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**The Legacy of Indian Knowledge System in Wireless Communication: Contributions of Sir Jagdish Chandra Bose**

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## Abstract
Over past few decades, wireless communication has evolved to enable the flow of information at rate as high as tens of Gbps. In this evolution of wireless technology, the contributions of the Indian knowledge system often get overlooked, including the late 19th century experiments of Sir Jagadish Chandra Bose, which demonstrated the basic principles for modern wireless communication. Sir J.C Bose is popularly known for his research in plant sciences, but indeed he was a man of many talents — a physicist, botanist, biologist, technologist, and even a science fiction writer. This paper gives a brief account of his contributions in the field of wireless communication, including his early demonstrations of electromagnetic wave generation, transmission, and detection, with the use of waveguide, dielectric lenses, horn antennas, and semiconductor detectors. The paper also acknowledges other pioneering contributions from ancient Bhartiya knowledge providing a broader perspective on its scientific importance. Overall, this article aims to highlight the knowledge and innovations from the Bhartiya pioneers in the field of wireless communication who have contributed to the modern science and technology.

**Keywords:** Wireless communication, Indian Knowledge System, Jagadish Chandra Bose, Electro-Magnetic waves, Radio Communication.

## Introduction
Information is source of power and wireless communication has given this power even in the hands of those sitting in remotest areas. This revolutionizing wireless communication technology has been an immensely powerful enabler for telecommunications, satellite communication, radar navigation, and the Internet of Things (IoT). Although these technologies evolved rapidly during the twentieth century, their conceptual and experimental foundations can be traced earlier to late 19th century when Sir J.C Bose conducted experiments demonstrating feasibility of the wireless transmission of signals.

During this time Bose conducted landmark experiments on the generation, transmission, and detection of electromagnetic (EM) waves at millimeter wavelengths(mmWaves), decades before the commercialization of radio communication. He performed these experiments using independently constructed semiconducting detectors, waveguides, and horn antennas. This has laid out the foundation for modern microwave and wireless systems. The significance of Bose's work has been recognized and validated by modern researchers as well. Emerson [1] provided a comprehensive account of his mmWaves experiments. In [2], Sarkar re-evaluated these experiments from the perspective of electromagnetic engineering and confirmed their accuracy as well as relevance to the contemporary microwave and wireless technologies. These studies reaffirm Bose's position as one of the earliest scientists to experimentally explore electromagnetic waves in the millimeter-wave region.

In this article, we provide a critical review of scientific contributions of Bhartiya scientists as a legacy of Indian Knowledge System(IKS) to the evolution of modern wireless communication. Within this framework, it focuses on the pioneering research of Sir J.C. Bose, whose mmWaves studies anticipated many devices and methods later used in microwave and mmWaves technologies. In addition, a brief account of notable innovative breakthroughs by Indian scientists is also highlighted covering the areas of mathematics, metallurgy, astronomy, and acoustics. This inclusion extends a broader perspective on the influence of IKS on modern scientific and technological advancements.

**Earlier Evolution of Wireless Communication**
The foundation of wireless communication was laid by James Clerk Maxwell, who, in 1864, formulated a unified theory of electromagnetism, predicting that electric and magnetic fields could propagate through space as electromagnetic waves. Two decades later (1887–1888), Heinrich Hertz validated this theory through the generation and detection of EM waves in the laboratory set up.

Sir J.C. Bose in India conducted independent and highly advanced experiments between 1894 and 1896 on the generation, transmission, and detection of EM waves at the mmWaves over 60 GHz frequency range. Unlike his most of the contemporaries who operated at long wavelengths, Bose explored extremely short wavelengths and developed first mmWaves communication system. He also developed innovative components including horn antennas, dielectric lenses, and semiconductor detectors. Bose had also performed extensive quantitative studies on reflection, refraction, and polarization of EM waves.

Table I describes the evolution of wireless communication in chronological order at global level vis-à-vis the important contributions of Sir. J.C. Bose among the pioneers. Inspired by Hertz's experiments, Guglielmo Marconi performed the successful long-distance radio transmission in 1895. By 1901, he achieved transatlantic communication. This experiment has been a milestone in the practical realization of radio communication technology.

**Table I** EVOLUTION OF WIRELESS COMMUNICATION

| Year | Scientist | Major Contributions |
|---|---|---|
| 1861–1865 | **James Clerk Maxwell** (Scotland) | - Developed EM wave theory.<br>- Proved EM waves travel at the speed of light.<br>- Formulated *Maxwell's Equations* (1873). |
| 1886–1888 | **Heinrich Rudolf Hertz** (Germany) | - Experimentally verified Maxwell's Theory.<br>- Generated and detected EM waves.<br>- Proved the existence of radio waves. |
| 1894–1896 | **Sir Jagadish Chandra Bose** (India) | - First to transmit and receive mmWaves (60 GHz) over 23 m.<br>- Demonstrated wireless power Transfer by ringing a bell and detonated gunpowder.<br>- Developed key components: spark transmitter, coherer, horn antenna, polarizer, grating.<br>- Pioneered communication at mmWaves. Foundation of today's 5G and radar systems. |
| 1895–1897 | **Guglielmo Marconi** (Italy) | - Transmitted signals over 1.5 miles (1897).<br>- Used Bose's mercury coherer in his radio system.<br>- Received the first patent in wireless telegraphy. |

## I. CONTRIBUTIONS OF SIR J. C. BOSE TO WIRELESS COMMUNICATION

Sir Jagadish Chandra Bose (1858–1937) was a pioneering Indian physicist, biologist, and inventor who conducted groundbreaking experiments in electromagnetism [3], [4] and plant physiology [5]. Educated at the University of Cambridge and Kolkata, he returned to India to teach at Presidency College. During this period at the Presidency College, he began his investigations on EM waves in the 1890s. The research career of J. C. Bose (1894–1937) can be broadly divided into three phases [6]. From 1894 to 1899, he generated the shortest EM waves referred to as microwaves. He further studied their optical properties. Between 1899 and 1904, he studied the response of metallic electric wave detectors. He extended his study toward the response of inorganic materials to different stimuli, leading to his idea of continuity between living and non-living matter. The third phase includes his studies of plant electrophysiology. It is interesting to note it is the plant electrophysiology for which he is famously known for. But certainly, his pioneering research work in the field of wireless communication and microwaves has set the foundation of modern communication technology including 5G and beyond.

### *A. Experimental Demonstrations on mmWaves*

J.C Bose began independent experiments at the Presidency College, Kolkata around 1894 to investigate short-wavelength EM radiation. Using a spark-gap oscillator with miniature resonant cavities and metallic reflectors, he produced radiation with wavelengths between 5 mm and 25 mm. This is now recognized as the millimeter-wave region.

In 1895, Bose gave a public demonstration at the Town Hall, Kolkata. He remotely rang a bell and ignited gunpowder through intervening walls at approximately 23 m. This experiment proved the ability of EM waves to penetrate the obstacles. These experiments preceded later radio-frequency experiments by Marconi and others. In May 1897, on the invitation of Lord Rayleigh, Sir J. C. Bose publicly demonstrated the generation, transmission, and detection of mmWaves at the Royal Institution in London. Fig. 1 illustrates this historic demonstration, where Bose used his self-designed apparatus to generate, transmit, and detect these waves. Bose extended his studies to measure reflection, refraction, diffraction, and polarization of EM waves at microwave frequencies, establishing that they obeyed the same optical laws as visible light. His seminal paper [7] presented precise measurements of wavelength and refractive index using dielectric prisms, confirming the wave nature of EM radiation at extremely short wavelengths.

The mmWaves have quasi-optical properties and Acharya Jagdish Chander Bose had successfully demonstrated their potential capabilities for communication systems more than 125 years ago. His inventions are being utilized probably in modernized form in the recent communication networks His pioneering and outstanding work on electromagnetic phenomenon made him one of the most deserving scientists for the Nobel Prize but he was deprived of this recognition.

### *B. Apparatus Design and Microwave Components*

Acharya J. C. Bose independently built every part of his experimental setup. This was the period when no microwave equipment existed. Through his innovative experimental skills, he transformed brass sheets, ebonite, Sulphur, and jute into the devices that resembled with the modern components used in modern wireless communication. He designed and developed mmWaves spark transmitter, self-recovering coherer detector, wire grid polarizer, cylindrical diffraction grating, dielectric lens and prism, rectangular waveguide, horn antenna, and microwave absorber. Some of these are described below in brief:

**Spark-Gap Transmitter:** The transmitter was designed with two metallic spheres separated by a small air gap. Oscillations generated by spark transmission were radiated as EM waves and the wavelength of these waves were determined by metallic resonant structures.

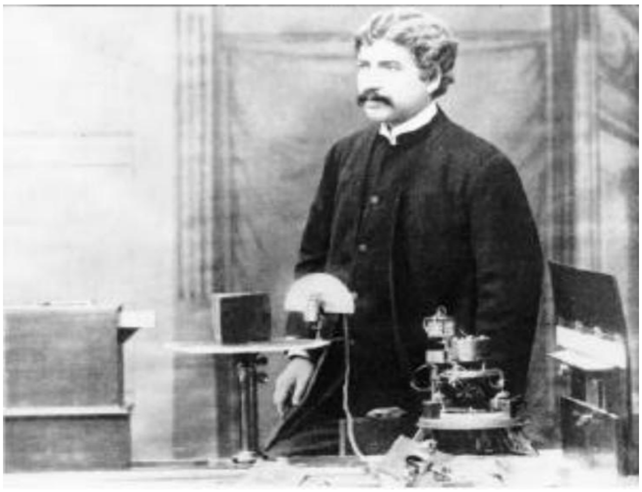

Fig. 1. J. C. Bose demonstrating mmWaves transmission at the Royal Institution, London (1897).

**Waveguides and Polarizers:** The generated EM waves were guided through hollow brass tubes which acted as waveguide and collected by the horn antenna at another end. Bose constructed a **polarizer using twisted strands of jute fiber** to simulate the polarization effect on light. He also designed free space polarizer using a book with tinfoil sheets interleaved in the pages. He also demonstrated the polarizing properties of the book without tinfoil sheets, where pages acted as dielectric sheets with small air gaps.

**Horn Antennas:** A pyramid shaped metallic funnel called horn antenna was attached at the c to receive the radiation were first used by Bose.

**Dielectric Lenses and Prisms:** Sir J.C Bose designed a waveguide lens made from paraffin and sulfur to focus and bend electromagnetic waves.

**Detectors and Coherers:** Semiconductors junctions were used as the detectors and Bose was granted the first semiconductor patent in 1904. He also used free space detectors built from metal springs to detect the millimeter wavelengths.

These components are now standard elements in microwave and radar systems. Emerson [4] noted that Bose's device geometry, material selection, and measurement precision anticipate modern microwave laboratory techniques.

### *C. Semiconductor Detector and Solid-State Innovation*

In 1901, Bose filed a patent in the United States for a device titled "Detector for Electrical Disturbances" [8]. The invention described a semiconducting crystal detector that rectified high-frequency signals. He utilized semiconductor materials such as galena (PbS) and metal point contacts to detect incident EM waves.

This critical review of his outstanding work again establishes the fact that he was well ahead of his time and he eminently deserves to be recognized as the Father of Radio Science.

For the sake of highlighting the legacy of our ancient Bharat in the field of science and technology, we also provide a brief account of a few prominent Bhartiya scientists and their innovations as follows:

## IV. Notable Contributions of Indian Knowledge System in Modern Technology

The knowledge and experiments conducted by Indian scientists have played a significant role in shaping the foundations of many branches of modern science and technology.

### 1) C.V Raman - Raman Effect in the field of Optics

In 1928, Sir Chandrasekhara Venkata Raman, along with K. S. Krishnan, performed experiments [9] using sunlight and monochromatic light sources. A monochromatic light beam was passed through transparent liquids and gases, and a part of beam experienced inelastic scattering i.e the wavelengths of scattered radiation was different from that of the incident light. The magnitude of the wavelength shift was affected by the type of molecules involved, revealing that light scattering was influenced by molecular vibrational and rotational energy levels. The inelastic scattering was termed as Raman scattering and the change in wavelength was termed as Raman effect. The discovery provided the first direct experimental evidence for quantum transitions in matter, linking classical optics with quantum theory. The Raman Effect became the foundation for Raman spectroscopy, which is a device used for chemical identification, molecular structure analysis, and materials characterization. For this pioneering work, C.V Raman was awarded The Nobel Prize in Physics in 1930.

### 2) K.S Krishnan in the field of Solid-State Magnetism

K.S Krishnan initiated research in crystal magnetism in India and conducted extensive experiments for measurements of magnetic susceptibility and anisotropy of single crystals. He developed a technique called critical torque method for the accurate measurement of magnetic anisotropy of single crystals. The modern static torque method for anisotropy measurement is basically a modification of Krishnan's critical torque method. He also solved the theoretical problem of correlating magnetic susceptibilities and the anisotropies of crystals with those of their constituent ions or molecules. His experimental precision marked the beginning of India's solid-state physics tradition and influenced subsequent research in condensed matter and materials magnetism worldwide.

### 3) Sir H. J. Bhabha

In 1935, H.J Bhabha [10] provided theoretical explanation for electron- positron scattering, which was termed as Bhabha scattering. The study provided the direct means to probe the electromagnetic structure of matter and played a foundational role in the development of quantum electrodynamics. H.J Bhabha theoretically predicted the cascade (shower) formation process in cosmic rays, which arises from successive electron–photon pair production and bremsstrahlung interactions. Later, he along with his collaborators conducted high-altitude experiments to study cosmic ray interactions and secondary particle production. The experimental observations from these studies confirmed his theoretical model. His experimentation work provided one of the earliest demonstrations for interaction of high-energy particles. He made significant contribution to the foundational understanding of the particle physics.

These examples illustrate that the Indian Knowledge System was not limited to philosophical speculation but embodied a spirit of systematic experimentation, quantitative reasoning, and technological innovation.

## CONCLUSION

The groundbreaking experiments performed by Sir J. C. between 1894 and 1897 demonstrated the working principles of modern wireless technologies. Long before the development of modern antennas, polarizers, and wireless detectors he designed these devices from materials—such as brass, sulfur, and jute—demonstrating and his exceptional creativity and experimental rigor. Similarly, the experimentation work of Sir C.V Raman demonstrated the inelastic scattering of light beam for the first time and provide the basis for Raman Spectroscopy. The work of C.V Raman proved to be significant for optics field and he was awarded The Nobel in Physics for the same. Sir H.J Bhabha's theoretical explanations of electron-positron scattering played an important role in field of quantum electrodynamics.

From ancient wireless communication to quantum electrodynamics, IKS has contributed significantly to the modern technological world through theoretical explanations and experimental demonstrations. Recognizing and integrating these contributions can inspire a deeper appreciation of indigenous knowledge as a complementary force in contemporary science and engineering. In essence, these contributions are more than a historical milestone; they represent the spirit of innovation rooted in the Indian Knowledge System.

Bharat since long has been a creator of new knowledge. Our ancient civilizational ecosystem has accorded huge importance to the knowledge in all areas of science and technology. It is imperative to carry out research and insightful understanding of Indian Knowledge System. We are consistently striving to explore the legacy of ancient India.

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