Introduction to the Classic Paper by Marconi

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Invited Paper

I. Background

Guglielmo Marconi was born on April 25, 1874, in Bologna, Italy. He contributed significantly to the development of wireless communications technology, demonstrated for the first time a successful setup for radio telegraphy (in 1895), and was a pioneer in the application of electromagnetic waves.

Radio communications is one of the most fascinating and perhaps spectacular successes of mankind in advancing science and technology. Few technological developments have had such great and far-reaching consequences as wireless communication. Founded upon the great scientific discoveries of the nineteenth century, it created a spectrum of technologies, each requiring scientific insight of its own, and fostered innovations in many related disciplines. Wireless communication involves technologies with huge potential for aiding world progress, improving the quality of life for every human being on this earth and leading to a better future for mankind.

Many persons have contributed to the development of radio communications [1], [2]. The theoretical foundation of electromagnetic waves was laid out brilliantly in 1864 by J. C. Maxwell, the British physicist who introduced the basic equations to relate the electric and magnetic fields and developed the foundation for electromagnetic waves. Maxwell's ideas, however, had to be confirmed. In 1887, H. Hertz, a physics professor in Karlsruhe, Germany, carried out laboratory experiments and demonstrated the existence of the electromagnetic waves as predicted by Maxwell.

Telegraphy, i.e., the transmission of Morse codes representing different characters via wire line, had already been in operation, and the idea of deploying wireless radio for distant sources was clearly present. Furthermore, the importance of using the propagation of electromagnetic waves for radio communication was known and its development had been predicted. For example, W. Crooke in 1892 had written about radio telegraphy at a wavelength of a yard or more [3].

Manuscript received July 30, 1997.
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Publisher Item Identifier S 0018-9219(97)07660-3.

Marconi, who had a true mind of engineers of his time, had sensed the practical application of Hertz's findings. The first radio telegraph system developed by Marconi put to work the concepts already developed by Hertz, Branly, Lodge, Popov, and a few others. It is said, however, that the major influential event in his development of radio telegraphy was the recognition of the potential application of the work done by his professor, A. Righi, who in turn had benefited from a commemorating lecture given in honor of Hertz by O. J. Lodge, a British physicist, in 1894.

Marconi recognized the importance of having more sensitive receivers in radio communications. Aside from radio telegraphy, he saw many other applications of wireless, including navigation, emergency and distress signaling, and remote control. In 1909, Marconi received the Noble Prize in physics (to be shared with K. Braun) for his contributions to radio telegraphy. He died in Rome on July 20, 1937.

II. Early Radio Communications Technology

During the early years of experimentation, Marconi's wireless telegraph system comprised a spark-gap signal generator, a resonator, an antenna, and a coherer as a detector. The transmitter was based on the spark gap and a tuning circuit composed of a coupled resonant circuit and an antenna, which was a metallic plate known as a capacitive antenna. The resonant circuit produced the higher frequency for modulating telegraphic signals at frequency f given by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where L and C are the effective inductance and capacitance, respectively.

When Morse key was activated, the capacitor was charged, and when it reached sufficient voltage level, a spark was generated across the gap and a current would flow over the tuned circuit into the inductance at resonating frequency (determined by the capacitance and inductance, as stated above). Thus, the transmitter produced periodic damped oscillations due to the capacitor discharge. That is, the amplitude of the current oscillating at frequency f would decay exponentially while the Morse key was

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pressed. The decay rate would be determined by the time constant.

Marconi attributed the successful demonstration of wireless telegraphy, as stated by him, mostly to the adoption of a coherer receiver [1]. E. Branly, a French physicist who developed the coherer (name given by O. J. Lodge), recognized that air is a good insulator but a spark through the air is a good conductor of electricity. Marconi improved the coherer by using a mixture of metallic powders for the filling of a glass tube with two silver plugs roughly a millimeter apart. The high resistance due to the gap will result in no current's flowing when a battery is connected to the two plugs. In the presence of electromagnetic waves, however, sparks forming across the gap will reduce the resistance significantly, and the current will start flowing and will continue even after removal of the electromagnetic waves. The glass tube would return to its original state by tapping. The receiver was tuned to the same resonating frequency.

Marconi used electromagnetic waves at about 250 MHz in his early experiments to demonstrate radio communications. His early apparatus resembled Hertz' setup. He recognized that the long waves propagate over a larger distance and used them effectively. In 1896, Marconi's apparatus could provide communication of up to 3 km. The antenna used consisted of a long vertical wire using ground, the elevated antenna as previously used by Popov.

Marconi continued work on his apparatus to increase the distance for communications. In 1901, he was able successfully to demonstrate the transmission and reception of the Morse code for the letter "S" across the Atlantic Ocean between England and Newfoundland, over 3000 km, at an operating frequency of less than 1 MHz. The first commercial service started six years later at frequencies less than 100 kHz.

The transatlantic experiment was important, as it was then generally believed that the range for radio communications was limited to 200–300 km. At the time of Marconi's transatlantic experiments, the surface waves were known but the theory of ionospheric waves and the regions of ionizations now known as D-, E-, and F-layer had not been developed. Indeed, it was more than two decades later that the propagation of the radio waves via the ionospheric reflection was clarified.

III. From Radio Telegraphy to Wireless Personal Communications

A number of other developments brought different perspectives to radio telegraphy and radio telephony, that is, applying the radio technology to carry voice, as developed by Fessenden in 1906. The vacuum-tube diode was invented by J. Fleming and was used as a detector. The device was modified by L. de Forest to become the vacuum-tube triode, to be used in the receiver as well as in the transmitter. The superheterodyne concept was introduced by Fessenden and developed further by Armstrong to improve the radio receiver.

Other important events included radio broadcasting, which started to be widely deployed in the 1920's. Television broadcasting, radar, and other navigation devices were realized. Deep-space communication became possible. The communications satellite concept covering the entire earth by transponders at geosynchronous orbit was developed and soon thereafter became a reality. Microwave radio for long-haul communication (line of sight) in 2–20 GHz using repeaters (transceivers) and reflector dishes on towers spaced a few to tens of kilometers apart was widely used. Vehicular communications, which started in a limited form with a few channels in each major city, led to the development of cellular mobile radio with millions of subscribers decades later.

The last several years have resulted in a significant change of direction in wireless communications. The original goal of radio communications for long haul has changed dramatically and has been replaced by optical fibers. On the other hand, access via radio to the switched telecommunications networks has become commonplace.

The successful deployment of the first-generation cellular communications has fueled a spectrum of activities and innovations in related areas. Digital communications techniques with advanced signal processing techniques have been applied to the second-generation networks. The miniaturization of radio handsets and base stations has been made possible by using very-large-scale integration application-specific integrated circuit and monolithic microwave integrated circuit techniques. Improvements from the antenna to battery technologies have made the handsets more and more an integral part of our daily life. Wireless local-area networks are beginning to facilitate access to the information. Next-generation wireless networks with increasing capacity are under study, and it in no way appears that we have yet tapped the huge potential of wireless.

IV. Marconi's 1922 Paper

Marconi, as witnessed by his writings, frequently gave credit to the work of those who contributed to radio communications, as in his 1922 paper [4], where he states:

> A very great impulse has been given to radiotelegraphy and telephony by the discovery and utilization of the oscillating electron tube or triode valve based on the observations and discoveries of Edison and Fleming, of those of de Forest and of those of Meissner in Germany, Langmuir and Armstrong in America, and H. W. Round in England, who have also brought it to a practical form as a most reliable generator of continuous electric waves.

In this paper, Marconi reports on his experiments and findings in the high frequency range, the work that he himself started in 1896 using directional rays with parabolic reflectors. Here, Marconi notes the effect of daylight on wireless transmission, the day-night variation, and, similarly, variation in westward and eastward propagation. We came to know the explanations for these effects years later.

It is interesting to note that the transmission of telegraphic signals by using the Hertzian or electromagnetic waves made common usage of "wireless telegraphy." The term "wireless" was replaced by "radio" per suggestion at the International Radio Telegraphic Conference held in 1906 in Berlin in order to refer precisely to this phenomenon [5]. The first usage of "radio" in the context has been attributed to Branly in December 1897 [6]. After almost 100 years, the term "wireless" is reborn and is now widely being used again in industry and academia. History has a way of repeating itself and, as the saying goes, "The more things change, the more they remain the same." Maybe it will take much less than 100 years to bring back the term "radio" or "wireless radio" to distinguish accurately between the alternatives at hand.

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