antennas look like antennas used nowadays. 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. They 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. He never reaped, until late in his life, any financial reward for his many wireless inventions, and 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 --- 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 judgement 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 31 March 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 science and technology of radio after that date. During the period 1912-c1921 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*" [26].

But, 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, in a series of articles entitled "*The Inventions of Reginald A. Fessenden*" (Radio News, January to November 1925, Parts I to XI); and "*How Ether Waves Really Move*" (Popular Radio, **Vol. IV, Number 5**, November 1923, pp. 337-347).

It is a wonder that Fessenden was able to withstand, mentally and physically, the barrage of negative events that befell him, and 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 22 July.

In summary Fessenden is clearly the father of AM radio. As an inventor, he held some 229 US patents [31]. 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 measurement of depth of oceans and ice berg 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.***

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And, in the Records (580 boxes in total) of The George H. Clarke Radioanna Collection c.1880-1950, Smithsonian Institution, Washington, DC, consisting of 21 boxes of correspondence to and from Fessenden when he was with the National Electric Signaling Company and in subsequent years (1900-1923). Reference "The Register of the George H. Clarke Radioana Collection c1880-1950", by Robert S. Harding, Archives Center, National Museum of American History, Smithsonian Institution, City of Washington, 1990, 114 pages.

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John S. (Jack) Belrose was born in Warner, Alberta on November 24, 1926. He received his BASc and MASc degrees in Electrical Engineering from the University of British Columbia, Vancouver, B.C. in 1950 and 1952. He joined the Radio Propagation Laboratory, of the Defence Research Board, Ottawa, ON in September 1951. In 1953 he was awarded an Athlone Fellowship, was accepted by St. John's College, Cambridge, England and by the Cambridge University as a PhD candidate, to study with the late Mr. J.A. Ratcliffe, then Head of the Radio Group, Cavendish Laboratories**.** He received his PhD degree from the University of Cambridge (PhD Cantab) in Radio Physics in 1958. From 1957 to present he has been with the Communications Research Centre (formerly Defence Research Telecommunications Laboratory), where until recently (19 December 1998) he was Director of the Radio Sciences Branch. Currently he is working at CRC (2 days/week) devoting his time to radioscience research in the fields of antennas and propagation --- a sort of transition to full retirement.

Dr. Belrose was Deputy and then Chairman of the AGARD (Advisory Group for Aerospace Research and Development) Electromagnetic Propagation Panel from 1979-1983). He was a Special Rapporteur for ITU-Radiocommunications Study Group 3 concerned with LF and VLF Propagation. He is Technical Advisor to the American Radio Relay League, Newington, CT in the areas of radio communications technology, antennas and propagation; a Fellow member of the Radio Club of America; and Life Senior Member of the IEEE (AP-S). He has been a licensed radio amateur since 1947 (present call sign VE2CV).

He is the author or co-author of over 125 papers, articles, and technical correspondence letters written relevant to the fields of radio communications, radio science, antennas and propagation; author of 2-chapters in a Prentise-Hall book on Physics of the Earth's Upper Atmosphere; author of a chapter in an IEE Publication The Handbook on Antenna Design; Lecturer and AGARD Lecture Series Director for four published lectures; and author of five papers concerned with the history of wireless communications.

Jack is married to Denise (ne Fenal of Paris), and they have three children (Katherine, John and Patrick), one granddaughter (Alexa), and one grandson (Jesse). Jack and Denise holiday in Europe; and in Canada and United States, traveling in a Ford F-250 truck pulling a Jayco Fifth Wheel trailer. He enjoys camping, swimming, cross country skiing, and amateur radio.