J C Bose and Early Radio Research

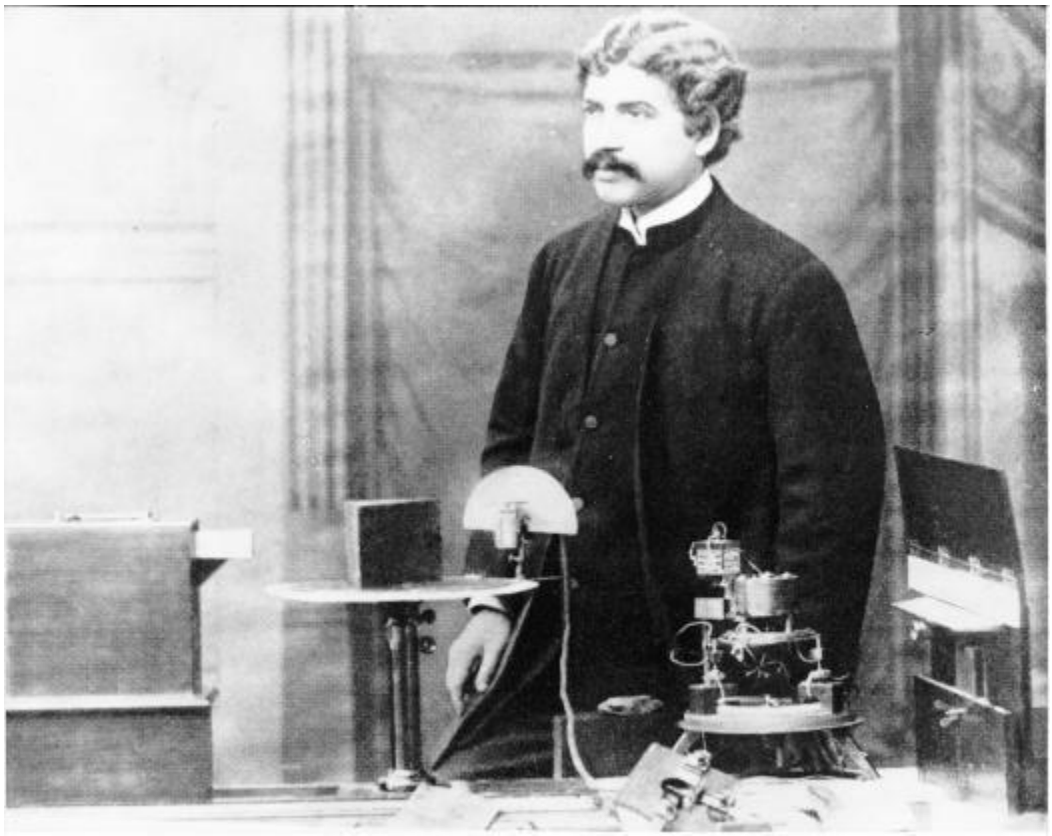
Animesh Maitra
Institute of Radio Physics and Electronics, University of Calcutta
Kolkata 700009, India
Email: animesh.maitra@gmail.com

Introduction

Sir Jagadish Chandra Bose was born on 30 November 1858 in Munshiganj, Bengal Presidency, now in Bangladesh. His undergraduate studies were at St. Xavier's College, Calcutta (now Kolkata, West Bengal, India). Bose earned a Bachelor of Arts degree from Cambridge University and a Bachelor of Science degree from the University of London. He joined Presidency College as an Assistant Professor in 1885. Bose resolved to devote himself to pursuing new knowledge on his 36th birthday in 1894. In a public lecture at the Town Hall of Calcutta in 1895, Bose demonstrated how electric waves could propagate over a distance of 75 feet through the intervening rooms, which could make a bell ring and fire a pistol was fired. A similar experiment was conducted at Presidency College. He published his first scientific paper, "On Polarization of Electric Rays by Double Refracting Crystals," in The Electrician in 1895. Bose conducted extensive research on microwave wireless systems between 1895 and 1901. Of 128 papers he published on his entire research activities, 27 were on wireless propagation studies.

Millimetre Wave System

In 1896, Bose demonstrated his millimetre wave apparatus, which was reported in Philosophical Magazine in 1897. The paper presents the most detailed description of his system for generating, transmitting, and detecting short-wavelength electromagnetic waves. In a public demonstration in Calcutta's Town Hall in 1895, he showed the signalling capability of electromagnetic waves by firing a pistol and ringing a bell from 25 metres away. The newspapers Indian Mirror and Daily Chronicle reported on this incident. An account of this demonstration appeared in Wireless Telegraphy and Hertzian Waves by S. R. Bottone. Bose subsequently mentioned this experiment in a Bengali article entitled *Adrishya Aloke*. Bose was said to have planned to set up a communication link between the Presidency College and the Bose Institute, but this never became a reality.



J. C. Bose at the Royal Institution, London

Historical Perspective

In 1888, Hertz launched decimeter-wave radiation with a parabolic mirror antenna and a dipole. Spark discharges generated by an induction coil excited the dipole. An antenna similar to the parabolic mirror was used to receive the radiation, while a transmission line fed the dipole to a spark gap detector behind the mirror. 66 cm was the wavelength of the radiation. Hertz's research demonstrated that the action was communicated to a distance by a wave motion analogous to visible light. He, therefore, substantiated experimentally the theoretical predictions of James Clerk Maxwell that the waves known to account for optical phenomena were electromagnetic.

Throughout the world, Hertz's experiments attracted attention. Scientists, whose primary interest was electromagnetism, immediately began studying Hertz's waves and their optical implications. Hertzian, or "the followers of Hertz," repeated Hertz's experiments and investigations, and extended the field of work considerably. Contrary to expectations, a separation of the optical and electromagnetic domains occurred at that time, resulting in two groups of researchers with different focuses.

Researchers who were optically minded mainly concentrated on demonstrating the quasi-optical properties of electric waves through laboratory experiments. They were not convinced of the viability of wireless for long-distance communication. A major focus of their efforts was to develop high-frequency generators, detectors, polarizers, dielectric lenses, and prisms so that optical properties of waves of electric waves could be demonstrated with smaller components. Researchers such as Heinrich Hertz, Oliver Lodge, Augusto Righi, Pyotr Lebedev, Lord Rayleigh, and J C Bose belonged to this group.

On the other hand, electrically minded researchers were mainly interested in developing wireless telegraphy systems. They focused on developing low frequency and high power transmitters, tuning circuits, and increasing communication distance with their experiments. Marconi, Nikola Tesla, Popov, Karl Ferdinand Braun, and Oliver Lodge (although initially unconvinced of the efficacy of long-distance wireless communications) were among the scientists interested in using electric waves for communications.

J C Bose and Quasi-Optics

Hertz's famous experiment in 1888 was the first Quasi-Optics experiment to generate electric waves using dipoles with spark gaps used both as generators and detectors and parabolic cylinder reflectors employed at both transmission and reception ends. In 1894, Righi in Italy modified Hertz's radiator dipole with three spark gaps to generate radiation with wavelengths of 2.5 cm and 20 cm, which were much smaller than Hertz's wavelengths. In 1895, Russian scientist Lebedov experimented with short wavelengths of 6 mm. Lebedev's components, such as wire polarizers, metallic reflectors, and phase shifters, were 100 times smaller than those developed by Hertz. The Russians claim that Lebedev invented mm waves. Using a wire radiator inside a circular copper pipe closed at one end and opened at the other, Oliver Lodge first proposed a waveguide feed in 1894 that produced wavelengths of 7.5 cm and 20 cm. Flaming, in 1900, produced radiation with a wavelength of 20 cm and experimented with a rectangular box feed that could represent the first rectangular waveguide. Bose in Calcutta carried out the most extensive quasi-optic experiments between 1894 and 1900, with wavelengths ranging from 5 mm to 2.5 cm. Bose developed radiators, detectors (including a semiconductor detector), horn antennas, double prisms, polarizers, absorbers, and gratings - virtually all of the components needed for optical systems.

J. C. Bose's wireless research was primarily concerned with determining the optical properties of electromagnetic waves. Bose describes it as "bridging the gap that had previously existed between the comparatively slow ether vibrations and the quick oscillations that give rise to radiant heat." Although Hertz's generation of electric waves confirmed Maxwell's electromagnetic theory, scientists remained sceptical about the optical properties of the "invisible" light generated by electric sparks. In order to study optical phenomena, scientists used electric waves with short wavelengths to build lenses, prisms, and polarizers which led to Quasi-Optics and Microwaves, though the terms were coined much later.

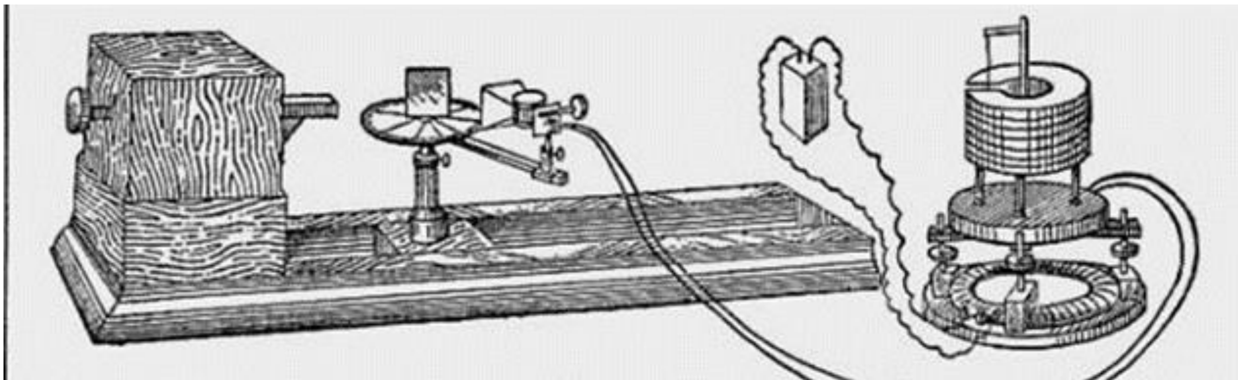
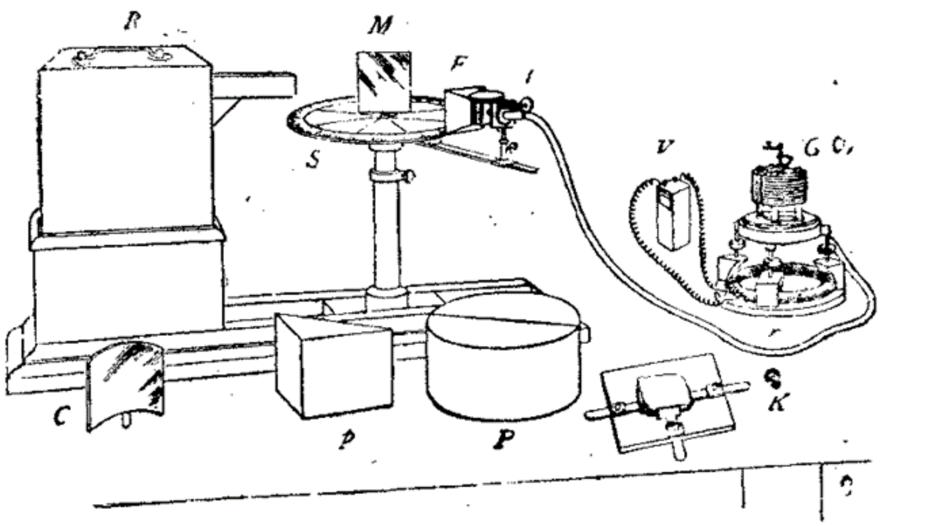


FIG. 5.

J. C. Bose’s equipment for Electric Wave generation sketched in the Britannica *Encyclopedia* article "Electric Waves," by J. J. Thomson, published in 1902

According to Bose, using millimetre waves would be advantageous because the physical size of various components required for the experimental setup would be smaller. Bose generated mm waves for this purpose and systematically used them for a variety of quasi-optical measurements. The components of his mm-wave systems are still widely used in some form or another. Bose developed a millimetre wave transmission and reception system operating at 60 GHz. In addition to developing devices necessary to generate, radiate, and receive mm waves, he demonstrated that the newly discovered Hertzian waves behaved like the light at millimetre- wave frequencies. At the Royal Institution in London, Bose presented his work on electromagnetic radiation in 1896. He stood out from other researchers of his time for several accomplishments: (i) generation, radiation, and detection of electromagnetic radiation in the wavelength range 2.5 cm to 5 mm, (ii) wavelength measurements in the millimetre wave range, (iii) measurements of the refractive index of various materials at millimetre- wave frequencies, (iv) development of a pyramidal horn antenna, called the "collecting funnel" at the time, (v) construction of a double prism attenuator, (vi) invention of a point-contact detector, a precursor to the diode, and (vii) the first use of a galena detector, a semiconductor, to detect electromagnetic waves.



R, radiator; S, spectrometer-circle; M, plane mirror; C, cylindrical mirror; *p*, totally reflecting prism; P, semi-cylinders; K, crystal-holder; F, collecting funnel attached to the spiral spring receiver; *t*, tangent screw, by which the receiver is rotated; V, voltaic cell; *r*, circular rheostat; G, galvanometer.

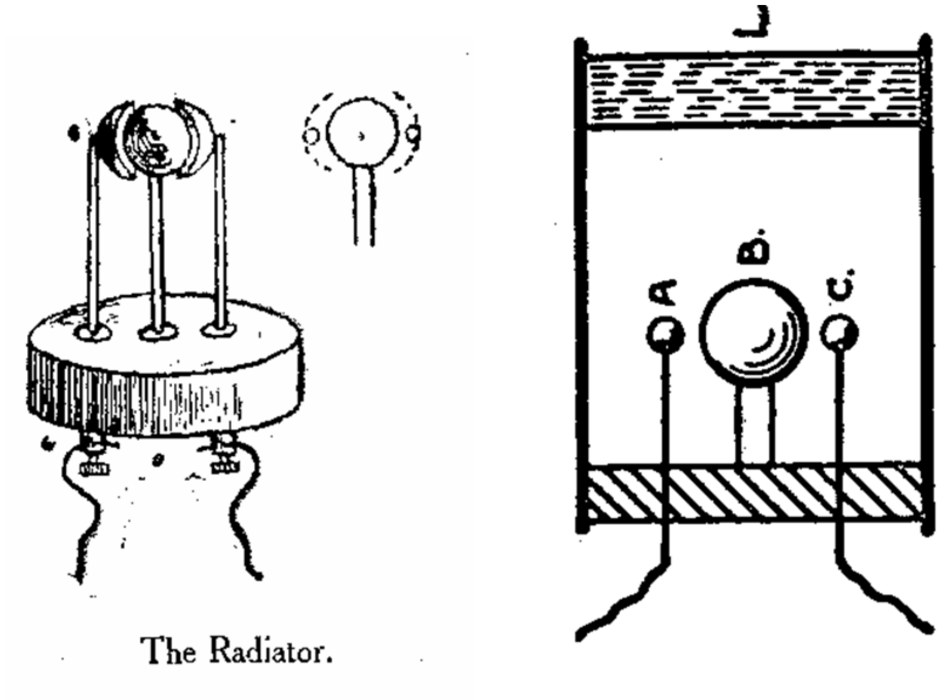
Arrangement of J. C. Bose's Apparatus

(After: J.C. Bose and Microwaves, Editors: P. Bhattacharyya and M.H. Engineer, Bose Institute, Kolkata, 1995)

Innovations in Bose Systems

Transmitter

In the time of Hertz, electromagnetic waves were generated by spark gaps, which generally produced broad bands of frequencies. In order to generate frequencies within a range, Lodge inserted a metal ball between the two sparking elements using an external resonator. However, this arrangement was problematic because the metal ball became rough after a few sparks, and it began emitting spurious waves. To improve the above setup, Bose placed the metal ball between two hollow metal spheres, inside which two platinum beads were attached. This arrangement endured for a more extended period, thus generating more sustaining electric waves. Bose was able to generate electromagnetic radiation within a relatively narrow frequency band by inserting a metal ball acting as an external resonator. Using this setup, he measured the wavelength of the radiated fields. The entire system was housed in a box Bose called the radiator. Bose used a rectangular metal tube to guide the waves generated, whose open end was used to radiate them. A lens was placed in front of the tube's open end to focus electromagnetic energy. Bose developed a device called a "collecting funnel" to receive the radiated waves, which is analogous to a pyramidal horn commonly used in modern communication systems.



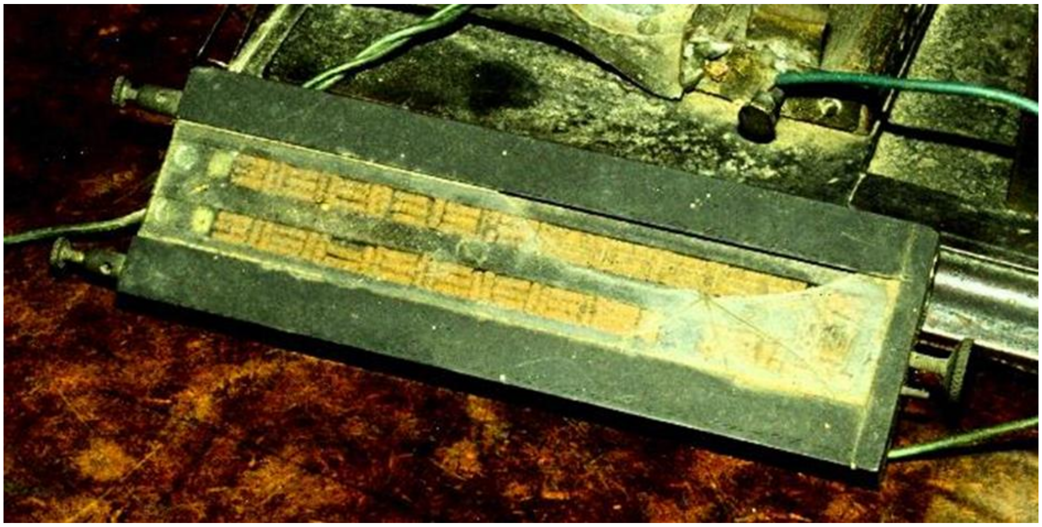
Bose's spark-gap arrangement for millimetre wave generation
(After: J.C. Bose and Microwaves, Editors: P. Bhattacharyya and M.H. Engineer, Bose Institute, Kolkata, 1995)

Receiver

Edouard Branly at Catholic University College of Paris developed a radio conductor using a glass tube filled with iron filings. With electromagnetic waves incident on the iron filings, the resistance of the circuit was found to decrease. There was a drawback to this radio conductor because, after some time, when the metal filings had acted as receivers, they needed to be shaken back to their original state. Bose realized that the most significant drawback to experimental investigations of optical properties was constructing a suitable receiver for detecting electromagnetic radiation. He modified the coherer by winding fine metal wires into narrow spirals laid in a single layer on a groove carved out of ebonite. The galvanometer put in an electric circuit would detect any small changes in the resistance offered by spiral springs. Bose was able to perform some of the most delicate experiments because the receiver's sensitivity to the radiation depended on the pressure on the spirals and the EMF acting on the circuit, which could be enhanced to a large extent. As Bose had chosen to use coatings of materials less prone to oxidation, he found that the sensitivity of the coherer was dependent on the metal coating, which led him to study the action of different metals in terms of their detection properties.

Interestingly, he found that the resistance decreased in some materials when irradiated and increased in others. Bose's receiver displayed remarkable self-recovery when the radiation source was withdrawn, as the resistance of the receiving circuit was almost entirely located at the contact surface, which was sensitive. He developed other types of receivers that outperformed the ones devised by others in terms of sensitivity, reliability, and uniformity of action.

So with the most efficient generation of millimetre waves at his command, he was the best equipped of his time to investigate the quasi-optical properties of electromagnetic radiations.

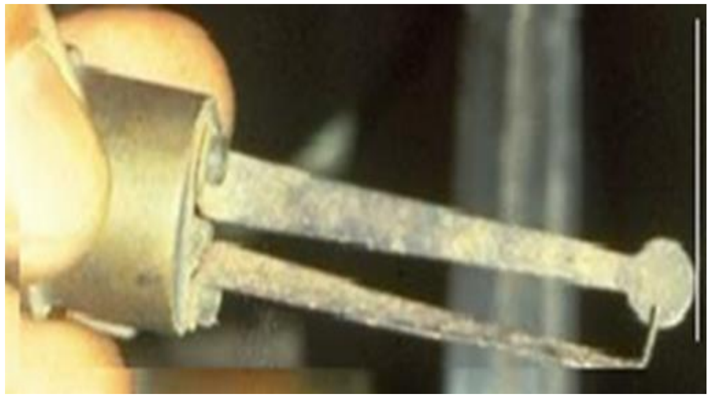


Spiral-spring Detector

(After: D.T. Emerson, National Radio Astronomy Observatory, The Work Of Jagadis Chandra Bose:100 Years Of Mm-Wave Research)

Galena Point-contact Detector – A Forerunner of Semiconductor Detectors

Bose used Galena for receiver detection following Braun's use of crystal coherers in the 1890s for wireless circuits. He observed that light produced variations in contact resistance in the galena receiver and showed a similarity between the response curves produced under electromagnetic radiation and light. Furthermore, he found that the detector's resistivity did not change monotonically with radiation intensity. The nature of the change depended on the intensity and duration of the incident electric radiation. In addition, he observed that the conductivity also changed under much slower electromotive variations. He developed a point-contact detector that displayed nonlinear V-I characteristics similar to those of semiconductor detectors and demonstrated fast self-recovery in the absence of electromagnetic radiation. In 1904, Bose filed a patent for his Galena point-contact detector, also called an artificial retina and a ‘tejometer’ (universal radiometer), in the presence of two witnesses, R. E. Ellis and T. L. Whitehead. It is now almost universally acknowledged that Bose was the first to use a semiconductor as a sensitive radio wave detector with the best sensitivity among contemporary devices.



Point Contact Detector

Detector for Electrical Disturbances Patent

JAGADIS CHUNDER BOSE

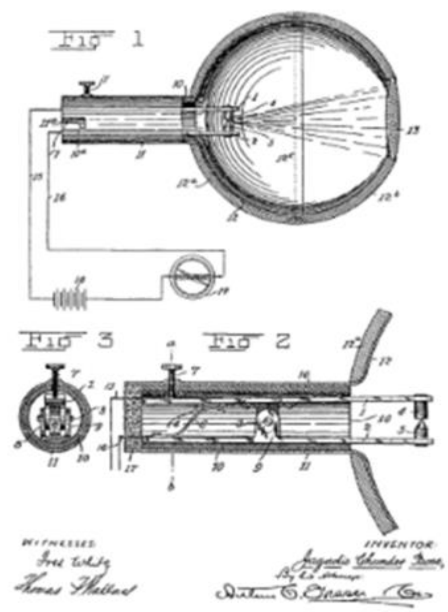
No. 755,840. PATENTED MAR. 29, 1904.

J. C. BOSE.

DETECTOR FOR ELECTRICAL DISTURBANCES.

APPLICATION FILED SEPT. 30, 1901.

NO MODEL.



Publisher Item Identifier S 0018-9219(98)00761-0.

U.S. Patent No. 7558840, Patented on May29, 1904

(After: J.C. Bose and Microwaves, Editors: P. Bhattacharyya and M.H. Engineer, Bose Institute, Kolkata, 1995)

J C Bose, Guglielmo Marconi and Nobel Prize

For years, there has been a debate over who deserves more credit for inventing wireless communications - Marconi or Bose. Particularly in the Indian scientific community, some feel that Sir J. C. Bose should have been awarded the Nobel Prize for the epoch-making invention and not Guglielmo Marconi. Any particular individual or individuals did not invent wireless telegraphy. Several scientists from different countries contributed to its development. On 9 December 1909, in his speech for awarding the Nobel Prize in Physics to Guglielmo Marconi and Karl Ferdinand Brown, who shared the honours, the President of the Royal Swedish Academy of Sciences mentioned:

"*While we are, this evening, conferring Nobel Prize upon two of the men who have contributed most to the development of wireless telegraphy, we must first register our admiration for those great research workers, now dead, who through their brilliant and gifted work in the fields of mathematical and experimental physics, opened up the path to great practical applications*."

"*But it was still a great step from laboratory trials in miniature where the electrical waves could be traced over but a small number of metres, to the transmission of signals over great distances.*"

"*The carrying out of this great task was reserved for Guglielmo Marconi.*"

"*Marconi's original system had its weak points.*"

"*It is due above all to the inspired work of Professor Ferdinand Braun that this unsatisfactory state of affairs was overcome. Braun made a modification in the layout of the circuit for the dispatch of electrical waves so that it was possible to produce intense waves with very little damping.*"

"*It is only through the introduction of these improvements that the magnificent results in the use of wireless telegraphy have been attained in recent times.*"

Marconi was not the first person to use electromagnetic waves for wireless communication. Mahlon Loomis received the first patent in the U.S. for wireless telegraphy in 1872, fifteen years before Heinrich Hertz published his first experiment with electromagnetic waves. Marconi, however, had realized the commercial potential of Hertz waves from the very beginning and directed all his efforts towards this goal. He was patronized by the British Electrical Engineering Circle and William Preece, the then Engineering Chief of the British Post Office. According to contemporary scientists, since radio waves behave like light waves, long-distance communication between two points on Earth would be impossible due to the curvature of the Earth's surface. A paper published in 1902 by the famous French mathematician Poincare indicated that communication by electric waves would be limited to 165 miles. Marconi conjectured that this was not the ultimate truth and that there might be some mechanism to expand the range of Hertz waves. He proceeded almost secretly to establish transatlantic wireless telegraphy. Using 25 kW power and 20 high-rise masts, he constructed a massive transmitting station at Poldhu, England. Initially, a receiving station was set up at Cape Cod in the USA, but gales destroyed it. Marconi later built a second receiving station in St John's, Newfoundland, Canada, using a kite as the antenna, and finally received a Morse code "S" signal on 12 December 1901. This demonstration was so impressive that all previous experiments in wireless communication seemed rather meagre in comparison.

Meanwhile, J.C. Bose, away from the galaxy of Western scientists, began experiments on the propagation of electromagnetic waves in a laboratory at Presidency College in 1894, then an obscure place in the world of science. The long-distance wireless transmission did not interest Bose. His main objective was to show the different optical properties of Hertz's waves. He chose millimetre waves because he required limited laboratory space and small equipment, yet he could be precise in the experimental results. Bose did extensive work in the field of quasi-optics and, in the words of Lodge, "obtained many admirable and interesting results" with his pioneering and meticulous experiments in millimetre waves. He believed in the free exchange of scientific knowledge, so he was not inclined to patent his inventions, which could have prevented their use commercially. However, as a result of his intuitive understanding of electromagnetic propagation, he developed many instruments that became the basis for the components of modern microwave and millimetre wave systems and radio observation techniques. Some of his inventions, like the horn antenna and galena detector, have already found entries in books and well-referred reviews. With all his experimental ingenuity, Bose was well ahead of his time, and his instruments could not be fully utilized until the advent of modern high-frequency communication systems. The best way to establish Sir J. C. Bose's rightful place in the history of radio science is to focus on his actual achievements.

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