BY JAMES P. RYBAK

How Wireless

When Reginald Fessenden demonstrated radiotelephony in would have any practical uses.

The wireless operators aboard ships within several hundred miles of Brant Rock, Massachusettes must have been astonished on Christmas Eve in 1906. Instead of the crackling of telegraph signals, they heard a voice and then music coming through their receivers for the first time ever. The ships had been alerted earlier by a telegraph message from Reginald Fessenden's Brant Rock station that a special transmission would be coming. But who could have imagined this?

Quickly, others aboard the ships crowded in to hear for themselves this first true broadcast of what would become known as "radio." The quality of the transmission was not outstanding by today's standards, but no one complained. They knew they were witnessing an amazing breakthrough in technology. They very likely could not imagine, however, the impact this new technology would have on the lives of countless people.

Proudly Canadian. Reginald Aubrey Fessenden was born on October 6, 1866 in East Bolton, a town in what is now Quebec. While he would live much of his adult life in the United States and eventually would become a U.S. citizen, Reginald Fessenden always proudly considered himself Canadian.

Consistently a serious and highly accomplished student, young Reginald excelled in mathematics and the classical languages. He entered Bishop's College in Lennoxville, Quebec at the age of 15. Fessenden's mathematical abilities were so advanced that he was given credit for the first year's courses merely by passing the final examinations. He was awarded a senior mastership in mathematics and taught low level college mathematics while he was studying more advanced topics. Reginald regularly read the magazines *Scientific American* and *Nature*. He was interested in the new "science" of electricity and in becoming an inventor.

In 1884, when he was not yet eighteen, Fessenden had completed most of the requirements for a college degree. Financial and health considerations, together with the desire to begin carving out a career, caused him to accept an offer to be the principal (and only teacher) at the Whitney In-

Got its Voice

1906, few thought it ever

stitute in Bermuda before completing the remaining degree requirements.

While Fessenden taught at the Whitney Institute, his fascination with electricity and the desire to be an inventor kept growing. After two years, it was clear to Reginald that he needed a career with brighter prospects for an adequate income and wanted a career that would allow him to pursue his electrical and inventing interests.

Fessenden knew electricity held the promise for producing a number of inventions for which the public would provide the market. Thomas A. Edison and others already had proven that point. But, if he was going to become a successful inventor of electrical devices, Reginald was aware that he had to learn much more about both electricity and inventing. He, therefore, headed for New York City in 1886, apparently with the brash idea of learning the science of electricity and the art of inventing from none other than Thomas A. Edison.

Fessenden was aware that he had to learn more about electricity before he would have any chance of being hired by Edison. So upon arriving in New York, he tried earning enough to sustain himself through jobs as a writer while studying electricity in his free hours.

After a few months of frustration and disillusionment as a writer, Fessenden decided he might as well seek employment with Edison immediately. At the Edison Company's New York office, Fessenden was told that Edison was spending most of his time at the Company's Lamp Works in Harrison, New Jersey.

When he arrived at the Lamp Works, Fessenden submitted his business card together with a piece of paper on which he had been told to state his business. These were taken to Edison in his laboratory. Reportedly, the paper came back with "What do you know about electricity?" written by Edison.

Fessenden knew that he possessed a solid mathematical background, but that his knowledge of electricity obviously was not up to Edison's standards. Not wishing to overstate his qualifications, Reginald replied "Do not know anything about electricity, but can learn pretty quick." The piece of paper soon returned with Edison's comment, "Have enough men now who do not know anything about electricity."

Fessenden Keeps Trying. Disappointed, but not discouraged, Fessenden went back to New York City and continued his attempt to support himself as a writer. Every week, however, he visited the Edison Machine Works in New York to see if there were any openings. Persistence paid off and Fessenden was eventually hired as an assistant tester for the Edison Company's underground electrical mains-laying project in the city.

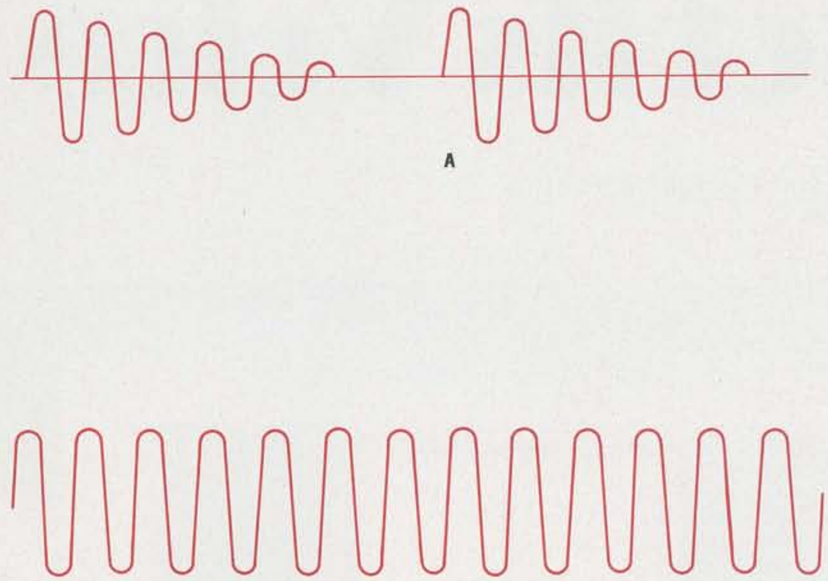
Fessenden worked diligently at his job and studied electrical theory during his lunch breaks. His hard work and ingenuity in developing more efficient ways for the crews to do their jobs did not go unnoticed. Very quickly, Reginald was promoted; first to tester, then to chief tester, and finally to inspecting engineer for a section of the work. He had earned the attention and respect of his supervisors.

After the project was completed at the end of 1886, Reginald Fessenden was offered his choice of a job with the Edison Company in Schenectady or at its Llewellyn Park Laboratory in West Orange, New Jersey as one of Edison's assistants. Needless to say, Fessenden chose to work with Edison.

Fessenden very quickly impressed Edison by developing an inexpensive and fireproof insulating material for the wire windings of dynamos. Reginald then developed a glass-blowing machine that greatly reduced the cost of making incandescent lamps. He also worked with Edison on the development of talking movies.

When seeking a solution to a problem, Fessenden followed the same approach used by Edison: he first tried to read everything in print that was known about the subject, and then go to the laboratory and try all the possible (and some seemingly impossible) combinations of materials and techniques. Merely finding *a* solution was not enough; Like Edison, Fessenden would not rest until the *best* solution was found.

In time, Heinrich Hertz's experiments with electromagnetic waves attracted Fessenden's interest. Reginald carefully read all of Hertz's writings on these intriguing waves. He obtained Edison's permission to conduct experiments on high-frequency electromagnetic oscillations, but financial problems caused Edison to close the Llewellyn Park Laboratory in 1890 before the experiments could begin.



A

B

Fig. 1. Pulses of damped oscillations (A) generated by spark gap transmitters differed significantly from the continuous oscillations (B) Fessenden sought.

From Edison to Westinghouse. Reginald Fessenden had received a number of offers for higher paying jobs over the years, but he had turned them down for the privilege of continuing his work in the environment of scientific investigation and invention provided by Edison. But, now that the opportunity to work with Edison no longer existed and he planned to get married soon, Reginald had to think in terms of both pursuing his scientific interests and earning a more substantial income. A job in Newark offered by the United States Company, a branch of Westinghouse, provided the needed salary and the opportunity to design both AC and DC electrical equipment.

One of Fessenden's first major accomplishments in his new job was the discovery of a new insulating material. It substantially reduced the number of dynamos returned to the company for repair. Probably more important to his later career, however, was Fessenden's discovery of a new silicon iron alloy. The metal produced very low eddy current and hysteresis losses when used in AC motors and generators.

Interestingly enough, Fessenden also developed a technique for using the same alloy in making the glass-to-metal seals needed for the lead-in wires of incandescent lamps. This breakthrough allowed Westinghouse to produce lamps that did not infringe upon Edison's patents. The lamps later enabled George Westinghouse to meet his contract for lighting the 1893 Columbia Exposition in Chicago. Providing the lights for the exposition enhanced the image of the Westinghouse Company and earned Fessenden the lasting gratitude of George Westinghouse.

Back to the College Scene. Alternating current was beginning to come into wider use. Fessenden kept abreast of the then-developing AC theory, as well as the work of Hertz, both on the job and in his spare time. He took a job with the Stanley Company of Pittsfield, Massachusetts late in 1891 where he could apply his knowledge to the design of AC motors and transformers.

Unfortunately, the Stanley Company soon fell on hard times due to the economic panic of 1892. When offered the chair of Purdue University's electrical-engineering program, he readily accepted. The prospect of coupling teaching with his own research interests was very appealing.

The following year, Fessenden received an offer to teach electrical engineering at the Western University of Pennsylvania (now the University of Pittsburgh). George Westinghouse had recommended Fessenden for the position and offered to provide financial and other material support for Reginald's research. Fessenden eagerly accepted the offer.

University life appealed to Reginald Fessenden. He enjoyed teaching students and having them help him with his electrical research very much. While at Pittsburgh, Fessenden developed a micro-photography technique for recording and storing printed documents. This technique has evolved into the microfilm and microfiche methods used today. He also made some important contributions to the development of equipment for using the then recently discovered X-rays to check the uniformity of steel used in Navy ships.

An Idea Begins. Fessenden maintained his interest in AC electronics, particularly because it held promise for long distance communication via electromagnetic waves. Telegraphy was thought by most at the time to be the only way electromagnetic waves could be used for wireless communications. Reginald Fessenden, however, was already beginning to think about a grander form of communications system: wireless telephony.

A thorough study of the "coherer," the most commonly used wireless telegraphy detector of the day, was carried out by students under Fessenden's direction to determine its suitability as a detector of wireless telephony signals. The coherer consisted of a thin glass tube filled with metal filings. The tube had an electrode at each end. When connected to an antenna and no wireless signal was received, the coherer acted as an open circuit. When the antenna delivered a strong signal, however, the coherer became a short circuit. The coherer was not very sensitive and required tapping between each telegraphic dot or dash to restore its detecting ability.

Fessenden soon realized that the coherer could not be made into a suitable detector for wireless telephony. What was needed was a more sensitive detector that operated continuously, not intermittently. Also, the desired detector needed to provide an output that was proportional to the received signal. These things the coherer could never do. Fessenden knew that he, himself, would have to develop the needed detector.

Other serious problems stood in the way of the development of wireless telephony. The spark transmitters in use at that time produced pulses of damped oscillations. The pulsed oscillations used occurred at audio frequencies in what we now call the low radio-frequency range. So the keyed signal received was a single audio tone. Since a tone of one frequency could be sent, Fessenden was convinced that the transmission of voice and music also might be possible However, he knew that the amplitude modulation necessary for wireless telephony could only be achieved if the transmitter produced undamped, continuous radio-frequency oscillations. The difference between the pulses of damped oscillations produced by a spark transmitter and the undamped, continuous oscillations Fessenden wanted are shown in Fig. 1.

It was apparent to Fessenden that spark-transmitters would not be suitable for another reason: the noise that resulted from the spark discharge would drown out the desired audio-frequency modulation.

Elihu Thomson had devised and patented an oscillating arc discharge in 1892, which produced distorted, but continuous, oscillations. Others attempted to refine the oscillating arc, but the technique could not produce oscillations of great enough frequency to be useful for wireless transmissions.

An Alternator is the Answer. Reginald Fessenden began to think that the ideal source of the continuous sinusoidal oscillations he needed would be an alternator or AC generator. However, it would have to be capable of producing a high-frequency output. Such an alternator would require a very large number of poles and would have to operate at an extremely high rotational speed to produce the power at the frequency Fessenden wanted. The frequency would have to be at least 100,000 cycles per second.

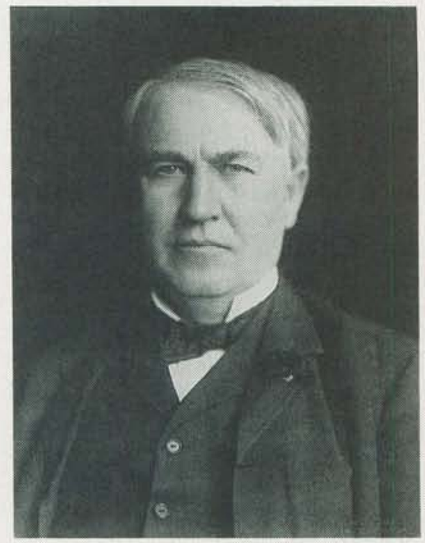
It was not at all clear at the time how, or even if, such an alternator could be constructed. John Ambrose Fleming (who would one day develop the diode-valve detector) maintained that such an alternator could not be built and would not produce useful radiation anyway.

Many others firmly believed that the thought of any kind of wireless telephony system was pure fantasy. Even if such a system could be developed, people argued, who would want it? There would be no means for automatically making a permanent record of the message on paper as there was with the telegraphy systems then in use. Undiscouraged, he began making plans for both the improved detector and the alternator he sought.

Although Fessenden had some knowledge of the design of AC rotating machines operating at power-line frequencies, the design of a high-frequency alternator would require more expertise than he, alone, could provide. He would have to get some outside help.

It was natural that Fessenden first approached Westinghouse to design his alternator. The Westinghouse Company declined, perhaps because they already were heavily involved in the design and manufacture of the alternators to be used at the Niagara Falls power plant.

The only logical choice remaining was the newly formed General Electric Company with the brilliant Charles Proteus Steinmetz as its expert on the design of alternating-current machines.



Thomas A. Edison helped Reginald Fessenden learn about both the "science" of electricity and the art of inventing.

Steinmetz was eager to tackle the problem, but designing and building the device would take several years.

In the spring of 1900, Fessenden decided to leave his university position in Pittsburgh. He had acquired some acclaim in wireless telegraphy and was offered a job with the U. S. Weather Bureau. His assignment was at Cobb Island, Maryland where he was to develop a wireless telegraph system that would enable remote stations to report and exchange weather conditions and forecasts.

The Weather Bureau had no interest in any farfetched schemes involving wireless telephony. Fessenden, therefore, had to confine his telephony research to his spare time and keep it unknown to his Weather-Bureau supervisor.

The First Wireless Telephony Transmission. While his plans for a high-frequency alternator were still very much in the beginning stages, Fessenden had formulated another plan for producing wireless telephony. He realized that if a spark transmitter produced pulses at a frequency higher than the audio to be transmitted, it might be possible to use it for crude, but acceptable, wireless telephony.

Utilizing the skills of a Pittsburgh craftsman whose abilities he respected very highly, Fessenden had an "interrupter" made to accomplish this feat. The interrupter was to act as a rotary mechanical switching device to increase the spark rate of the transmitter to about 10,000 pulses per second. While this was not out of the audible frequency range, it was above the voice frequencies Fessenden intended to send.

Toward the end of 1900, Fessenden set up his interrupter-equipped transmitter with a carbon microphone in the antenna circuit at Rock Point, Maryland. Another antenna, this one connected to a receiver equipped with a continuous-acting but low sensitivity detector Fessenden had developed, was set up about a mile away with Fessenden's assistant listening for Reginald's voice.

Fessenden succeeded in transmitting very noisy, but intelligible speech with this arrangement. The experiment earned Fessenden credit for the first successful wireless transmission of speech. As Fessenden's Weather-Bureau superiors would have taken a dim view of these activities, no account of this experimental success was reported until several years later.

Many improvements would be needed before this approach could produce wireless telephony of acceptable quality. The interrupter did not provide the switching rate hoped for and the oscillations still were too highly damped. At a minimum, the switching rate would have to be doubled and the amount of damping of the oscillations would have to be greatly reduced. Fessenden clearly knew, however, that even if these changes could be made, a spark generator would never produce the continuous waves he needed. A high-frequency alternator was still the device of choice.

The Needed Detector. The next major success toward achieving a practical wireless telephony system came in 1902 at Roanoke Island, North Carolina. Fessenden had been sent there by the

Even though Reginald Fessenden has done so much to advance electronics, how many school children would know him from this photograph?

Weather Bureau to set up a wireless telegraphy station. Still pursuing his own research on the side, he succeeded in developing a detector that possessed the qualities he was seeking: the "liquid barretter," as he called it, provided continuous reception and an output proportional to the received signal. In addition, it was significantly more sensitive and reliable than the coherer or any other detector then available.

The liquid barretter design evolved, literally by accident, from a "hot-wire barretter" Fessenden had developed while still in Pittsburgh and had used in his 1900 Rock Point wireless-telephony experiment. The hot-wire device consisted of a short length of very thin, silver- coated platinum wire bent in a "U" shaped loop and enclosed in an evacuated glass envelope (see Fig. 2). The

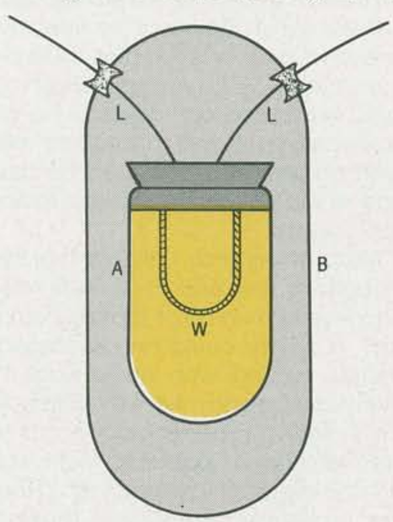


Fig. 2. Fessenden's hot-wire barretter provided continuous detection but was not very sensitive. The device was made up of lead-in wires (L), a wire loop (W), an evacuated inner envelope (A) and a silvered outer bulb (B).

glass envelope was enclosed in a silvered glass bulb to shield the wire from external radiation. The middle of the wire loop had its silver coating removed by nitric-acid etching.

A wireless signal passing through the hot-wire barretter caused its resistance to change. That produced an audible response in a telephone earpiece connected between the barretter and ground, in series with a battery and a resistor.

The hot-wire barretter detector was about as insensitive as the coherer, but it was continuous in operation and did provide a response that was approximately proportional to the intensity of the signal received. Fessenden was awarded a patent on the hot-wire barretter in 1902.

Good fortune struck in early 1902 when a wire filament being prepared for a hot-wire barretter was inadvertently left too long in the etching acid. A meter connected to the wire to monitor the etching process responded very strongly to electromagnetic waves being produced in the laboratory. The acid had completely dissolved the wire, leaving only a stub of the platinum making contact with the acid. Thus was born the "liquid barretter."

Basically, the liquid-barretter detector in operational form consisted of a short length of fine platinum wire and a small pool of 20% nitric acid solution. The tip of the wire barely penetrated the surface of the acid solution. The basic features of the liquid barretter are shown in Fig. 3.

The liquid barretter was not without its drawbacks, however. The need to have the wire tip make shallow contact with the acid solution made operation difficult on a ship rolling in a stormy sea. Nonetheless, Fessenden's liquid barretter was the standard to which other detectors were compared for many years until de Forest's triode audion detector, which after considerable refinement, became the standard.

A patent on the liquid barretter was issued to Fessenden in May of 1903. Many infringements of his liquid barretter patent occurred, however. One of the most serious violations was perpetrated by Lee de Forest. A Federal Court ultimately affirmed Fessenden's rights and ordered Lee de Forest to stop the infringement. However, this did not occur until de Forest already had sold a number of the devices to the U.S. Navy and others as a sensitive detector for wireless telegraphy reception.

Fessenden succeeded in developing a much improved wireless telegraphy system for the Weather Bureau. So much better in fact, his supervisor ordered him to share the patent rights. When Fessenden refused, the result was predictable. Reginald Fessenden's employment by the Weather Bureau was terminated in August of 1902.

A few months later, two wealthy men from Pittsburgh, named Given and Walker, offered to supply the financial backing that would enable Fessenden to further develop and market his wireless telegraphy and telephony systems. The three men formed the National Electric Signaling Company (NESCO). That provided Fessenden with the opportunity he had been seeking.

The Heterodyne Principle. The liquid barretter worked well for detecting either wireless telephony or spark-generated wireless telegraphy signals. Fessenden, however, knew that it had a serious drawback for use in a wireless-telegraphy system using undamped waves. The barretter would produce only a click in the telephone earpiece if the keyed signal consisted of continuous oscillations (or waves) rather than the pulses of damped oscillations occurring at an audio frequency. Fessenden understood well that undamped, continuous waves (CW) would be desirable for both wireless telegraphy and telephony, because they can be selectively tuned via resonant circuits.

After studying the problem, Fessenden arrived at a solution that eventually would be recognized as a milestone in wireless technology. He realized that if the continuous-wave telegraphy signal to be detected was combined ("mixed") with continuous waves of a slightly different frequency generated at the receiver, an audible note or tone would be produced.

Using his knowledge of languages, he coined the word "heterodyne" to describe the phenomenon. The word has its foundation in the Greek *heteros*, which means "different," and *dynamos*, which means "power."

The result of heterodyning, or mixing, two signals of frequencies f1 and f2 is the production of two additional signals of frequencies f1 + f2 and f1 − f2, respectively. The new frequencies are called "beat" frequencies. (Other signals also are produced, but the two resultant frequencies mentioned are the important ones.)

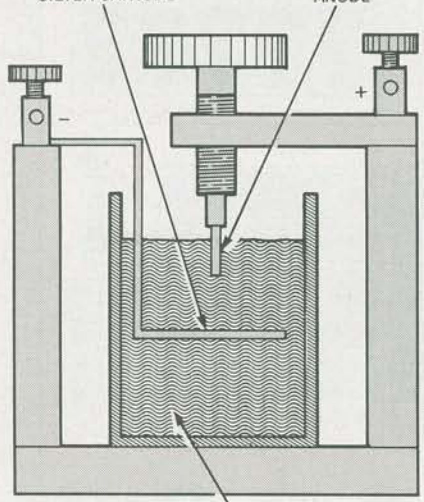


Fig. 3. The liquid barretter provided both the continuous detection and the sensitivity Fessenden wanted.

This idea of Fessenden's to heterodyne two signals truly was insightful. The principle still is commonly used in the superheterodyne receivers of today. At the time, however, detection of the damped oscillation pulses from the spark transmitters did not need the heterodyne principle. A stable source of sinusoidal high-frequency waves would still have to be developed before CW telegraphy would be feasible.

Fessenden, however, was able to demonstrate the fundamental merits of the heterodyne principle by using an arc, which was both noisy and lacking in frequency stability, as his source of local oscillations at the receiver. The combination of the receiver's telephone earpiece and the human ear provided the necessary mixing of the signals to provide an audible tone. However, the poor quality of the arc-generated oscillations seriously degraded the audio output of the heterodyne receiver.

The First Alternator is Tried. A high-frequency alternator designed by Steinmetz was delivered in 1903. It produced one kilowatt of power, but at a frequency of only 10 kHz. The signal generated had neither the audio quality nor the range Fessenden sought. He wanted an output of 25 kilowatts at a frequency of 150 kHz! These requirements could not be met quickly or easily. Charles Proteus Steinmetz then turned over the job of redesigning the alternator to Ernst Alexanderson, a young engineer at GE who had already shown considerable talent.

Alexanderson took on the task enthusiastically. Studying both Fessenden's requirements and some of his design suggestions, Alexanderson discarded many traditional alternator-design approaches, which seemed unworkable at the frequency specified. The first goal would be to achieve the output frequency Fessenden wanted. Achieving Fessenden's desired output power would have to come later.

Two-way, Trans-Atlantic Wireless Telegraphy. Demonstrating the advantages of improved wireless telegraphy with the intent of marketing it commercially was an important goal of the NESCO organization. What more convincing demonstration could they provide than two-way, trans-Atlantic telegraph communications? That being so, the work of Fessenden and his NESCO staff continued while they waited for the alternator to be built.

A rotary spark-gap transmitter and Fessenden's improved receiving system were set up at Brant Rock, Massachusetts. An identical station also was built at Machrihanish, Scotland. A 400-foot high antenna of Fessenden's own design was erected at each station. Tests of the system were begun near the end of 1905. The Brant Rock station was first heard at Machrihanish on January 2, 1906.

On January 10, after Brant Rock finished its transmissions, the Ma-

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chrihanish station started sending. Its signal was weak, but the Machrihanish station was heard at Brant Rock. For the first time in history, two-way wireless telegraphy had spanned the Atlantic Ocean!

The exchange of messages between the two stations continued fairly regularly for several weeks, depending on the condition of the ionosphere. The onset of summer made regular communications impossible at the frequencies used. Trans-Atlantic communication was not resumed until October 1906. The communication capabilities of the Fessenden system were demonstrated for several months to a number of scientific, commercial, and military observers until the antenna at the Machrihanish station was destroyed by a fierce storm.

Other exciting developments were also occurring at Brant Rock during the late summer of 1906. The Alexanderson-designed alternator was delivered and tests were begun. Again, neither the frequency produced nor the output power met specifications. Fessenden would have to redesign the alternator himself. The alternator was rebuilt in NESCO's shop incorporating Fessenden's numerous modifications. Finally, in the fall of 1906, approximately 500 watts of output power at a frequency of 75 kHz was obtained.

Successful wireless telephony was established between Brant Rock and Plymouth, a distance of 11 miles. Communications also took place between Brant Rock and a small fishing boat located in the ocean 12 miles away. Fessenden, however, had a much grander demonstration in mind.

The First Broadcast. Numerous ships at sea were using the Fessenden liquid-barretter receiving system, some legally and many illegally as far as patent rights were concerned. That provided Fessenden with a golden opportunity for his demonstration. The ships were notified by telegraph from Brant Rock to listen for a special transmission on Christmas Eve in that year of 1906, but no hint was given concerning what the transmission might be.

At the appointed hour, the radio operators on the ships were amazed to hear Reginald Fessenden's voice. Next came phonograph music followed by a violin solo performed by Fessenden. A reading of the Christmas story from the Bible and an announcement that a similar transmission was planned for New Year's Eve concluded the first wireless broadcast in history.

The listeners were encouraged to send in reception reports to Brant Rock. Reports of the Christmas Eve broadcast were received from ships as far away as Norfolk, Virginia. The New Year's Eve transmission was received in the West Indies.

Amazing as Fessenden's wireless telephony demonstrations were, the world did not beat a path to his door. Telegraphy was more reliable for long-distance commercial and military message-handling purposes. No need existed for wireless telephony in 1906.

Commercial broadcasting to homes would not be recognized as economically practical until after World War I. Then, relatively easy-to-operate and reliable receivers could be produced at a price the public could afford. In addition, means for generating large amounts of power at higher, more effective frequencies were available. "Radio" broadcasting as we know it today, nevertheless, can trace its beginnings to that 1906 Fessenden broadcast from Brant Rock, Massachusetts. ■