Introduction to "The Heterodyne Receiving System, and Notes on the Recent Arlington–Salem Tests"

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Invited Paper

I. Introduction

John Vincent Lawless Hogan (Fig. 1) was a radio pioneer and a broadcaster. In his 1913 Classic Paper, he described the radio equipment used in the Arlington–Salem tests, explained the principle of heterodyning, and claimed that an equipment employing this principle had greatly improved the sensitivity of radio receivers. For an appreciation of Hogan's paper, an understanding of the types of equipment used for radio transmission and reception, as well as the technology available at the time, is essential. With this in mind, this introductory paper aims to present a brief history of the invention of radio and the development of apparatus used at that time. Some discussion on National Electrical Signaling Company, where Hogan worked at the time of presenting the paper, and his biography are also provided in this paper. For more details the readers are referred to [1] and [2]. The first one is a chapter in a book by Hogan, written in 1923, and now available on the worldwide web with many hypertext links to other websites of historical significance. The second one is a paper by Belrose, presented at a conference on "100 Years of Radio."

Fig. 1. Photo of Hogan.

II. Invention of Radio

The invention of radio was a slow and laborious process, spanning more than half a century. Many scientists and engineers from all over the world have contributed to this process [2]; notable among these were: Henry, Edison, Thomson, Tesla, Dolbear, Stone-Stone, Fessenden, Alexanderson, de Forest, and Armstrong in the United States; Hertz, Braun, and Slaby in Germany; Faraday, Maxwell, Heaviside, Crookes, Fitzgerald, Lodge, Jackson, Marconi, and Fleming in the United Kingdom; Branly in France; Popov in the U.S.S.R.; Lorenz and Poulsen in Denmark; Lorentz in Holland; and Righi in Italy.

The following are some of the milestones leading to the invention of radio (wireless transmission) and developments thereafter [1].

1842	Morse successfully sent telegraph message across a canal using water to carry electrical current.
1875	Bell built his first telephone.
1882	Preece utilized magnetic induction between two circuits to transmit messages.
1885	Edison used metallic plates in the air (as antennas) to send wireless telegraph messages.

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1886 Hertz confirmed Maxwell's electromagnetic waves (1867) by creating and detecting these waves.

1896/97 Marconi demonstrated electric-wave telegraphy.

1902 Fessenden patented heterodyne principle.

1904 Fleming invented valve diode.

1907 De Forest patented Audion: a three-element vacuum tube.

1913 Armstrong invented feedback.

1918 Armstrong (and others) produced super heterodyne receiver [3].

A. Transmitters

Early transmitters used a spark, generated by applying high voltage across a gap. The high voltage (up to 150 kV has been talked about) was generated by discharging a very large capacitor. The two sides of the gap were connected by two extended wires, one acting as an antenna and the other one as an earth wire. The spark gap transmitter was used first by Hertz to create electromagnetic waves and later by Marconi for his demonstration of a telegraph message. Marconi discovered that connecting one side of the spark gap to Earth and the other to a very high vertical aerial one could transmit over a large distance. Improvements in spark gap transmitters were made later by dividing the sending assembly into two parts—a driving circuit and a loosely coupled radiating circuit—and by introducing the idea of tuning.

Spark gap transmitters had serious defects as transmission only occurred for a very small fraction of the time during which they were powered. This was not only highly inefficient, but it also was not suitable for continuous transmission. A system to generate continuous waves was invented by Fessenden. He devised various ways to generate radiating energy continuously using alternators. Alexanderson later developed these alternators large enough to send signals across the Atlantic Ocean. These ac generators were driven by steam engines.

A strong competitor of the RF alternator at that time was to generate continuous waves by using a steady electrical arc. The voltage and current characteristics of an arc exhibit a region of negative differential resistance, and this phenomenon was exploited in generating permanent oscillation by inserting an arc in a tuned circuit. The characteristics of an arc depend upon such factors as the distance between the electrodes and the temperature of the electrodes. An arc generates heat and thus requires cooling; however, the electrode has to be warm for its proper function. The type of gas used also affects the behaviour of ions. The best results were obtained using hydrogen, but it was dangerously explosive. Thus the hydrocarbon gases were preferred [4].

The latest development in transmitters came with the invention of vacuum tubes and feedback mechanisms to cause sustained oscillations.

B. Receivers

In early experiments, a device, referred to as a coherer, was used as a detector. A coherer was a bistable device. In its normal state it exhibited high resistance, however, it showed a substantial decrease in the resistance when subjected to voltage above a certain threshold. The change in resistance was detected by listening with a telephone earpiece or using a secondary relay circuit. Many variations of this device were investigated using loose carbon filling as well as a mixture of carbon dust and cobalt dust. One employed by the Italian Navy used mercury filling between a carbon plug and a movable iron plug. These devices had very poor sensitivity and were not very reliable due to loose contacts. The transition from one state to the other was caused by an application of a voltage, but the reverse transition required a mechanical tapping. In 1902 Marconi produced a magnetic detector which was dependable, but it was not much more sensitive than that of a coherer. In the same year Fessenden patented a thermal receiver of similar sensitivity.

In 1903 Fessenden produced a liquid receiver (Barretter), which was stable and very sensitive. It was adopted in practical radio by the U.S. Navy and became their standard of sensitivity. The Barretter, on the other hand, was useless for reception of telegraph signals. It only produced clicks as the Morse key was closed and opened. Fleming's incandescent lamp receiver came in 1904, but in its original form, its performance was not comparable to that of liquid detectors. During this time various forms of crystal detectors were also investigated using materials such as silicon, lead ore, and iron pyrates. The sensitivity of crystal detectors was similar to that of the liquid types, and these detectors later superseded the old ones due to their ease of manipulation.

In Hogan's paper the use of the ticker receiver is mentioned. The ticker was a switch operated by a buzzer. It used to be inserted in the secondary circuit of the receiver where it used to act as a kind of chopper. The chopping operation was similar to multiplying the received signal by a square wave [4].

There was a great improvement in the sensitivity of receivers when de Forest introduced the three-element vacuum tube. The earlier "diode" vacuum tube receivers were unstable and were not used in practical radio until about 1912. The invention of feedback circuits by Armstrong, and the discovery that the grid audion was able to amplify, made the vacuum tube "triode" receivers popular in years to come. The use of improved tuning in transmitters and receivers and the refinement in the heterodyne receivers later led to the development of superheterodyne receivers.

C. Superheterodyne Receivers

Almost all radio and TV receivers today employ a superhetrodyne, also known as a superhet, receiver. It transforms all incoming carrier signals to a common intermediate frequency (IF) where the signals are amplified using common tuned amplifiers and thus overcomes the need to build a tunable high Q filter. A schematic block diagram of a typical superheterodyne receiver consisting of an RF section, mixer and local oscillator, IF amplifier, detector, power amplifier, and a loudspeaker is shown in Fig. 2.

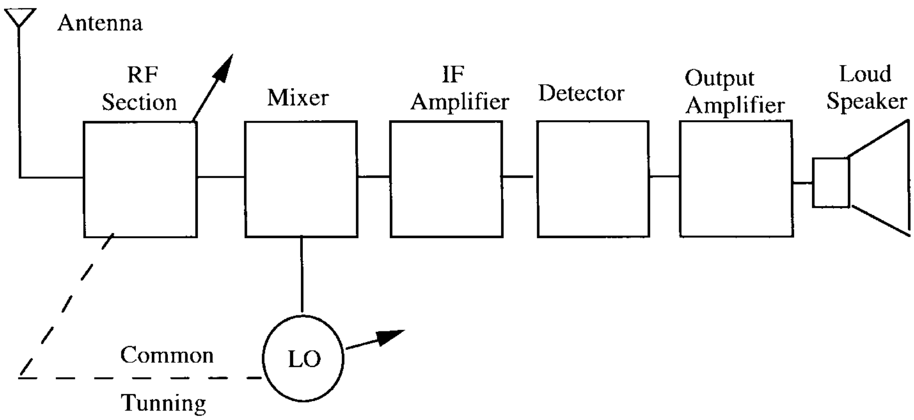

Fig. 2. A schematic block diagram of a heterodyne receiver.

The RF section, tuned to the carrier frequency of the incoming signal, picks up the signal from an antenna, acts as a bandpass filter to discriminate against image and intermediate frequency signals, and provides amplification. This signal is multiplied with the local oscillator signal in a mixer to change the carrier frequency to the predetermined intermediate frequency. The typical midband frequencies of IF sections of AM and FM receivers are 0.455 MHz and 10.7 MHz, respectively. The IF section provides amplification using tuned amplifiers with bandwidth of AM and FM receivers being equal to 10 kHz and 200 kHz, respectively. The output of the IF section is fed to a detector where the baseband signal is recovered. The signal is further amplified and fed to the output device such as loudspeakers in the case of a radio signal.

III. National Electrical Signaling Company

In 1902 Fessenden joined two Pittsburgh capitalists to found National Electrical Signaling Company (NESCO) to develop his work on radio [5], [6]. In 1905 he completed a 420-ft radio tower (Fig. 3) at Brand Rock, MA, and used it as a transmitting station [7].

Radio signals were transmitted from Brand Rock using 50-kHz high-frequency alternators developed by Alexanderson of General Electric. On December 24, 1906, wireless operators were surprised to hear music and speech on their own receivers from as far away as Norfolk, VA.

Fessenden's relationship with his financiers started to deteriorate as he wanted to compete with Marconi, and they wanted to sell the company and its patents. In the end, Fessenden broke away from NESCO to form a new company and NESCO dismissed him. He sued the company for breach of contract and won. NESCO went into receivership and was later sold to Westinghouse after World War I along with its patents [5].

IV. Biography of Hogan

The following biography of Hogan has been compiled by Dilks [8]. John V. L. Hogan was born in Bayonne, NJ, on February 14, 1890. At the age of 12, Hogan built his first amateur radio station, using the coherer as a detector, at his home in Bayonne. By 1906, he was employed as a laboratory assistant to Dr. Lee De Forest; he was just 16 years old. De Forest was experimenting with the audion and radiophone. Hogan's assignment was to make the first quantitative study of the plate current characteristics of the De Forest's grid triode.

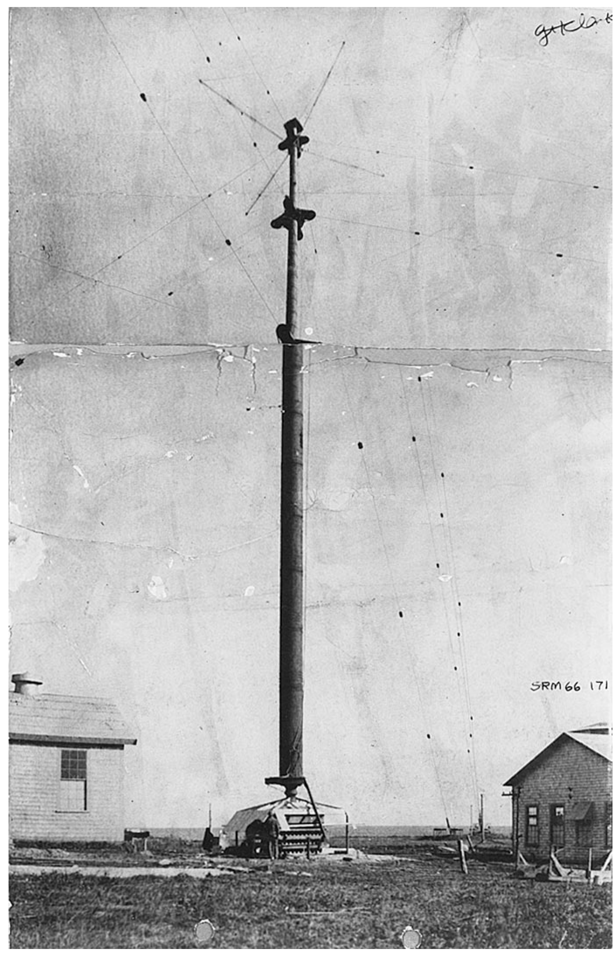

Fig. 3. The 420-ft radio tower at Brand Rock, MA [1].

Hogan attended the Sheffield Scientific School at Yale University during 1908–1910, specializing in physics, mathematics, and electric waves.

It was in 1910 when he went to work for R. A. Fessenden and the National Signaling Company at the famous Brant Rock station. He served as a telegraph operator. He helped develop Fessenden's first patent on the crystal detector, issued in 1910. Hogan also discovered the "rectifier heterodyne." His associate, J. W. Lee, had observed some peculiar effects when a special transmitter was being operated while the station was receiving messages. Referring back to some of his work at Yale, Hogan succeeded in increasing the sensitivity of the radio receivers by more than 100 times. He reported this to the Institute of Radio Engineers in 1913.

Fessenden was so impressed with Hogan that he assigned him the important job of Supervisor for the erection of the Bush Terminal Station in Brooklyn, NY. There he developed perhaps the first ink tape siphon for recording transatlantic radio signals, using an audion amplifier.

Hogan would work for Fessenden until 1914, but his respect and admiration for the man would last until his death. Later he would write about Fessenden at some length, in his 1923 book *The Outline of Radio*.

In 1912 he was instrumental in the formation of the Institute of Radio Engineers (by consolidating the Society of Wireless Telegraph Engineers with the Wireless Institute). In 1913 he had charge of the acceptance tests of the U.S. Navy's first high-powered station at Arlington, VA. Later he became the chief research engineer from 1914 to 1917. He worked on high-speed recorders for long-distance wireless.

In 1917 he was appointed Commercial Manager of the International Signal Company. He was placed in charge of operations and manufacturing with emphasis on radio outfits for submarine chasers and aircraft. In 1918 he was made Manager of the International Telegraph Company, and in 1920 he was elected President of the Institute of Radio Engineers.

It was his 1912 patent of a single-dial tuning system for radio receivers that would mark his place in history. The advent of home radio and radio broadcasting in 1920 required a simple, one-knob control for tuning in stations. He would capitalize on this. Broadcast radio also inspired Hogan to write many scientific articles for the technical press.

Hogan established his own consulting practice in 1921, where he specialized in broadcast apparatus and radio regulations. In 1928 he added facsimile and television to his laboratory work. Always interested in tonal quality, he built the first high-fidelity radio station, first licensed as W2XR, a 250-W experimental station in 1934. Later this station would become New York City's WQXR with 10 000 W, playing classical music.

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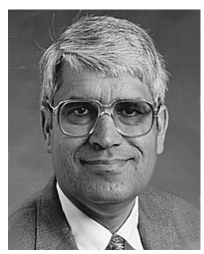

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