Special Section on
Sir J.C. Bose 160th Anniversary Celebration Presentations

1858-1937

Sir J.C. Bose 160th Anniversary Celebration on 17th Feb 2019 at Bangalore

Guest Editor Message

Sir Jagadish Chandra Bose is a physicist, biologist, biophysicist, botanist and archaeologist. He pioneered plant science, and laid the foundations of experimental science in the Indian subcontinent. He proved by experimentation that both animals and plants share much in common. He demonstrated that plants are also sensitive to heat, cold, light, noise and various other external stimuli. It is widely considered that J.C. Bose was at least 60 years ahead of his time.

In 1895, Sir Jagadish Chandra Bose first demonstrated in Presidency College, Calcutta, India, transmission and reception of electromagnetic waves at 60 GHz, over 23 meters distance, through two intervening walls by remotely ringing a bell and detonating gunpowder. For his communication system, Bose pioneered in development of entire millimeter-wave components like a spark-gap transmitter, coherer, dielectric lens, polarizer, horn antenna, and cylindrical diffraction grating. This is the first millimeter-wave communication system in the world, developed about 125 years ago. This is the oldest Milestone achievement from the Asian continent. Bose's experimental work on millimeter-band microwave radio was commemorated as an IEEE Milestone on 14th September 2012 and a plaque in this regard may be viewed in the main corridor of the Acharya Jagadish Chandra Bose Auditorium in the Main Building of Presidency College, Kolkata, India.

IEEE celebrated the 160th anniversary of Sir Jagadish Chandra Bose by reflecting on his life and works through eminent speakers compassionately projecting his work to 150 plus IEEE members and engineers on Sunday, 17th February 2019 at the landmark World Trade Center Auditorium in Bengaluru, India. This workshop showcased the innovations of Sir J C Bose and its relevance and contribution to the modern technology.

While Dr. B.S. Sonde (ASM Technologies), Dr. D.P. Sengupta (NIAS) and Dr. Surendra Pal (DRDO) reflected on the life of Sir Jagadish Chandra Bose, Mr. C.S. Rao (Quadgen Wireless Solutions) and Dr. Yashwant Gupta (NCRA) presented the applications of Sir J C Bose's work in unlicensed 5G band for communication networks and Radio Astronomy. The highlight of the workshop was the demonstration of the working replica model of JC Bose's millimetre wave experiment by Dr. Shaik Kareem Ahmmad and Dr. Syed Ilyas Mohiuddin (MJCET) and demonstration of microwave apparatus by Mr. Sudhir Phakatkar (NCRA).

IEEE Foundation as part of the "Furthering Indian Perception of IEEE" project sponsored the J.C. Bose workshop organized by IEEE Bombay Section, IEEE India Council and IEEE Bangalore Section, and supported by IEEE SPS Bombay Chapter and IEEE APS-MTTS Bangalore Joint Chapter. A detailed report on this event was published in the Jan-Mar 2019 issue of the IEEE ICNL. Please refer http://ieeecs-madras.managedbiz.com/icnl/19q1/p20-p21.pdf.

Inspired by the quality of talks by the eminent speakers and unanimous demand by the participants, it was decided that we bring out manuscripts of these talks delivered as a Special Section in the IEEE India Council Newsletter. This Section includes the following articles:

1. Sir Jagadish Chandra Bose: Scientist Par Excellence: A Tribute by Dr. B.S. Sonde
2. Jagadish Chandra Bose: The Physicist who was forgotten by Dr. D.P. Sen Gupta
3. Sir Jagdish Chandra Bose, James Clerk Maxwell and there on….. by Dr. S. Pal
4. mmWave Applications in NextGen Wireless Broadband Evolution in 5G Era: Impact of Sir JC Bose invention by Mr. C.S. Rao, Ms. Arpita Hura and Ms. Mouna Jain
5. Radio Astronomy: How J.C. Bose's invention opened a new window to the Universe by Dr. Yashwant Gupta
6. Design and Construction of Working Replica of Sir J.C Bose 60 GHz Experiment by Dr. Shaik Kareem Ahmmad, Dr. Syed Ilyas Mohiuddin and Dr. Mohammed Arifuddin Sohel
7. Sir Jagadish Chandra Bose: Biologist, Biophysicist, Botanist, Physicist, Archaeologist and Polymath by Mr. Sudhir Phakatkar

We are highly grateful to all the speakers for providing us with their articles in spite of their very busy schedules. I can't thank enough Shri HR Mohan, Editor, IEEE India Council Newsletter for his patience and persuasion as well as his painstaking efforts in producing this Section so beautifully. We sincerely hope that the readers will find this compilation very informative and its contents, highly inspiring.

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SIR JAGADISH CHANDRA BOSE
Scientist Par Excellence: A Tribute

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Article based on the *Key-Note Address* delivered at 'Celebrating Sir Jagadish Chandra Bose', a special event organized by IEEE, India Council at Bengaluru on 17th February 2019.

Introduction:

India has been commemorating the 160th birth anniversary year of Sir Jagadish Chandra Bose (1858-1937), a scientist of great eminence well known for his contributions in many fields, particularly physical sciences and physiology and for the revival of scientific research in the country on modern lines in the pre-1900 era. IEEE deserves to be complimented for bringing out a Special Section of the *Proceedings of the IEEE* in 1998 [1] to commemorate the *Centennial of Solid-State Diode Detector* by giving due credit to J. C. Bose for its invention and use in his 60 GHz Microwave Spectrometer during 1896-98. The Special Section has also brought out the importance of this device in his microwave communication experiments in Calcutta in the pre-1900 period and its use in G. Marconi's highly successful, long-distance, trans-Atlantic radio communication experiment of 1901, which paved the way in the following years to establish radio as a major means of global communication. Besides, IEEE has also ensured in 2012 that J. C. Bose is included in the same *Hall of Fame on Radio* jointly with G. Marconi *(Italy)* and A. Popov *(Russia)*, the only two other inventors recognized earlier. It is in this backdrop that the event organized by IEEE-India Council in Bangalore on 'Celebrating Sir Jagadish Chandra Bose' assumes much significance as it provides the present generation an excellent opportunity to pay respects and tributes to this great scientist. Besides being a *devoted researcher* in *cutting-edge* areas in multiple disciplines in those days, J. C. Bose was an inspiring teacher, a skillful experimenter who designed his own research equipment, a committed institution builder and a great humanist who believed that the benefits of science should reach out to the society at large. Thus, even today, J. C. Bose stands out as a *Role Model* for the younger generation intending to take up careers in academics and research work. These aspects are briefly covered in the Article along with the *lessons to be learnt* from the life and work of J. C. Bose.

J. C. Bose and his Career:

Looking at his intelligence and scholastic abilities in his childhood, parents of J. C. Bose sent him to Calcutta for high school education where better and more opportunities were available for this. This enabled him to proceed to England after his graduation from the Calcutta University for further studies at the famous Cambridge University in England. Here he became a student of Lord Raleigh, eminent Physicist and Cavendish Professor of Physics at the University. Lord Raleigh was much impressed by his intelligence, knowledge of Physics, devotion to studies and independence of thinking. This developed into a life-long friendship between the two greatly benefitting young J. C. Bose from the *mentoring, guidance and patronage* in his research work received from Lord Rayleigh throughout his career. After obtaining his *Natural Science Tripos* from Cambridge, J. C. Bose returned to Calcutta, where he was appointed as a faculty member in the Physics Department of Presidency College, Calcutta a prestigious college of long-standing. In this capacity he was engaged in both teaching and research and built many useful instructional facilities in the Physics laboratory at the College. Being an inspiring teacher, he was able to educate and train many young students to get interested in Physics studies and carve out productive careers in this subject area. Being interested and familiar with issues of contemporary relevance in electromagnetism, J. C. Bose pursued this area for his research work at the Presidency College. Box A presents a brief outline of major milestones in the life and career of J. C. Bose.

Box A: J. C. Bose-Life and Career: Major Milestones

1858, Nov. 30: Born in Mymensingh, East Bengal (in present-day Bangladesh), Enlightened and encouraging parents, Well-known family background.

1870-76: Student at St. Xavier's School, Calcutta.

1876-80: Student at St. Xavier's College, Calcutta, obtained his B. A. Degree from Calcutta University.

1880-84: Student at Christ Church College, Cambridge University, England, under Lord Rayleigh, Cavendish Professor of Physics, obtained his *Natural Science Tripos* from the University in 1884.

1885: Joined Presidency College, Calcutta as Officiating Professor of Physics; Promoted as Permanent Professor a few years later, became Senior Professor and continued until superannuation (1915) from Indian Educational Service; Emeritus Professor at Presidency College: 1915-20.

1896: Received D.Sc. Degree from the University of London, England on the Recommendation of Lord Rayleigh.

1896-98: Conducted pioneering mm-wave propagation experiments with certain polarizing crystals leading to development of 'solid-state detector for electrical disturbances' included in a seminal paper in the Proc. of the Royal Society, London in January 1897, named by him as 'Electric Eye', but by others in his time as 'Coherer', as 'Diode' years later.

1901: G. Marconi used the solid-state detector based on the work of J. C. Bose in Trans-Atlantic Radio Communication experiment.

1904: US Patent on 'Detector for Electrical Disturbances' granted to J. C. Bose.

1917: Knighthood conferred by the British Government.
Bose Research Institute the first such Institute in the country established in Calcutta, with J. C. Bose as its first Director.

1920: Elected Fellow of the Royal Society, London.

1927: Elected General President of the Indian Science Congress.

1937, Nov. 23: Breathed his last in Calcutta at the age of 79.

J. C. Bose and his Research:

In the physics of electromagnetism of the pre-1900 era, three path-breaking discoveries as follows stand out [1, 2]:

a) *Electromagnetic Induction* by which relative motion between a magnet and a nearby conductor produces an electromotive force in the conductor and vice versa, i.e., magnetism producing electricity and electricity producing magnetism, discovered almost simultaneously in 1831 by Michael Faraday in England and Joseph Henry in U. S. A.
b) *Electromagnetic Theory of Light* and the famous Field and Wave Equations of the electro-magnetic field postulated and explained in 1873 by James Clark Maxwell in England, based on Faraday's discoveries in electricity and his concept of electric and magnetic lines of force.
c) *Experimental Researches* verifying Maxwell's Theory during 1887-89 by Heinrich Rudolf Hertz in Germany demonstrating the generation of electromagnetic waves and their transmission in free space over a few meters in the laboratory.

These discoveries attracted the attention of many scientists/investigators in the succeeding years to conduct further experiments on the Hertzian doublet and the radiation emerging from it as well as on antennas and wave propagation. J. C. Bose was also fascinated by this research direction and he took up his work on quasi-optical researches with electromagnetic waves at a wavelength of 5 mm (Frequency ~60 GHz). Through this he demonstrated in 1898 a microwave spectrometer containing transmitter, receiver, horn antennas and waveguides, which many years later turned out to be the essential parts of a millimeter wave / microwave communication link. The invention of the solid-state detector device came from his millimeter-wave propagation measurements through certain polarizing crystals by following the optics route. In particular, his seminal paper in 1897 'On the selective conductivity exhibited by certain polarizing substances' published in the Proceedings of the Royal Society, London [1] led directly to this invention. He had named this device as the 'electric eye' or 'artificial eye' as it was transforming the electromagnetic radiation of any wavelength impinging on it into an electrical signal. J. C. Bose also invented many other useful solid-state detector devices for 'wireless' waves in this period, known as 'self-restoring coherers'. He conducted much of his research in the area of millimeter wave and microwave physics wherein he is considered to be a pioneer. As an extension of these studies, J. C. Bose went on to the discovery of some similarity in the response of the living and the non-living and conducted path-breaking research work in the response phenomenon in plants and made many significant contributions in Physiological Science, particularly plant physiology.

J. C. Bose was a prolific writer and he travelled frequently to Europe and U. S. A. on various scientific missions and for technical lectures. He was a firm believer that scientific knowledge needs to be shared, as only through this means that the knowledge can grow and expand. It was with this conviction that J. C. Bose got immersed in disseminating his research contributions through lectures and publication of papers in learned journals for their wider utilization. It is interesting to note that J. C. Bose had great reluctance in getting his research contribution patented to safeguard its intellectual property. This is because he was against any commercialization of science, which was gathering momentum in those days. However, it was only through the sage advice and insistence of his long-term friend, Swami Vivekananda that J. C. Bose was prevailed upon to patent his unique invention of 'Detector for Electrical Disturbances' in U. S. A. in1904 as a one-time gesture. However, J. C. Bose ensured that a specific clause was included in the Bose Research Institute's founding registration document (1917) that no member of the Institute may be allowed to apply for patent for any idea and/or device developed at the Institute!

J. C. Bose and his Friends/Admirers:

J. C. Bose had several friends and admirers, both in India and abroad, whom he considered to be instrumental in enhancing his scientific research and capabilities. They included eminent scientists, such as Lord Rayleigh, Lord Kelvin and Sir J. J. Thomson in England and great luminaries such as Swami Vivekananda and Nobel Laureate Poet Rabindranath Tagore in India to name a few. Each one of these had lasting impact on the career of J. C. Bose as can be seen below:

a) *Lord Rayleigh, Cavendish Professor of Physics (1879-85) at Cambridge University* taught Physics to J. C. Bose and became his life-long friend, philosopher and guide. He was also responsible for patronizing the research contributions of J. C. Bose in the area of millimeter waves at the Royal Society, London, in the Victorian British Empire and in the western world.
b) *Lord Kelvin, after whom the absolute scale of temperature (K) is named,* was a great admirer of the pioneering research work of J. C. Bose and also his patron in England and European countries. On his advice, J. C. Bose used a highly sensitive Kelvin Galvanometer in his revolutionary experiments as the end detector.
c) *Sir J. J. Thomson, discoverer of the particle 'electron' in 1897* was an admirer of J. C. Bose and his pioneering contributions to millimeter wave communication. In his Foreword to a Book by J. C. Bose containing a collection of his papers (1926), Sir J. J. Thomson writes: *"Another aspect of these papers is that they mark the dawn of the revival in India of interest in researches in Physical Science; this which has been so marked a feature of the last thirty years is very largely due to the work and influence of Sir Jagadish Chandra Bose".*
d) *Swami Vivekananda, an erudite scholar and Indian religious leader,* a friend and admirer of J. C. Bose for many years had visited U.S.A (1893) and seen the benefits of science to mankind and the usefulness of patenting of scientific inventions. On his advice, J. C. Bose agreed to patent his pioneering development of the solid-state detector in spite of his committed reluctance to do patenting. Swami Vivekananda also made arrangements with his disciple, S. C. Bull in U.S.A. to endorse /file the patent application of J. C. Bose in1901) and the U.S. patent was granted in 1904.
e) *Rabindranath Tagore, Nobel Laureate (1913)* was also a friend and admirer of J. C. Bose for many years and they used to enjoy each other's company whenever they met. Rabindranath Tagore utilized every possible opportunity to encourage J. C. Bose in his research work and to scale new heights in his 'science'. On being informed of his path breaking invention of the solid-state diode detector in 1897 by J. C. Bose, Rabindranath Tagore sent him a congratulatory poem written in Bengali, especially suited for the occasion. An English translation of this poem is reproduced below as extracted from [1] which sums the warm feelings of the great poet towards J. C. Bose!

Box B: Congratulatory Poem composed by Poet, Rabindranath Tagore, NL

To: Professor Jagadish Chandra Bose

Across the oceans, on the western shore,
Reigns the temple of the Goddess
Of wealth of science.
There you have journeyed, my friend,
And returned richly crowned.
You anointed the motherland,
Modest at heart, poor and shy.

The great and the gloried
Of these far-off lands
Assembled and acclaimed
Your work in unison,
The words resounding their message,
Far and wide, the seas beyond.

Her eyes welled up in tears,
Mother sends you the Message
Of her humbled heart,
Through a poet of whom
The world of science has never heard.
Only in the inner self of yours,
Will these words echo
As gentle murmurs of
Mother's whispered tone.

19th July, 1897 Rabindranath Tagore

(English translation from Bengali by Sugata Basu Sengupta, July 1997; Reproduced from Proc. IEEE, Vol. 86, No.1, pp. 221-222, Jan. 1998)

Concluding Remarks:

As can be seen from this Article, J. C. Bose was indeed a great teacher, researcher and humanist of international fame and he brought glory to India through his scientific contributions in multiple fields and his concern for the society at large. He is truly a *role model* for any academic of 21st century India, as he demonstrated that both inspiring teaching and cutting-edge research can be handled by an individual at the same time with each one contributing to the quality and standard of the other. Besides, his thoughts on dissemination of knowledge with a view to permit it to grow freely at a rapid rate and his commitment not to commercialize knowledge are worthy of careful consideration by the present generation in the context of the on-going trends in globalization. These and other lessons learnt from the life, work and contributions of J. C. Bose during his time in the 19th-20th centuries are worth emulating in present-day India as well.

References:

1) P. K. Bandyopadhyay, *et al (Guest Editors),* Special Section on the "Centennial of the Semiconductor Diode Detector", Proc. IEEE, Vol. 86, No. 1, pp.218-285, January 1998.
2) B. S. Sonde, "100 Years of Radio:1895-1995, Some Reflections", Current Science, Vol.70, No. 4, pp.322-325, February 1996.

About the author

Prof. B. S. Sonde received his B.E. (Telecom) and M.Sc. (Engg.) degrees from the University of Pune (1958, 1959) and Ph.D. in Engineering from the IISc (1963). He was a member of the academic staff of IISc (1964-97) until his appointment as Vice Chancellor, Goa University (1997-2002). During this period, he was also appointed as Member of the Council of IISc (1998-2001). His fields of interest cover Microelectronics, Instrumentation, Digital Technology & Applications in Electronics and Communications, wherein he has trained scores of students for B.E., M.E., M.Sc.(Engg.) and Ph.D. Degrees of IISc, published over 90 papers in prestigious scientific/technical journals, a series of 10 text/reference books widely used in engineering education in India and also many technical reports.

He has been Chairman/Member of Advisory/Governing Bodies of many Institutions in India, including CSIR laboratories, ISRO centres, UGC, AICTE, NAAC, NBA, KSHEC and IITs/Universities. Prof. Sonde has been an invited speaker at many national/international Conferences. He has been a recipient of many awards, notably Ramlal Wadhwa Gold Medal of IETE (1978), Jaya Jayant Award for Teaching Excellence of IISc (1992), Distinguished Alumnus Award of College of Engineering, Pune (1994), Chapter Development Award of ISHM-The Microelectronics Society, USA (1996), Life-Time Achievement Awards of Instruments Society of India (2002), Systems Society of India (2010) and IETE (2013) and IEEE-Bangalore Medal of Honour (2018). Prof. Sonde is a Distinguished Fellow of IETE and SEE, Honorary Fellow of ISTE and a Senior Member (LS) of IEEE (USA). Prof. Sonde has been an active participant at Conferences/Symposia held by IETE, IEEE and other technical professional societies, edited/published many proceedings of such events and he has been closely connected with the development of quality higher education in general and electronics & communication engineering education, research and industry in the country.

Jagadish Chandra Bose
The Physicist who was forgotten

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This paper touches upon the life of the great Polymath, Acharya Jagadish Chandra Bose, his upbringing, his academic achievements, his researches with emphasis on his wireless transmission of millimeter waves that were far ahead of his time and hence went unrecognized for decades, his invention of diode which would not have been recognized had it not been for a patent that he was forced to apply for and was granted. With radical changes in communication technology, he is recognized as the forerunner of smart phones widely used today.

Jagadish Chandra Bose, grew up on the shoulders of a dacoit. His father Bhagavan Chandra Basu was a Deputy Magistrate and he appointed a dacoit who on being released from the jail came to Bhagawan Chandra for a job. Bhagawan Chandra appointed him as a servant to take care of his four-year-old son Jagadish. Bhagavan Chandra set up a primary school for children of washer men, sweepers and other low earning people of the town and sent Jagadish to the same school. After completing high school education away from home, he went to St. Xavier's College in Calcutta where he came under the influence of Father Lafont. After studies at St. Xavier's College under Father Lafont., He set off for England in 1880 to study medicine. Afflicted by *Kala azar* before he left India, he had difficulties to continue the study of medicine and joined Christ's College, Cambridge, in 1881 under the tutorship of Lord Rayleigh, who was a polymath. Rayleigh got the Nobel Prize for discovering Argon. He took Jagadish under his wings. Jagadish also studied under Francis Darwin, son of Charles Darwin, Sir James Dewar and Sydney Vines the great physiologist. Europe was surging ahead in scientific studies and research. Cambridge was in the front line.

Jagadish completed his *Tripos* in *Natural Sciences,* Physics, Chemistry and Botany. He also obtained a degree from London University. Equipped with excellent recommendations he returned home after four years (1881-1885) to seek an interview with the Viceroy Lord Ripon who was very pleased to meet Jagadish. But despite the instructions from the Viceroy, the Director of Public Instructions ned to offer a Professor's position to Jagadish Chandra but was compelled to offer him one after much hassle, described in reference (1)

Jagadish teamed up with his mentor Father Lafont and helped him in science popularization. Jagadish Chandra also gave lectures at the Indian Association for Cultivation of Science (IACS) set up by Dr Mahendralal Sircar in 1876. This was the time when Bengal renaissance had brought extraordinary people from all walks of life together, in self-assertion as Indians. Several years passed and Jagadish Chandra realized that rather than spend his life as a Science teacher he would like to become a Scientist and a teacher.

It was in the year of 1894 that Jagadish Chandra made the resolve of getting involved in research. Abala Bose, his wife, fully supported his resolve. Jagadish Chandra used to visit the Asiatic Society where he came across a paper written by Professor Oliver Lodge, entitled…" Heinrich Hertz and his successors". He was fascinated by the article.

Choosing an area of research is always difficult. As a matter of fact, Jagadish Chandra changed his area of research at different stages of his life. But at every stage his research was based on accurate experiments since Jagadish Chandra knew that experimental research was his forte.

According to D.M. Bose (1), his nephew and a well-known physicist the research activities of J.C. Bose, extended from 1894 to 1937, the year he died, can be divided into three periods.

1) *During the first period extending from 1894 to 1899, he produced the shortest of then possible electromagnetic waves (the microwaves) and extensively studied their quasi-optical properties. His researches with coherers not only led to the anticipation of semi-conductors but the effect of microwaves on the coherers led to the next important phase of research.*
2) *During the second period, extending from 1899 to 1904, began with his study of the fatigue effect in metallic coherers, used for detection of electric waves, from which he went over to the study of various other inorganic systems which exhibit stress under different kinds of physical stimulation. The similarities in responses of inorganic and organic systems led to his famous and controversial generalization about the responses in the living and the non-living.*
3) *The third period that logically followed from the second phase led to his studies of Plant Electrophysiology and led to monumental investigations, which like most of his researches, were ahead of his time. These researches lasted till the end of his life.*

Jagadish Chandra after reading the book of Prof. Lodge decided to take up experimental study of Maxwell's electromagnetic waves and their validity for different frequencies and wave lengths. He chose frequencies just beyond infrared and was the first person to produce and wirelessly transmit millimeter waves. today.

Maxwell unified various theories pertaining to electricity and magnetism and came to the stupendous discovery that visible light is nothing but a small section of electromagnetic waves that travel at the speed of about 310740 km per second which was remarkably close to the measured value of speed of light.

Maxwell stated .....

"The agreement of the results seems to show that light and magnetism are affections of the same substance and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws."

This proposition threw up many questions. Can light be produced by electromagnetic interaction? Do electric waves have the same characteristics as light waves? Can they be reflected, refracted, diffracted and polarized? How does one produce electric waves and detect them and subject them to various tests?

Heinrich Hertz, the Maxwellians, namely Oliver Lodge, G.F. Fitzgerald, Oliver Heaviside and independently Jagadish Chandra Bose were some of those pioneers to answer these questions.

Maxwell died at the age of 48 before these questions were answered by experiments. . Professor G.F. Fitzgerald of Dublin University had no doubts about the correctness of Maxwell's waves. He suggested the following:

"Get hold of a Leyden jar. Charge it. Discharge it into a loop of wire. The arrangement will generate very high frequency."

That may have been the lead, way back in 1882.

Heinrich Hertz (1857-1894) was believed to have been advised by his teacher Herman von Helmholtz (1821-1894) to undertake the research suggested by Fitzgerald to carry out experiments to produce electric waves and showing that they have optical properties.

Bose came across an interesting paper. The author had discussed how the ships out into the open sea were helpless without any signals from the lighthouses. Light signals shone from the light houses in the coasts would be scattered as they passed through fog and be invisible and even red light, the longest visible light would not be visible (2) (*The Electrician,1891).* If signals with electric waves having wavelength larger than infrared could be used that would possibly not be impeded by fog and reach the ships out into the ocean.

Bose made up his mind to undertake research on Maxwell's waves. In his own words, he wanted to show

"That the waves had all the properties that light was known to have, and the theory of electromagnetism said that they ought to have "

Bose was fully aware that he was an experimental scientist and not a mathematical physicist (as one of his celebrated pupils S.N. Bose later turned out to be) (3). His strength lay in planning and designing instruments to carry out experiments that would offer legitimacy to theoretical physics.

He built his laboratory, 20 sft in area, adjacent to a bathroom in his office in Presidency College. The first thing that he noted were the limitations of the experiments that had been reported by the researchers in England and Europe.
The electric waves that were produced got reflected on the walls and stray waves interfered with the main electric waves whose properties were to be studied. The appliances required to study the usual optical properties of electrical waves were unwieldy because the waves were long.

It fell on Bose to realize that the wavelengths should be larger than infrared yet small enough with enough energy to penetrate walls rather than get reflected and he devised ingenious gadgets to guide the waves and recapture them. The lecture delivered at Royal Institution on 29^{th} January 1897, Bose summarized his objective of going for electrical waves of millimeter wavelength:

"For experimental investigation, it is also necessary to have a narrow pencil of radiation, and this is very difficult to obtain, unless waves of a very short wavelength are used. With large waves diverging in all directions and cutting around corners, all attempts at accurate work is futile…All these drawbacks were ultimately removed by making suitable radiators emitting very short waves."

A complete millimeter wave bench that he prepared with the clear objective of radiating millimeter waves, guiding them, receiving them and detecting them. Several parts of this bench could be patented, but Jagadish Chandra's revulsion for patenting, discussed later in the paper, prevented him from doing so. The entire apparatus could be fitted into a box measuring 60cmx30cmx30cm.

The deflection of a Galvanometer helped in carrying out the experiments to verify the quasi optical properties of the electromagnetic waves. Jagadish Chandra used ingenious methods to detect polarization and other properties of light.

He used devices, like ringing a bell, a telephone or firing a cannon ball for spectacular demonstrations of remote signalling by invisible rays.

Coherer

Detection of electrical waves is as important as producing and transmitting it (5). Professor Lodge modified the detection device produced by Professor Branly which Lodge called the Coherer and the name stuck. Bose used various types of metal contacts and came to find that point contact on a metal or cat whiskers provided the best type of detectors (4). He used many materials in this device. He measured and plotted the current/voltage or the I/V characteristics. Instead of the usual straight lines (Ohm's Law), he found two groups, one in which the current increased as the radiation was absorbed i.e. the resistance decreased e.g. in iron (as in Branly's coherer) and the other where the current decreased i.e. the resistance increased as in Potassium. The first ones, he designated as positive and the second as negative.

Quoting from Engineer (ref4) "His masterpiece, made from galena, could detect the entire EM wave spectrum lying between millimeter electric waves and violet light. He called it an "Electric eye" and patented it." and in this, one could see how close he had come to anticipating p-type and n-type semiconductors.

Instant recognition

Bose published his first paper in the Asiatic Society in 1895.He was invited to deliver a demonstration lecture at the Town hall of Calcutta where the Governor Sir William Mackenzie was present. Jagadish Chandra sent a signal longer than the infrared and the invisible ray penetrated blocks of wood, human body, two walls and rang a bell and fired a cannon ball 23m away. This was an amazing demonstration of remote control which held the audience spellbound. That was in the year 1895. So, in less than a year, Jagadish Chandra, working alone, helped by a tinsmith, produced an instrument that generated microwaves which could travel through space and activate relays and also make a novel self- adjusting Coherer respond. The Statesman and The Electrician were full of praise for Jagadish Bose's inventions. Emphasizing particularly on the usefulness of Bose's Coherer, and taking lead from the publication by *The Electrician*, the Englishman wrote: (3)

"Should Professor Bose succeed in perfecting and patenting his "Coherer", we may in time see the system of Coast lighting throughout the navigable world revolutionized by a Bengali Scientist single-handedly in our Presidency College."

Bose's second paper, "On the index of Refraction of sulphur for the electric ray" communicated to the Royal Society for Publication by Lord Rayleigh and a second paper on a unique method of measuring wavelength of electromagnetic waves, communicated by Lord Rayleigh, led to the conferment of D. Sc degree by the University of London, (1896) ,with the rare distinction of his being exempted from further examinations.

Jagadish Chandra was invited to make a presentation of his research at the Royal Society and based on strong recommendations of Sir Alfred Croft and Sir William Mackenzie, sanction for Bose's visit to England was officially announced, (on 1st July 1896)

"It has been settled that Professor Bose should proceed at once on deputation to England to be present at a meeting of the British Association."

Jagadish Chandra went to England and delivered his lecture on the quasi-optical behavior of millimeter waves to an august gathering of scientists at the British Association at Liverpool on 21st September, 1896. Among the eminent scientists present were, Lord Kelvin, Sir Gabriel Stokes, Professors J.J. Thomson, Fitzgerald, Everett, Oliver Lodge and a few continental scientists. Bose, 38years old, was *"a little nervous at the beginning. It has not often fallen on me to address such a critical audience. But I soon got interested in my subject and was encouraged by the kind manner with which the paper was received."*

Lord Kelvin, (1824-1907), the famous Physicist broke into a warm applause. He climbed up the gallery to meet Abala Bose and congratulated her on the brilliant performance of her husband. He did not stop there. He wrote to Lord George Hamilton, then the Secretary of State for India:

"*It would be conducive to India and the scientific education of Calcutta, if a well-equipped physical Laboratory is added to the resources of University of Calcutta in connection with the Professorship of Dr. Bose.'*

The Baker Laboratory, it is believed, is the outcome of the mail from Lord Kelvin.

Nikola Tesla and Guglielmo Marconi (3)
Unknown to most in Europe, an extraordinary inventor, a Serbian American, was "playing with" remote control using electromagnetic waves around 1893. He built a boat and a handheld device which could control the speed and direction of the boat. He was Nikola Tesla (1856-1943), famous for his inventing Induction motor and introducing Alternating Current power supply. Tesla coil invented by him was widely used by scientists all over the world. His work was going on in parallel to that of Bose, unknown to each other. Unlike Bose, Tesla lost no time in patenting his inventions. He had eight American patents on electrical wave transmission all of which preceded those of Marconi.

Guglielmo Marconi (1874-1937) a rich Italian with Aristocratic connections had a single point agenda. It was to use electrical waves for message transmission. He had no compunction about infringing into available technology without acknowledgement.
He used Tesla coil, Tesla earthing and with the help of a friend L. Solari in the Italian Navy had a receiver made which, it is believed, used the receiver technology of Bose which was not patented.

Marconi was a good engineer and an extraordinary marketing manager. Sending the letter 'S' (based on Morse code) across the Atlantic, brought him International fame. In response to Edison's dismissal of the claim of transmitting and receiving an electrical signal round the curved earth as "A figment of Marconi's imagination", Marconi travelled in a ship SS Philadelphia to US on February 1902 and arranged to keep receiving radio signals, noting them and getting them countersigned by the Captain. He did not waste time in throwing a huge party where he invited Graham Bell, the inventor of telephones. Marconi came to be known as the inventor of Wireless Telegraphy. Marconi's connections with Italian Aristocracy and British Royalty enabled him to arrange sending a message from the American President Theodore Roosevelt to King Edward VII in 1901 and make big news.

It is alleged that Marconi in his speech at the grand party with Graham Bell, did not mention Tesla or Bose or even his childhood friend L. Solari in the Italian navy. Bose never claimed that he invented the radio. His preceding Marconi by two years in wireless telegraphy is attributed to a letter that Sister Nivedita had written to Rabindranath Tagore. (6). That may have given rise to the widely held idea in India that "Marconi had cheated out on Bose in the invention of Radio"

It has to be admitted that it was Marconi who made "wireless telegraphy" into a viable technology which caught on.

Marconi received the Nobel Prize in the year 1909. Neither Bose nor Tesla had any share of it. Years later, in 1943, the American Supreme Court dismissed the claim of Marconi's company in US, and annulled the patent with Marconi as the inventor of Wireless Telegraphy. The long judgment was interpreted by the followers of Tesla as favouring Tesla to be the inventor of Wireless Telegraphy. There were others who disputed such an interpretation.

When Bose was asked by his nephew as to who Jagadish Chandra believed was the true inventor of Radio, Jagadish Chandra replied that "*It is not the inventor but the invention that matters"* (3)

That Jagadish Chandra's role in Wireless Technology has not been duly acknowledged in the West has much to do with Bose's aversion to patenting. The following section from Dasgupta (6) is a transcription of Bose's letter to Tagore:

"A week after his lecture in the Royal Institution in May 1901, Bose wrote to Tagore that just prior to the lecture, the proprietor of a famous telegraphy company (most likely Dr. Alexander Muirhead, a D. Sc in Electricity) had sent him a cable indicating that he wanted to see Bose urgently. When they met, he pleaded with Bose not to reveal the details of his work in the lecture but rather allow him to take out a patent on Bose's behalf, so that they may share the profit." (possibly from making crystal radio)

Bose's repugnance at the overture made by the billionaire," who to make further profit came to me like a beggar," was undisguised. "If only Tagore would witness the country's (England's) greed for money", he wrote to Tagore in disgust. "What a dreadful all-consuming disease it was." (3)

It is possible that Bose believed that we Indians are superior to the Westerners at the very least in our apathy to worldly possessions.

Patric Geddes (7) described Jagadish Chandra as a *Rishi* (hermit)

Aversion to Patenting
It may also be possible that Bose genuinely believed that knowledge should be available to all and should not be constrained by patenting (8). Patenting, it is believed, was forbidden in the Bose Institute that Jagadish Chandra had founded. It is interesting to note in this context that Bose's recognition as a pioneer in semiconductor technology was due to his American Patent (1904), the first Indian to have an American Patent. Bose was almost forced by two Western ladies,

one was Sister Nivedita and the other Mrs Ole Bull to make the Patent application, for his "electric eye". Mrs Bull lent Bose the $80 necessary for submitting the patent application. That was in the year 1901.

By now Jagadish Chandra had moved away from his research in Microwave generation, transmission and reception. This is evident from the articles in the "History of wireless" (5) which is an exhaustive study. Out of nineteen authors only two had mentioned Bose. Out of a total of 705 references made by seventeen authors there are only two references to Jagadish Chandra except for one chapter dedicated to him written by two Bengali authors, one of them being the main compiler of this collection. Had Jagadish Chandra got patents or commercialized crystal radio using galena, the situation possibly would have been different.

That Bose was forgotten in the West had other reasons as well.

Long distance Wireless telegraphy became the most sought-after engineering achievement and it could be carried out only with long waves and not short or microwaves. The short waves penetrate the ionosphere and are not reflected as long waves are. That explained how Marconi's signals with long waves could negotiate the earth's curvature.

The use of and interest in millimeter waves, first invented by Jagadish Chandra, almost ended with his establishing the validity of Maxwell's equations at millimeter wave range. The use of Wireless telegraphy using long waves assumed great importance during the first world war by which time John Ambrose Fleming's Valves (diodes) had been invented and their complex versions were being widely used. Transistors were yet to come. The use of microwaves was far off.

It was around the year 1900 that Jagadish Chandra changed track. He could not continue with researches on millimeter waves or his point contact detectors that anticipated semiconductors. Quantum mechanics was unknown and possibly beyond the mathematical training of Jagadish Chandra. Fleming's discovery of electronic Valves, diodes, was a different kind of Technology that could hardly be practiced and developed in an ill-equipped laboratory of Bose. The physicists of the first few decades of the twentieth century, namely Max Planck, Albert Einstein, Niels Bohr, Paul Dirac, S.N. Bose to name a few of the pioneers, were totally engaged in a different type of Physics. Technologies that grew afterwards were very different.

Changing Track

Jagadish Chandra got engaged with a different problem altogether. The question was "Where is the boundary between the living and the non-living?" An extract from Bose's Royal Institute discourse (10th May 1901) below reflects his observations:

"I have shown you this evening an autographic record of the history of stress and strain in the living and the non-living. How similar are the writings? So similar indeed that you cannot tell one apart from the other. We have seen the responsive pulse wax and wane in one as in the other. We have seen response sinking under fatigue, becoming exalted under stimulants and being killed under poison.

Amongst such phenomenon, how can we draw a line of demarcation, and say here the physics ends, and there the physiological begins? Such absolute barriers do not exist.

……………………………………………………………………………………………………

It was when I came upon the mute witness of these self-made records, and perceived in them one phase of a pervading unity that bears within it all things—the mote that quivers in ripples of light, the teeming life upon our earth, and the radiant Sun that shines above us –it was then that I understood for the first time a little of the message proclaimed by my ancestors on the bank of the Ganges thirty centuries ago ---"They also see but one, in all the changing manifolds of the universe, unto them belongs the Eternal Truth—unto none else, unto none else!"

It was his faith in Universalism that may have made Bose mentally bridge the gap between the living and non-living. Bose and many illustrious thinkers of his time who were somewhat carried away when Bose's experimental results appeared to hold answer to the unresolved philosophical question and their faith. Bose possibly made the mistake of basing his conclusions on the fulfilment of necessary conditions of electric response only but not sufficient conditions. (3)

To quote D.M. Bose, (1)

"Bose *was not familiar with the contemporary physicochemical investigations carried out by men like Ostwald, Bredig and their school and was therefore unable to undertake a correct interpretation of these borderline investigations of his. While his Western contemporaries designated them as inorganic models of some properties of living systems, Bose with his pantheistic background saw in the similarity an evidence that the responsive process seen in life has been foreshadowed in the living."*

Bose's presentation in the Royal Society evoked mixed response. Some were ecstatic and some skeptical and Dasgupta (6) believes, that this was when Bose began to be marginalized as a scientist in the Western world."

His researches on Plant electrophysiology using instruments, such as the Resonant Recorder, that he got made with unbelievable accuracy and amplification revealed facts about plants that were sensational and controversial. These are, belatedly, receiving attention. (10)

There is a "resurrection" of Jagadish Chandra Bose not only in the area of Plant physiology but also in Physics where he was, as just stated, virtually forgotten.

Millimeter waves that had no use about one hundred years from now, have come back in a big way. Having a short wave length (1 to 10 mm) these have high frequency and can pack a lot of information. These may be designed to have a narrow beam width. (remember Bose's lecture at the Royal Institution. 29th January 1897, trying to get a narrow pencil of radiation). Millimeter waves interact with the atmosphere and lose energy to oxygen. These are suitable for short distance transmission (hand held mobile phones, televisions) or inter-satellite communication where oxygen is absent.

In recognition of his contributions "IEEE IN MILESTONE RECOGNITION" have commemorated a milestone based on the early radio experimental work by Dr. Jagadish Chandra Bose. His experiments in the early 1900's was conducted on equipment operating at 60GHz approximately at 5mm wavelength. The plaque was installed in the main building of Presidency College, Calcutta on 15th September, 2012.

Pearson and Brattain (Brattain received the Nobel prize for inventing Transistor along with Shockley and Bardeen) in their seminal paper (ref 11) acknowledged:

"*The demonstration of the existence of radio waves by Hertz in 1888 created potential demand for a suitable detector, but it was not realized until 1904 (Bose's American patent) that semiconductor rectifiers were well-suited for this purpose. J.C. Bose found that point contacts (cat whiskers) on galena, silicon carbide, tellurium, silicon etc. were good detectors of radio waves"*

It is also on record that Sir Neville Mott, Nobel Laureate in 1977, for his contributions to solid state electronics, remarked, *"J.C. Bose was at least 60 years ahead of his time and he had anticipated the p-type and n-type semiconductors."*

Bose's ability to look much ahead of his time may be explained in the words of his good friend Rabindranath Tagore….

"I found in him (Bose), a dreamer and it seemed to me, what surely was a half-truth, that it was more his magical instinct than the probing of his reason which startled out secrets of nature before sudden flashes of his imagination……."

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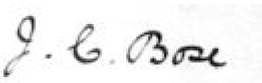
About the author

Dr. D P Sengupta An honours graduate in Physics from Calcutta Presidency College and in Electrical Engineering from IIT Kharagpur, Dr. Sen Gupta took his Ph.D from Liverpool University. He carried out teaching and research for about three decades at the Indian Institute of Science (IISc), Bangalore. He received awards for teaching excellence at both Liverpool University and IISc where he was awarded a special chair for Energy Studies. He was an AICTE Emeritus Fellow at the IISc as well as a Visiting Professor at the National Institute of Advanced Studies, Bangalore. He has co-authored several books including "Remembering Sir J C Bose", which was published by IISc Press and World Scientific Publishing Company. Among many others, he won Prof. S.N.Bose award from Government of West Bengal.

Born	30 November 1858 Mymensingh, Bengal Presidency, British India (now in Bangladesh)
Died	23 November 1937 (aged 78) Giridih, Bengal Presidency, British India (now Giridih, Jharkhand, India)
Residence	Kolkata, Bengal Presidency, British India
Citizenship	British Indian
Alma mater	Hare school St. Xavier's College, Calcutta Christ's College, Cambridge University College, London[1]
Known for	Millimetre waves Radio Crescograph Contributions to plant biology
Spouse(s)	Abala Bose
Awards	Companion of the Order of the Indian Empire (CIE) (1903) Companion of the Order of the Star of India (CSI) (1911) Knight Bachelor (1917)
	Scientific career
Fields	Physics, biophysics, biology, botany, archaeology, Bengali literature, Bengali science fiction
Institutions	University of Calcutta University of Cambridge University of London
Academic advisors	John Strutt (Rayleigh)
Notable students	Satyendra Nath Bose Meghnad Saha Prasanta Chandra Mahalanobis Sisir Kumar Mitra Debendra Mohan Bose

Signature



Source and Courtesy:* *https://en.wikipedia.org/wiki/Jagadish_Chandra_Bose

Sir Jagdish Chandra Bose, James Clerk Maxwell and there on…..

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Dr. DS Kothari DRDO Chair
Former: Vice Chancellor, DIAT, Pune
Distinguished Scientist and Senior Advisor SATNAV-ISRO

Abstract

IEEE India Council, Bangalore & Bombay sections arranged lectures on Sunday 17th Feb 2019, on the topic "Celebrating Sir Jagdish Chandra Bose"; I had an opportunity to deliver a talk on: Sir. Jagdish Chandra Bose, Maxwell and there on.

There is quite a bit commonality between Acharya Jagdish Chandra Bose and Maxwell. Both of were "Polymath", who influenced the science of that era, in their own way, while their work & theories are quite relevant even today. Due to the efforts of some dedicated Indian Scientists in US, IEEE in 2012 recognized Sir Jagdish Chandra Bose as one of the founding fathers of RF/EM. The talk mostly concentrated on Acharya Jagdish Chandra Bose, his work and impression of his contemporary, workers and friends like Swami Vivekananda, Gurudeo Tagore and his students on his life and work. Similarly, a brief is given on James Clerk Maxwell and his work on various topics with more emphasis on EM equations.

Acharya (Sir) Jagdish Chandra Bose
CSI, CIE, FRS, IPA
(Nov 1858 – Nov 1937)
CSI-Companion of Star of India
CIE-Companion of the Indian Empire
KB-Knight Bachelor

Acharya Jagdish Chandra Bose born on 30 Nov 1858, at Mymen Singh (now in Bangladesh), was an Indian Plant Physiologist & Physicist of great repute. He was a Polymath (Physicist, Biophysicist, Botanist and Archaeologist). He was also a science & science fiction writer in Bengali, in early British India. He is more known for his pioneering investigation of RF & Microwaves (millimeter waves), optics, plant science and first one to lay the foundation of experimental science in the Indian subcontinent. He invented Cresograph, a device for measuring the growth of plant. It is worth mentioning that due to the efforts of some of the Indian scientists, working in US, in 2012 after 127 years of his invention of millimeter waves, IEEE recognized him as one of the founding fathers of RF/EM Engineering. A crater on moon is also named after him. A 1.3mm multibeam receiver, now as the National Radio Astronomy Observatory (US) 12-meter telescope, Arizona, incorporates his original papers of 1897.The Bank of England has decided to redesign the 50 Pounds note with an eminent scientist, Sir J.C Bose has been featured in the nomination.

Perhaps Acharya Jagdish Chandra Bose was never interested in developing communication receiver. He wanted to study the optics like properties of RF waves (at millimeter wavelength). Apparently he was not interested in patenting and publicity otherwise he would have been the inventor of wireless RF communication. In 1896 Marconi met him and gave a proposal for business, which Sir. J.C Bose declined. In the year 1899 Bose announced the development of "Iron-Mercury-Iron coherer with telephone detector". It is believed that his this work influenced the work done by Marconi, Popov and other researchers working on radio communication. Sir. J.C Bose was first to use semiconductor junction to detect radio waves, can be called as father of semiconductor junction diodes. In the year 1897 he presented his work on MMW at Royal Institution in London. He used waveguides, horn antennas, dielectric lenses, various polarizers and even semiconductors at ~60 GHz. We can call him even the father of waveguides and horn antennas.

As per Sir Nevill Mott (Noble Laureate – 1977). Sir J.C Bose was at least 60 years ahead of his time. In fact, Bose anticipated the existence and use of P&N type semiconductors.

As far as education is concerned, he had his graduation from St. Xavier's College Calcutta, Christ's College Cambridge, University College London. He was fortunate to have teachers at Cambridge like Lord Rayleigh, Michael Foster, James Dewar, Francis Darvin, Francis Balfour & Sidney Vines.

Acharya J.C Bose had two famous friends. : Acharya P.C Roy and Gurudeo Rabindranath Tagore. Sister Nivedita, who arranged financial support for his patent, on his coherer invention, in US, also supported him.
Before and besides Sir. Jagdish Chandra Bose and Maxwell, there were many pioneers, who put the formation of electricity, magnetism and electromagnetics: Following is the list of those pioneers.

William Gilbert	1544-1603	Electroscope
Stephen Gray	1627-1691	Electricity
Benjamin Franklin	1706-1727	Static electricity/electricity
Ewald George Von Kleist	1744-	Leyden jar
Charles Augustine de Coulomb	-	Electric charge
Alexander Voltas	1745-1782	Electric cell
Andre Ampere	1775-1786	Electric current
Michael Faraday	1791-1867	Electromotive force Generation of electricity and magnetism Studied the time variation effects on electric and magnetic field
Tesla	1856-1937	Modern A/C system
G.Macaroni	1874-1937	Radio Communication

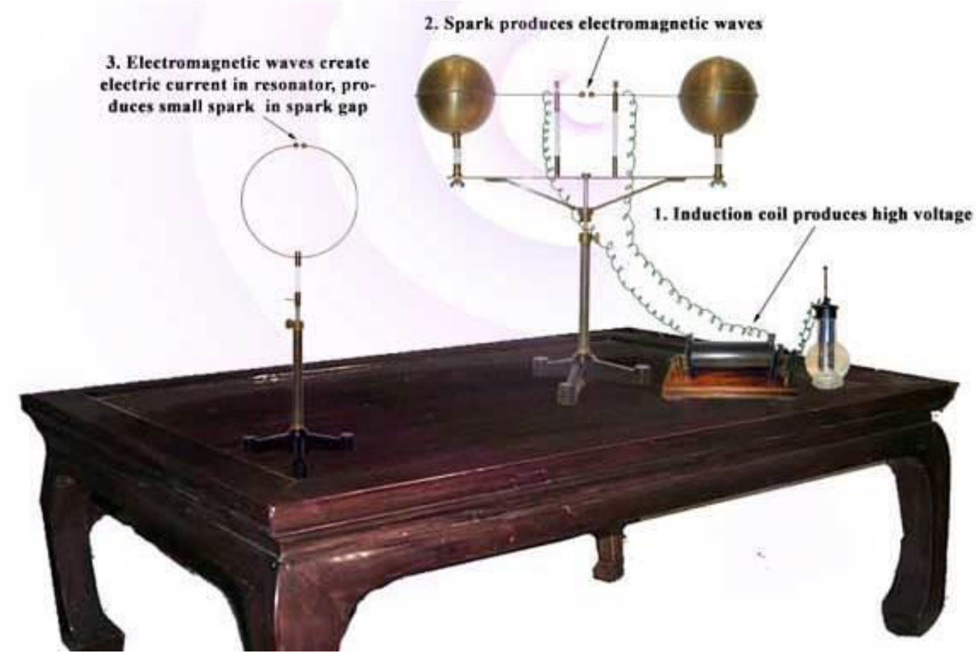
The list is representative and does not include the names of Sir. J.C Bose (1858-1867) & Maxwell (1831-1879), since the talk is about these two great scientists.

RF Wave Experimented demonstration of transmission.

After Theoretical Physicist James Clerk Maxwell who predicted the existence of electromagnetic radiation and work by Heinrich Hertz, Oliver lodge, Acharya Jagdish Chandra Bose in the field of microwave research where he reduced the wavelength to millimeter level (~ 5mm) did most remarkable experimental research. He wanted to study the light like properties of electromagnetic waves like polarization, diffraction, reflection etc which were not possible at long waves. Apparently, he did not use RF for communication purposes.

In 1895 Acharya Jagadish Chandra Bose gave his first demonstration of electromagnetic waves, by ringing a bell remotely across a wall and exploded some gunpowder in the presence of then Lieutenant Governor of Bengal Sir William Mackenzie at Calcutta town hall. He visualized that these invisible rays can pass through a wall and message can be transmitted by using these without using wires. Truly, he was the inventor of wireless communication, though he did not pursue it further.

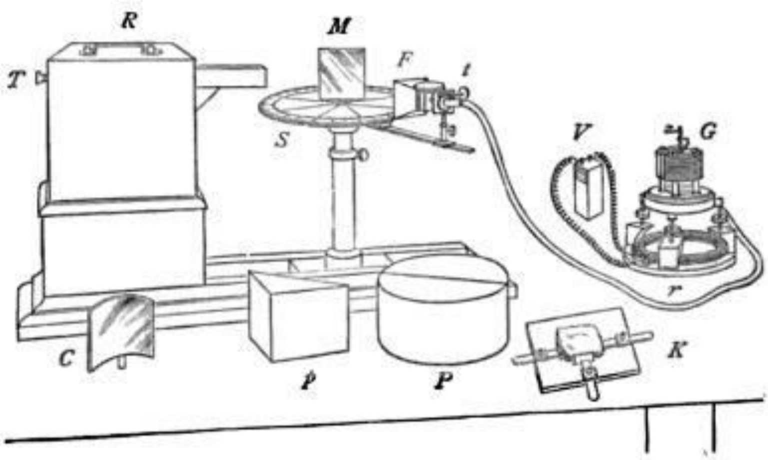
Rudolph Hertz a German Scientist (1857-1894)



Hertz Experiment (1879)

MM Wave Apparatus at JC BOSE Museum Kolkata

Acharya J C Bose with his RF equipment



Line Diagram Of The RF Equipment

In the year 1895 he published a scientific paper “On polarization of electric rays (EM) by double refracting crystals”(Asiatic Society of Bengal). Lord Rayleigh in Oct 1895 communicated Sir Jagdish Chandra Bose’s second paper to Royal Society of London. In Dec 1895, London Journal Electrician (Vol 36), published Bose’s paper, “On a new electro-polariscope”. During the same period, he invented coherer, which he later on patented in US, and was used by G. Marconi to receive signals across Atlantic in Dec 1901. Marconi was celebrated worldwide for his achievement, but the fact that Bose invented the receiver was totally concealed.

Acharya Jagdish Chandra Bose besides working on radio waves (MMW) carried out studies on plants, cell response, metal fatigues.

Sir Jagdish Chandra Bose was a brilliant scientist of his period and his work was appreciated and acknowledged by great scientists of that era like Lord Rayleigh, Lord Kelvin and others. Although in the initial stages he did face some racial discrimination in the British era,in India but his talent was recognized by then Viceroy who supported him to get academic position in Presidency College with full pay enpar with Britishers. I feel Acharya J.C Bose was well recognized by great scientists and even literary figures like Gurudev Rabindranath Tagore.

Acharya J.C. Bose was a great teacher and researcher. Some of his famous students who influenced science in pre and post independence era were:

Prof S.N. Bose, Prof. Meghnath Saha, Prof. Prasad Chandra, Prof. S K Mitra, Prof. Mahalnobis & Prof. D.M. Basu

Acharya Jagdish Chandra Bose and Gurudeo Rabindranath Tagore

Sir Jagdish Chandra Bose had a great admirer and friend in Gurudeo Rabindranath Tagore.*

In 1931, on the occasion of Tagore's Seventieth birthday, Bose confessed, how the Poet had influenced his ideas and his work, opening before him a wider view of life: His friendship has been unfailing through years of my ceaseless efforts during which I gained step by step- a wider and more sympathetic view of continuity of life and its diverse manifestations.

(*Acknowledgement:Biswanth Banerjee Vishva Bharty India)

Tagore found Jagadish Chandra to be endowed with a rare faculty of poetic sensibility and imagination, who appeared to him someone more than a scientist: …" to my mind he appeared to be the poet of the world of facts that waited to be proved by the scientist for their final triumph.. in the prime of my youth I was strongly attracted by the personality of this remarkable man and found his mind sensitively alert in the poetical atmosphere of enjoyment which belonged to me" Hence, to both Tagore and Bose, there never existed any rigid distinction

BOSE and Literature

In his presidential address at the Bengal Literary – Conference in 1911, Bose suggested

"You are aware that, in the West, the prevailing tendency at the moment is, after a period of synthesis, to return upon the excessive sub-division of learning, Such caste-system in scholarship, undoubtedly helps at first, in the gathering and classification of new material. But if followed too exclusively, it ends by limiting the comprehensiveness of truth. The search is endless. Realization evades us. The Eastern aim has been rather the opposite, namely that, in the multiplicity of phenomena, we should never miss their underlying unity. After generations of this quest, the idea of unity comes to us almost spontaneously, and we apprehend no insuperable obstacle in grasping it".

BOSE IN HIS LAST PHASE OF RESEARCH

He pursued in a research to draw a link between the animate and the inanimate in their responses to electric stimulus, and wrote his seminal book, Responses in the Living and Non-living (1902). This project of Bose served to fulfill two crucial purposes: firstly, to contest the Western stereotypical image of India as 'a nation of dreamers', by leaving a distinctly Indian imprint in the corpus of modern science, and secondly, to widen the world view of modern science and to bring a refreshing spirit to the excesses of Western scientific methodology by infusing the Eastern spiritual resources and Vedantic beliefs which proclaim the ideal of the Unity of Life.

Rabindranath Tagore, who had always been an avid supporter of Bose's researches and discoveries, found in his works an essence of Indian scientific spirit, a reflection of Indian national culture, its national pride and heritage. In his poem for Bose, published in Kalpana, Tagore, addressing the scientist, was effusive in praise:

Tagore as a poet on Bose

From the Temple of Science in the West,
Far across the Indus,
Oh, my friend, you have brought
the garland of victory,
decorated the humbled head of the poor Mother ….
Today, the mother has sent blessings
In words of tears,
of this unknown poet.
Amidst the great Scholars of the West
Brother, these words will reach only yours years

BOSE AS A TRUE NATIONALIST

In his letter to Tagore, dated 29th November, 1901, Bose acknowledged his responsibilities as a scientist to revive the national pride of his county: I am alive with the life force of the mother Earth, I have prospered with the help of the love of my countrymen. For ages the sacrificial fire of India's enlightenment has been kept burning, millions of Indians are protecting it with their lives, a small spark of which has reached this country (through me)

Bose's discoveries on electric responses, which were premised alleging the distinctions between the living and the non-living, actually reiterate the ideals of Hindu Vedic Monism that asserts a sense of unity and strength, a grand cosmic unity within the diversity. In this respect, Bose was considerably influenced by Rammohan Roy, who is often designated as the pioneer to rediscover and identify this essential monism within Classical Indian thought, and who according to Bose, was the first to see the "Unity of All Intellectual Life", and the "importance of absolute freedom in all fields of inquiry.

BOSE'S FINAL PHASE OF DISCOVERY

In the final phase of Bose's research could be characterized as the continuation of his endeavor to search for the Unity of Life, in which he attempted to bridge the gulf between the inanimate and the animate worlds by posting the plant world as the progressive connecting link. This phase of Bose's research thus promised to collapse the further existing barriers between different fields of scientific research, thereby strengthening his commitment to his Vedantic belief in cosmic unity.

Acharya JC Bose and Gurudev Rabindranth Tagore

In a tribute to his friend Sir Jagadish Chandra Bose (1858-1937) who died on 23 Nov 1937, Rabindranth Tagore (1861-1941) wrote: Years ago, when Jagadish Chandra, in his militant exuberance of youthfulness, was contemptuously defying all obstacles to the progress of his endeavor, I came into intimate contact with him, and became infected with his vigorous hopefulness. There was every chance of his frightening me away into a respectful distance, making me aware of the airy nothingness of my own imaginings. But to my relief, I found in him a dreamer, and it seemed to me, what surely was a half-truth, that it was more his magical instinct than the probing of his reason which startled out secrets of nature before sudden flashes of his imagination.

James Clerk Maxwell (1831–1879)

James Clerk Maxwell was another Polymath. He is more famous for the theoretical formulation of electromagnetic theory, although he contributed in many areas of Physics.

Maxwell is considered by many physicists to be the nineteenth century scientist with the greatest influence on twentieth century physics. His contributions to the science are considered by many to be of the same magnitude as those of Isaac Newton and Albert Einstein, although he was not as fortunate as the other two in getting laurels and recognition during his life. In 1931, on the centennial of Maxwell's birthday, Einstein himself described Maxwell's work as the: *"most profound and the most fruitful that physics has experienced since the time of Newton"*. Einstein kept a photograph of Maxwell on his study wall, alongside pictures of Michael Faraday and Isaac Newton.

History of Maxwell's equations

Electromagnetism, one of the fundamental fields of physics, the introduction of Maxwell's equations (mainly in *"A Dynamical Theory of the Electromagnetic Field"*) was one of the most important aggregations of empirical facts in the theory of physics. It took place in the nineteenth century, starting from basic experimental observations, and leading the formulations of numerous mathematical equations, notably by Charles-Augustin de Coulomb, Hans Christian Orsted, Carl Friedrich Gauss, Jean Baptiste Biot, Felix Savart, Andre-Marie Ampere and Michael Faraday. The apparently disparate laws and phenomena of electricity and magnetism was integrated by James Clerk Maxwell, who published an early form of the equations, which modify Ampere's circuital law by introducing a ***displacement current term***. He showed that these equations imply that light propagates as electromagnetic waves. ***His laws were formulated by Oliver Heaviside in the more modern and compact vector calculus formalism,*** he independently developed. Increasingly powerful mathematical descriptions of the electromagnetic field were developed, continuing into the twentieth century, enabling the equations to take on simpler forms by advancing mathematics that is more sophisticated.

The concept of electromagnetic radiation originated with Maxwell, and his field equations, based on Michael Faraday's observations of the electric and magnetic lines of force, paved the way ***for Einstein's special theory of relativity, which established the equivalence of mass and energy. Maxwell's ideas also ushered in the other major innovations of 20th century physics, the quantum theory***.

His description of electromagnetic radiations led to the development (according to cassical theory) of the ultimately unsatisfactory law of heat radiation, which prompted Max Planck's formulation of the quantum hypothesis – i.e, the theory that radiant-heat energy is emitted only in finite amounts or quanta. ***The interaction between electromagnetic radiation and matter, integral to Planck's hypothesis, in turn has played a central role in the development of the theory of the structure of atoms and molecules.***

James Clerk Maxwell the Polymath, as a child ad maintained an unquenchable curiosity, for which all came on his way. He developed interest in optics by observing various colours on soap bubbles.

He considered electric & magnetic fields as fluids, wanted to use: **Newton's formula f = ma**

Besides EM theory, he worked on thermodynamics, statistics, atomic movements, RGB (Red, Green & Blue) Colur combination & viscoelastic materials.

Maxwell's equations are a set of partial differential equations that, together with the Lorentz force law, form the foundation of classical electromagnetism, classical optics, and electric circuits. The equations provide a mathematical model for electric, optical, and radio technologies, such as power generation, electric motors, wireless communication, lenses, radar etc. Maxwell's equations describe how electric and magnetic fields are generated by charges, currents, and changes of the fields. One important consequence of the equations is that they demonstrate how fluctuating electric and magnetic fields propagate at the speed of light. Known as electromagnetic radiation, these waves may occur at various wavelengths to produce a spectrum from radio waves to γ-rays. The equations are named after him. He also first used the equations to propose that light is an electromagnetic phenomenon.

$e + \frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz} \quad 0$	(1)	Gauss' Law
$\mu\alpha - \frac{dH}{dy} \quad \frac{dG}{dz}$ $\mu\beta - \frac{dF}{dz} \quad \frac{dH}{dx}$ $\mu\gamma - \frac{dG}{dx} - \frac{dF}{dy}$	(2)	Equivalent to Gauss' Law for magnetism
$P - \mu\left(\gamma\frac{dy}{dt} - \beta\frac{dz}{dt}\right) - \frac{dF}{dt} - \frac{d\Psi}{dx}$ $Q - \mu\left(\alpha\frac{dz}{dt} - \gamma\frac{dx}{dt}\right) - \frac{dG}{dt} - \frac{d\Psi}{dy}$ $R - \mu\left(\beta\frac{dx}{dt} - \alpha\frac{dy}{dt}\right) - \frac{dH}{dt} - \frac{d\Psi}{dz}$	(3)	Faraday's Law (with the Lorentz Force and Poisson's Law)
$\frac{d\gamma}{dy} \quad \frac{d\beta}{dz} = 4\pi p' \qquad p' - p + \frac{df}{dt}$ $\frac{d\alpha}{dz} \quad \frac{d\gamma}{dx} = 4\pi q' \qquad q' - q + \frac{dg}{dt}$ $\frac{d\beta}{dx} \quad \frac{d\alpha}{dy} = 4\pi r' \qquad r' - r + \frac{dh}{dt}$	(4)	Ampère-Maxwell Law
$P - \xi p \quad Q - \xi q \quad R - \xi r$		Ohm's Law
$P - kf \quad Q - kg \quad R - kh$		The electric elasticity equation (**E** = **D**/ε)
$\frac{de}{dt} + \frac{dp}{dx} + \frac{dq}{dy} + \frac{dr}{dz} - 0$		Continuity of charge

Maxwell's Original EM equations

Oliver Heaviside (1850-1925

$\nabla \cdot \mathbf{D} = \rho$	(1)	Gauss' Law
$\nabla \cdot \mathbf{B} = 0$	(2)	Gauss' Law for magnetism
$\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$	(3)	Faraday's Law
$\nabla \times \mathbf{H} = \dfrac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$	(4)	Ampère-Maxwell Law

Modern Maxwell's Equations (As modified by Oliver Heaviside

The four most common Maxwell relations are the equalities of the second derivatives of each of the four thermodynamic potentials, with respect to their thermal natural variable (temperature T; or entropyS) and their mechanical natural variable (pressure P; or volume V):

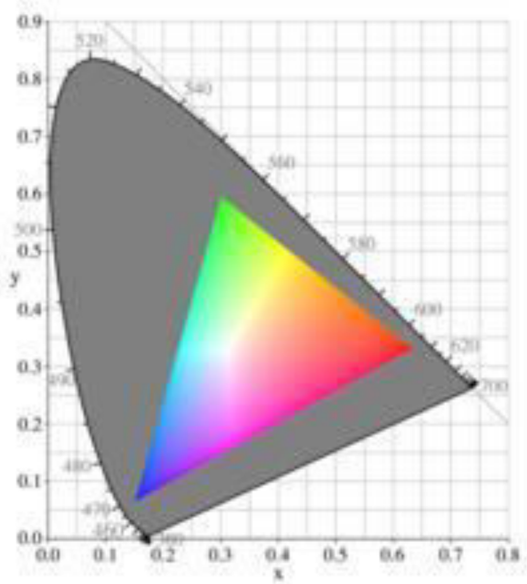
$$
\begin{aligned}
+\left(\frac{\partial T}{\partial V}\right)_S &= -\left(\frac{\partial P}{\partial S}\right)_V = \frac{\partial^2 U}{\partial S \partial V} \\
+\left(\frac{\partial T}{\partial P}\right)_S &= +\left(\frac{\partial V}{\partial S}\right)_P = \frac{\partial^2 H}{\partial S \partial P} \\
+\left(\frac{\partial S}{\partial V}\right)_T &= +\left(\frac{\partial P}{\partial T}\right)_V = -\frac{\partial^2 F}{\partial T \partial V} \\
-\left(\frac{\partial S}{\partial P}\right)_T &= +\left(\frac{\partial V}{\partial T}\right)_P = \frac{\partial^2 G}{\partial T \partial P}
\end{aligned}
$$

where the potentials as functions of their natural thermal and mechanical variables are the internal energy U(S, V), enthalpy H(S, P), Helmholtz free energy F(T, V) and Gibbs free energy G(T, P). The thermodynamic square can be used as a mnemonic to recall and derive these relations. The usefulness of these relations lies in their quantifying entropy changes, which are not directly measurable, in terms of measurable quantities like temperature, volume, and pressure.

Maxwell Boltzmann Distribution

In physics (in particular in statistical mechanics), the Maxwell–Boltzmann distribution is a particular probability distribution named after James Clerk Maxwell and Ludwig Boltzmann

Maxwell's Colour Triangle



The RGB color triangle, shown as a subset of x,y space, a chromaticity space based on CIE 1931 colorimetry

Maxwell Boltzmann distribution in gasses

Maxwell Boltzmann Distribution:In physics (in particular in statistical mechanics), the Maxwell–Boltzmann distribution is a particular probability distribution named after James Clerk Maxwell and Ludwig Boltzmann.

MAXWELL'S THEOREM

In probability theory, Maxwell's theorem, named in honor of James Clerk Maxwell, states that if the probability distribution of a vector-valued random variable X = (X1, ..., Xn)T is the same as the distribution of GX for every n×n orthogonal matrix G and the components are independent, then the components X1, ..., Xn are normally distributedwith expected value 0, all have the same variance, and all are independent. This theorem is one of many characterizations of the normal distribution.Since a multiplication by an orthogonal matrix is a rotation, the theorem says that if the probability distribution of a random vector is unchanged by rotations and if the components are independent, then the components are identically distributed and normally distributed. In other words, the only rotationally invariant probability distributions on Rn that have independent components are multivariate normal distributions with expected value 0 and variance σ2In, (where In = the n×n identity matrix), for some positive number σ2.

Maxwell's Materiala

Maxwell material is a viscoelastic material having the properties both of elasticity and viscosity. It is named for James Clerk Maxwell who proposed the model in 1867. It is also known as a Maxwell fluid.

Generalized Maxwell Model:The **Generalized Maxwell model** also known as the **Maxwell–Wiechert model** (after James Clerk Maxwell and E Wiechert[1][2]) is the most general form of the linear model for viscoelasticity. In this model several Maxwell elementsare assembled in parallel. It takes into account that the relaxation does not occur at a single time, but in a set of times. Due to the presence of molecular segments of different lengths, with shorter ones contributing less than longer ones, there is a varying time distribution. The Wiechert model shows this by having as many spring–dashpot Maxwell elements as are necessary to accurately represent the distribution. The figure on the right shows the generalised Wiechert mode

Displacement Current

In electromagnetism, **displacement current density** is the quantity $\partial \boldsymbol{D}/\partial t$ appearing in Maxwell's equations that is defined in terms of the rate of change of $\boldsymbol{D}$, the electric displacement field. Displacement current density has the same units as electric current density, and it is a source of the magnetic field just as actual current is. However it is not an electric current of moving charges, but a time-varying electric field. In physical materials (as opposed to vacuum), there is also a contribution from the slight motion of charges bound in atoms, called dielectric polarization.

The idea was conceived by James Clerk Maxwell in his 1861 paper *On Physical Lines of Force, Part III* in connection with the displacement of electric particles in a dielectric medium. Maxwell added displacement current to the electric current term in Ampère's Circuital Law. In his 1865 paper A Dynamical Theory of the Electromagnetic Field Maxwell used this amended version of Ampère's Circuital Law to derive the electromagnetic wave equation. This derivation is now generally accepted as a historical landmark in physics by virtue of uniting electricity, magnetism and optics into one single unified theory. The displacement current term is now seen as a crucial addition that completed Maxwell's equations and is necessary to explain many phenomena, most particularly the existence of electromagnetic waves.

Maxwell's coil

A **Maxwell coil** is a device for producing a large volume of almost constant (or constant-gradient) magnetic field. It is named in honour of the Scottish physicist James Clerk Maxwell.A Maxwell coil is an improvement of a Helmholtz coil: in operation it provides an even more uniform magnetic field (than a Helmholtz coil), but at the expense of more material and complexity.

Maxwell and light

- Maxwell theoretically showed that EM waves are light waves and vice versa.
- He also calculated the velocity which almost matched with the measured one much after his death.

Maxwell's all calculations were based on observations and empirical formulations which were letter on proved. Hertz was the first to show the generation and propagation of EM waves through spark gap experiment.

The lecture was based on the following open/published literature:

- An appreciation of J.C Bose's pioneering work:. Sarkar T.K & Sengupta D.L (1997) IEEE
- Yogananda Paramhansa (1946) "India's Great Scientist, J.C Bose". Autobiography of a Yogi (1st Edition) New York:
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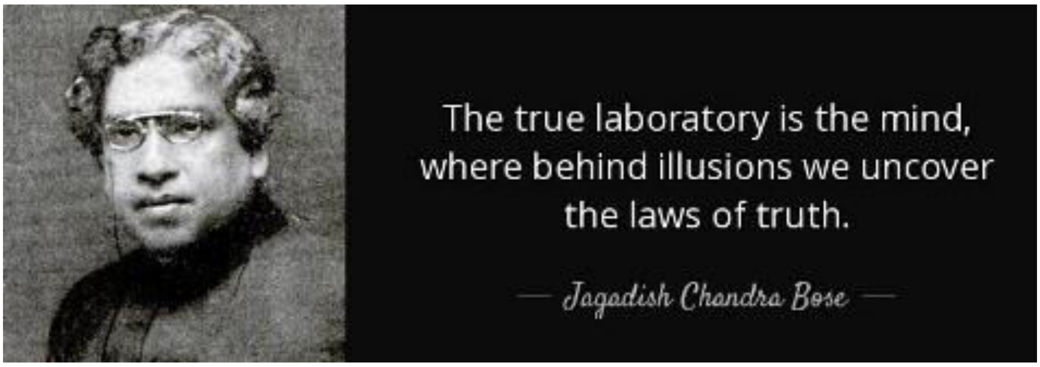
- Wikipedia (on J.C Bose & Maxwell)
- The Scientist and the Poet: Acharya Jagdish Chandra Bose and Rabindranath Tagore by Biswanath Banerjee-Vishwa Bharati India
- Maxwell's Legacy by James C. Rautio IEEE-Microwave Magazine-June 2005
- Encyclopedia Biography of World Great Scientists
- History of Wireless Communication-Microwave Journal 2015.

About the author

Dr.Surendra Pal is a space communication, RF, EM and GNSS expert. He is currently Dr. D.S.Kothari DRDO Chair. He was the Vice Chancellor of Defence Institute of Advanced Technology (DIAT), Pune, Prof. Satish Dhawan Professor, Senior Adviser and Programme Director of Satellite Navigation, ISRO, Bengaluru. He was also the Distinguished Scientist, Associate Director and Chairperson of GAGAN-PMB. He is a Fellow of IEEE, Fellow of Indian National Academy of Engineers (FNAE), Fellow of National Academy of Science (FNASc), Distinguished Fellow of IETE and Fellow of the IET. He had served as the national President of IETE during 2012-12.



mmWave Applications in NextGen Wireless Broadband Evolution in 5G Era Impact of Sir JC Bose invention

Mr. C.S. Rao, Co-Founder
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QuadGen Wireless Solutions

Abstract

Sir JC Bose, the Original Inventor, Pioneer, and Scientist was first in the past era to discover the mmWave based Radio communications and his famous invention has become now a reality in mass adoption in this world of 5G Wireless communications. 5G and mmWave Communications have now become the defacto choice for Mobile Gigabit Broadband Speeds based Internet Access. mm Wave technology, coupled with MIMO Antenna technology invention by Prof Arogya Swamy Paul Raj of Stanford University, USA, another living legend in this 2019 era paved the way for Mobile Internet Access in Megabits era from Minutes era of Wireless Phone communications on Smart Phones/Laptops and many other form factor-based end user devices. Prof Paulraj, an Indian is a globally acclaimed Scientist, Engineer, Technologist, and Academician who is also in the National Inventors Hall of Fame, USA. Now with 2 global societal life impacting inventions of mm Wave communications and massive MIMO from 2 great Indians, we are set to experience Gigabit speed of Internet access in 5G NR (New Radio) era starting from 2020.

1. Introduction.

mmWave technology historical invention by Sir JC Bose 100 years ago has been used with practical products only since a decade through what is known as E and V Spectrum bands. Telecom NW Operators have deployed them as Point to Point and Point to Multipoint Radio links as Back haul links as “Wireless Fiber” high speed links. Now mmWave has come to be seen as Wireless Access technology for cellular applications .This is a huge transformation for mmWave adoption at massive global scale and is ready to serve Billions of people for Mobile Gigabit speed experiences .Telecom operators have done trials since past 2 years and now ready to launch live mmWave radio based 5G NR networks in USA/Europe/APAC/China /Middle East and India.

2. Digital Transformation of Our World

Digital Transformation of our World is taking place around the Mobile going from 4G to 5G driving Gbps speed Internet connectivity. If we can recall the LAN speed what we experience in our day to day office has gone from 10Mbps to 100Mbps to 1Gbps and now 10Gbps.LAN based access to Internet is the reality on the copper wire .Same kind of LAN speed we are now set to experience from the Wireless LAN (WLAN) from 1G to 10G through 5th Gen WiFi in offices and the new 5G Wide Area Radio Access technologies like 4G.

To make this Digital transformation a true reality, we need to adopt the 100 years old mmWave invention from Sir JC Bose.

JC Bose invention of mmWave is all about facilitating GHz spectrum band hitherto not used for adoption in 26/28/29 GHz bands with wide RF channel widths of n* 20 MHz to n*100Mhz bands for Gigabit Broadband delivery. Thus, a massive Digital Transformation of our world from 3 to 4 Billion People having access to high speed Internet to approximately 50 Billion Devices getting connected on Internet on massive Machine Type Communications (mMTC).

3. IT/Telecom/Internet/Media, Silicon Technologies driving the scaling potential in the society

In that, the following 5 technologies are defining the 3C’s i.e. Computer, Communication, and Civilization

5G / MEC / Cloud Tech Base
Blending technologies of Communications and Computing in new ways is unleashing next generation Communication and Computational networks like **M**obile **E**dge **C**omputing

Machine Intelligence (MI)
Moving from cognitive MI toward augmented human intelligence in Radio NW planning and Performance monitoring and Optimisation has reached a level where past algorithms used have reached a limit and MI and ML based Dynamic algorithms and tools have become an imperative need due to massive scale of Network elements, devices and users in any geographic coverage.

NB-IoT
Internet of Things (IoT) getting connected is a revolutionary adoption in every walk of life, be it environmental sensors, Traffic sensors, Video Surveillance, Defence sector, Manufacturing, Automobiles, Railways, Electricity distribution Airline industry and Agriculture.

AI
AI for Analysis, computation, and decision making has become a compelling need in Telecom networks

AR/VR (Augmented Reality /Virtual Reality)
Immersive user experience to the physical world is rapidly becoming a huge adoption level.

4. Drivers & Prerequisites for 5G NR in India

Drivers
Aim for End user_Enhanced Mobile Broad Band (eMBB) Target Speeds from average of evolution from 4 Mbps to 10Mbps …100Mbps ….to 1Gbps and potential 100 M Subs to 500 M subs to 1B subscribers by 2025

Aspire for massive Machine Type Communications (IoT)
300M devices to 3 B devices…to 5B devices In India to be connected during 2019 to 2025 period

Evolve large scale Sensor centric Connected Smart Cities
50 …to 100…. to …..1500 Smart cities

Prerequisites for 5G NR NW Infrastructure Launch
Ubiquitous availability of OFC Tx NW with Tbps Bandwidth.
Scalable Cloud Architectures in place for Core NW with strong Cyber Security framework
Always available &reliable Energy Infrastructure and Attractive Right of Way (RoW) policies

5. Diverse User demands for services

Users
Anywhere 1Gbps service
Ultra-high definition mobile video experiences

Battery Consumption
Battery consumption capability where it survives 5-6 hours a day. Making GPU's, CPU's and audio processor in the devices need to go to sleep mode whenever it is not in use so that the battery power stays longer for phone use.

Latency
<1ms NW latency

NW Element level Capacity at the Point of Presence (PoP)
<10 Gb/s peak data rates and **100 Mb/s** whenever needed

Ultra-low cost for massive machine type communications

6. mmWave 5G Network level - 5 Attributes

Cell Site Perspective
Today 300 Mbps is the capacity on the 4G /cell and in the order of migration it has go from 300Mbps to 50Gbps per cell at the expectations of anytime, anywhere, anyone (human beings or IoT devices to anything connectivity needs for 5G at higher scale.

Performance Perspective
Ultra-High Capacity(x1000) more than current level at **1,000,000** user devices per km² with Massive Connectivity (IoT) (Peak Data Rate > 50Gbps/cell) 4A Connectivity (Anytime, Anywhere, Anyone, Anything)

Management Perspective
Energy-efficient infrastructure
TCO Reduction
Flexible Configuration /Mgmt.
Load /Resource Balancing)

Architecture Perspective
Flat Structure/High Scalability
S/W- based Flexibility & Agility (Ease of innovation)
Analytics- based NI/BI
Network as-a-Service (NaaS)-Operation Perspective
High Reliability & Security
Automatic Optimization & Recovery
E2E QoE Control

7. mmWave based 5G NR – KPI s

Area	Requirements
Cell Spectral Efficiency	DL:10 bit/Hz/Cell(@10/30 Km/h)
	UL: 5 bit/Hz/cell(@10/30 Km/h)
Peak Data Rate	DL: 50 Gbps
	UL : 25 Gbps
Cell Edge Data Rate	DL : 1 Gbps(@ 10/30 Km/h)
	UL : 0.5 Gbps (@ 10/30 Km/h)
Latency	Control Plane: 50 ms
	User Data Plane : 1ms
Handover Interruption Time	10 ms

Above Peak data rates or the KPIs will not be possible if we don't have mmWave Spectrum band and the wide RF channels

8. India -Telecom NW Infra - mm Wave Scaling

Today we have around 1.8 Million Route KM route of fiber connecting all the cell towers whether Intra city or Inter City

To make 5G as a reality in India this order of the magnitude has to increase 3X times of the existing fiber i.e. from 1.8 M to 3M to cover all the cell towers and Point of presence

We need this huge magnitude increase because we are now going into mmWave which has the lesser range and hence we need that many more cell sites as the points of presence

Need to move from 500K cell sites to 1.5Million cell sites when we move to 5G

Today we have 0.5M cell towers but we need at least 0.5M cell towers additional or the poles, since we cannot have many towers, we may plan to use the existing street poles or the electrical poles to put a 5G mmWave Radio to bring the 5G technology for ubiquitous coverage reality. In summary we will approximately need the following additional NW infrastructure for 5G NR.

2 M RKM urban Intracity Fiber NW
3 M RKM Intercity Fiber for 6000 Cities
Addl 1.5 Million BTS with 4G/5G capacity
Addl 0.5 Million Poles &Towers

9. Next generation 5G mobile experience varieties are indicated below

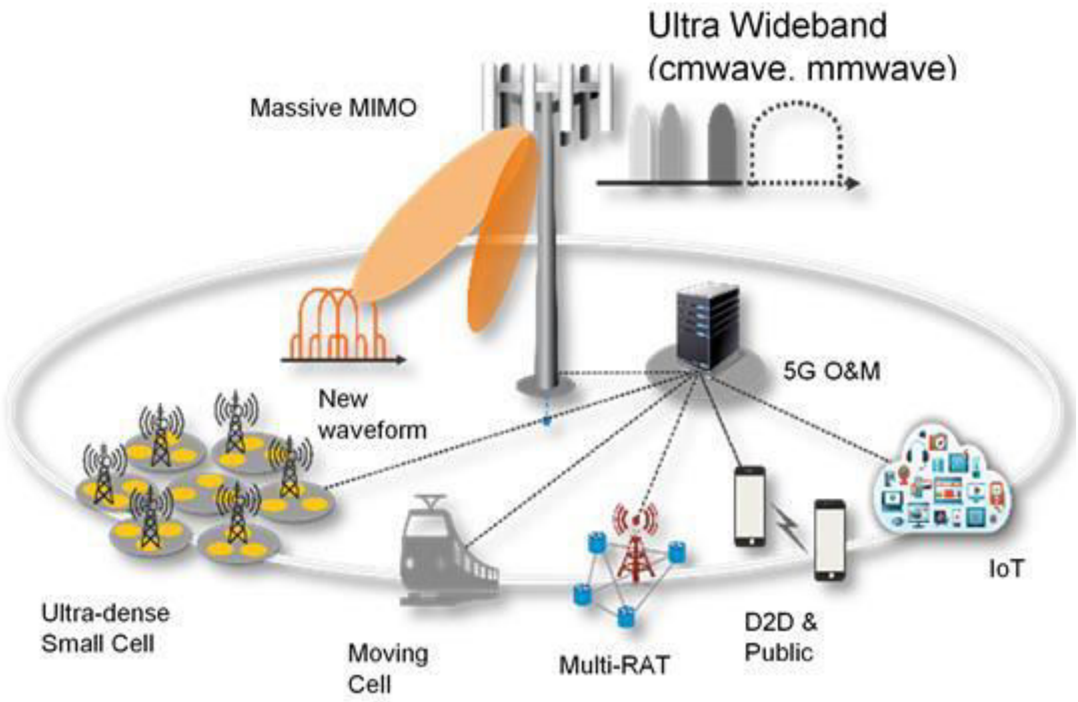
10. mmWave based 5G Applications.

Below listed Applications are driving 5G mmWave adoption need.

High speed mobility
Augmented Reality
Virtual Reality
Real-time remote-control cars
Sensors
Telepresence
Hologram Gaming

Till a few years ago the Content were getting generated by the Media and the Broadcasting houses. But in today's real life the content is getting generated by users and so the uplinking is also significantly higher compared to downlink data consumption because people want to update any events in the real time. All this content has to be backhauled and hence again this will be the big application for mmWave backhaul.

11. 5G mmWave NR Deployment Considerations



Higher Spectral Efficiency needs

Ultra-Wideband: While moving to mmWave, the RF channel bandwidth will move from 5MHz to 100MHz and upto n*100MHz and n*1 GHz facilitating high throughputs.

New Waveform will be adopted (NOMA, FBMC).

Massive MIMO, Full Duplex: From a Cell site to Handset, a MIMO of 8x8/64x64/256x256 Antenna array. facilitates Beamforming and Beam-tracking to guarantee required speeds with Radio resources. MIMO of higher degree will need higher spectrum which is provided through mmWave. 5G spectrum allocation with sub 6GHz (3.5-6GHz) will provide required coverage whereas in mmWave bands 28/39GHz will achieve capacity requirements.

Cell Densification

Ultra- dense Small Cell: mmWave Spectrum transmissions will not penetrate enough through concrete walls, and this requires small cell deployments for Ultra-Dense areas.

More Spectrum Bands and need for the following will arise like cm/mm Wave Transmission

Unlicensed Spectrum, D2D as Relay, Moving Cells will also be used.

Operational Efficiency based tools for NW Performance Monitoring (NPM)will be needed.

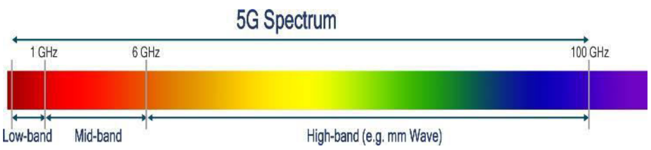
Advanced SON-Self Optimised Networks

Analytics based Control of Networks

IOT and Public Safety Networks

12. Key spectrum initiatives across the world for 5G:

Across low-band, mid-band, and high-band including mmWave FCC of USA considered the following



Low-band

- Successfully auctioned a portion of the 600 MHz band
- Spectrum availability timing aligns with 5G

Mid-band

- Opening up 150 MHz in 3.5 GHz band.
- CBRS Alliance launched to drive 5G like eco system
- 3.7-4.2 GHz and 5.9-7.1 GHz

High-band

- Opened with 11 GHz Bands leading in to mmWave bands
- 70% of newly opened spectrum is shared or unlicensed.
- Considering adding 24.25-24.45, 24.75-25.25 GHz, and 42-42.5 GHz

13. High-band: Spectrum for 5G mmWave with Ultra-Wide RF Channel widths can be seen below

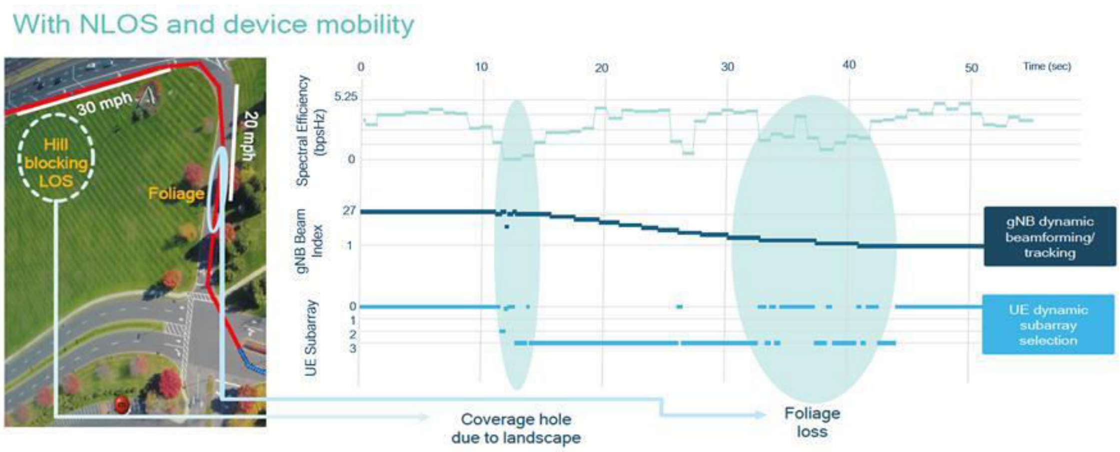
- 27.5to 28.35Ghz-850MHz@2x425 MHz of RF Channels)
- 37.6 to 38.6 GHz: 1 GHz @5x200 MHz)
- 38.6 to 40 GHz: 1.4 GHz @7x200 MHz)
- 37 – 37.6 GHz: 600 MHz @3x200 MHz)
- 64 - 71 GHz: 7 GHz @1Ghz

14. Global snapshot of 5G spectrum allocations Around the world, these bands have been allocated or targeted.

15. European Commission driving a Gigabit Society

Pioneer spectrum bands for 5G adoption in Europe are

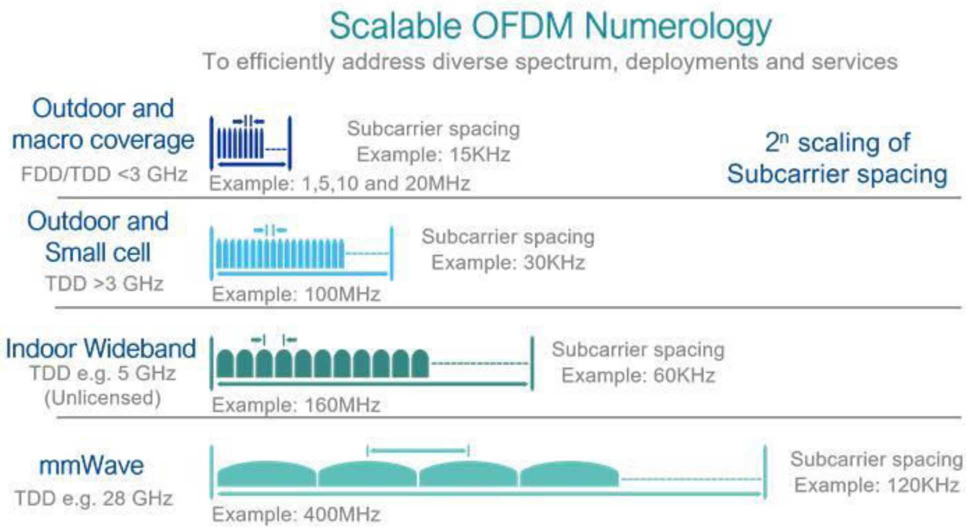
- CEPT - 26 GHz mm Wave band
- 5G commercial services to use both 3.4–3.8 GHz and 26 GHz mmWave in Europe by 2020
- Bands as per WRC-19 (e.g., 31.8 – 33.4 GHz, 40.5 – 43.5 GHz in addition to 24.25 – 27.5 GHz)



16. mmWave –NLOS-Device Mobility

Cellular Access network is always on a Non-Line of Sight (NLOS) where devices can transmit/receive data despite of foliage, constructions appearing between the transmissions. As 5G device is in mobility at 20-30 mph speed in mmWave mode of use due to landscape and foliage, spectral efficiency varies and throughput goes down, with inspite of dynamic Beamforming/Beam-tracking on UE.

17. 5G – mmWave – Numerology



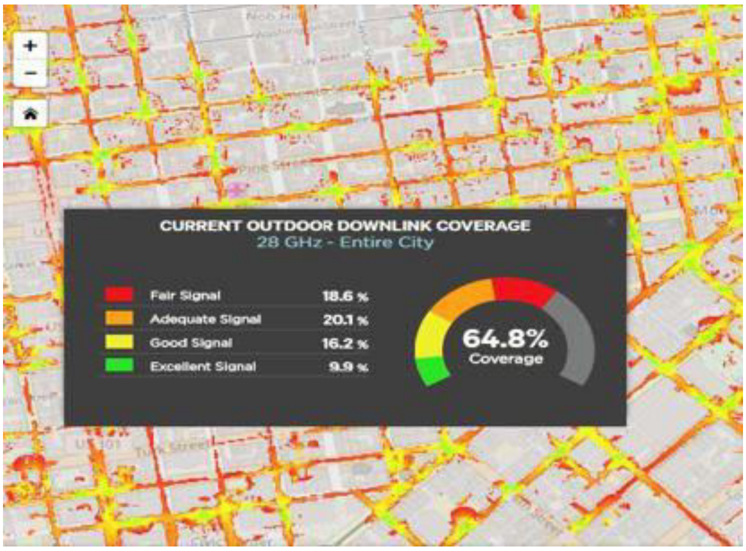
- RF Channel Width in OFDM Technology changes from 5MHz to 20MHz in 4G era
- RF Channel Width in OFDM Technology in 5G era varies from n*20 to n*100 to n*400MHz upto n*1 GHz
- Sub carrier spacing increases from 15KHz to 120KHz and Mbps era to Gbps Internet access era on mobiles.

18. Mobilising 5G mmWave in Real world environments

Car based 5G Devices, Small cell BTSs, Embedded Medical Devices, Robots, and Smart Phones deployed in mmWave trials for testing outdoor coverage as well as Indoor coverage applications are given below indicating seamless handover at speeds of 30 mph.

mmWave mode of RF propagation in 5G is fully dependent on adaptive Beamforming/Beam-tracking with upto 128 antenna elements on gNodeB and UE supporting 4 sub arrays.

19. 5G NR mmWave Network Coverage Simulation



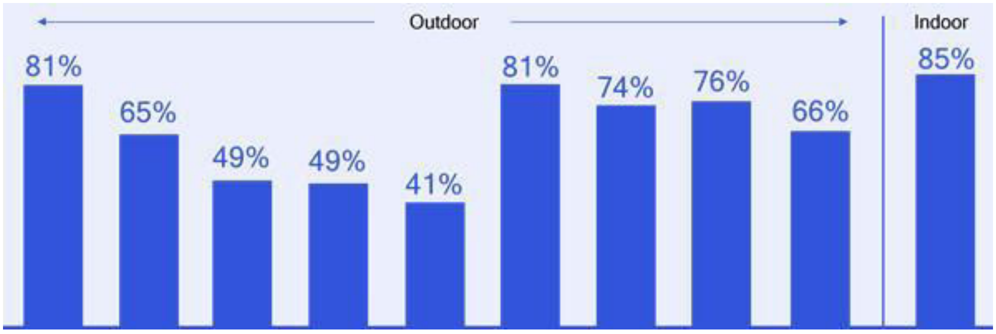
- Outdoor coverage simulated using existing LTE sites.
- Outdoor coverage complements indoor deployments.
- Below Table captures simulation results of DL coverage in mmWave coverage mode indicated.

Frequency	mm Wave 28GHz
Site Locations	Entire City
Total Area	9.77km2
Macro sites	77
Small cells	275
Site Density	36/km2
Excellent to Fair Signal	65 % Coverage

- Cell Site density per Sq.km is far higher in mmWave bands.

20. Significant 5G NR mmWave coverage via co-siting Simulations

Extensive over-the-air testing and channel measurements shown below for % of coverage with different cell density deployments in different cities is shown below.



US City 1 US City 2 US City 3 US City 4 EU City 1 Korea City 1 Korea City 2 Hong Kong Japan City 1 LVCC Venue

28 GHz downlink coverage % Co-siting with LTE

Site density (per km2)	Total	48	36	32	31	28	41	31	39	37	134
	Macro	0	8	15	14	7	33	31	39	37	
	Small	48	28	17	17	21	8	0	0	0	

21. Mm Wave – Pico Radio Deployments
3 distinct form factors of BTS sites shown for mmwave based 28 -39GHz for 5G NR

Pole Top Mounted Cylinder   Pole Wrap-Around Mounting   Flat Panel

Pole Top Mounted Cylinder: 12" tall x 14" OD cylindrical shape 5G BTS on pole tops Provide 360-degree coverage

Pole Wrap-Around Mounting: 12" H x 8" W x 4" D
Provide 120-degree coverage per 5G radio unit

Flat Panel :8" H x 8" W x 4" D Traditional Flat panel design. Provide 120-degree coverage per radio unit

mmWAVE Band
28-39GHZ FWA form factor Small cell BTSs

22. Conclusion
Inventions made by Sir JC Bose 100 years ago is becoming a reality now. This will transform next generation Wireless Access technologies for global citizen around the world. Upcoming interoperability testing at sub-6 GHz & mmWave will ensure future 5G deployments to be great success. OEMs like Nokia, Ericsson, Huawei, Samsung and ZTE etc. and Telcos like AT&T, China Mobile, Sprint, SK Telecom, Vodafone conducting trails in their Networks & laboratories promises 5G to be great success ***for pioneering invention based mmWave centric Gigabit era***

References

a) *Qualcomm 5G Technical literature.*
b) *Telco trial data simulations*
c) *QuadGen 5G Network element database*

About the authors

Former President and CEO of Lucent, India, Mr. Rao have had a distinguished career in telecommunications. In addition to holding executive positions with BT India, Intel India, Tellabs India, CDOT India and Reliance Communications India, Mr. Rao is the President of AUSPI India, Chairman of the WiMAX Forum India and former Chairman of ASSOCHAM - a premier national Chamber of Commerce India.

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Radio Astronomy: How J.C. Bose's invention opened a new window to the Universe

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Prologue: Sir J.C. Bose's work in radio microwave optics was specifically directed towards studying the nature of the phenomenon and was not an attempt to develop radio into a communication medium. His experiments took place during the same period (from late 1894 on) when Guglielmo Marconi was making breakthroughs on a radio system specifically designed for wireless telegraphy. In 1895, he demonstrated the generation & reception of radio waves in Kolkata, a good 2 years before the experiment by Marconi. It is thanks to this stellar breakthrough that we are able to probe the Universe in a unique manner using radio wavelengths.

1. Introduction to Radio Astronomy

Astronomy is one of the oldest sciences. It started from the time mankind turned its gaze upwards to try and understand the heavens. It began with use of naked eyes which are natural detectors for light waves, but evolved dramatically with the advent of the telescope. Galileo turned the recently invented optical telescope to the heavens and revolutionised astronomy forever (figure 1). Over the times since then, optical telescopes have evolved from the simple ones that Galileo used to the large, sophisticated facilities that modern day astronomers employ.

Figure 1: Galileo and the telescope, c.1609

There are two main factors that drive the need for larger telescopes. A bigger telescope is able to collect more light, hence can see fainter sources i.e., they are more sensitive and can see more objects in the Universe. Bigger telescopes also provide higher resolution – the ability to distinguish between nearby objects or sources in the sky. The sensitivity depends on the size of the aperture of the telescope (D) and is proportional to D^2. The resolution depends on the ratio of the wavelength of the radiation λ to the size of the aperture of the telescope, and is proportional to λ/D. Thus, a bigger telescope gives both higher sensitivity and better resolution.

Going beyond light waves : Light is a form of electromagnetic radiation and is part of a much wider spectrum of waves, ranging from the lowest frequency (largest wavelength) radio waves to the highest frequency (smallest wavelength) gamma rays, as shown in figure 2. The same object can emit, or be studied, at different wavelengths of the electromagnetic spectrum. Studying the same object in the Universe at different wavelengths can give different and complementary information about the object, and hence a more complete picture can be assembled. Figure 3 illustrates this with an example from studies of the Andromeda galaxy at different parts of the electromagnetic spectrum. However, there are some objects and phenomena can be studied ONLY at some specific wavelengths. Thus, multi-wavelength astronomical observations could greatly improve our understanding of the Universe.

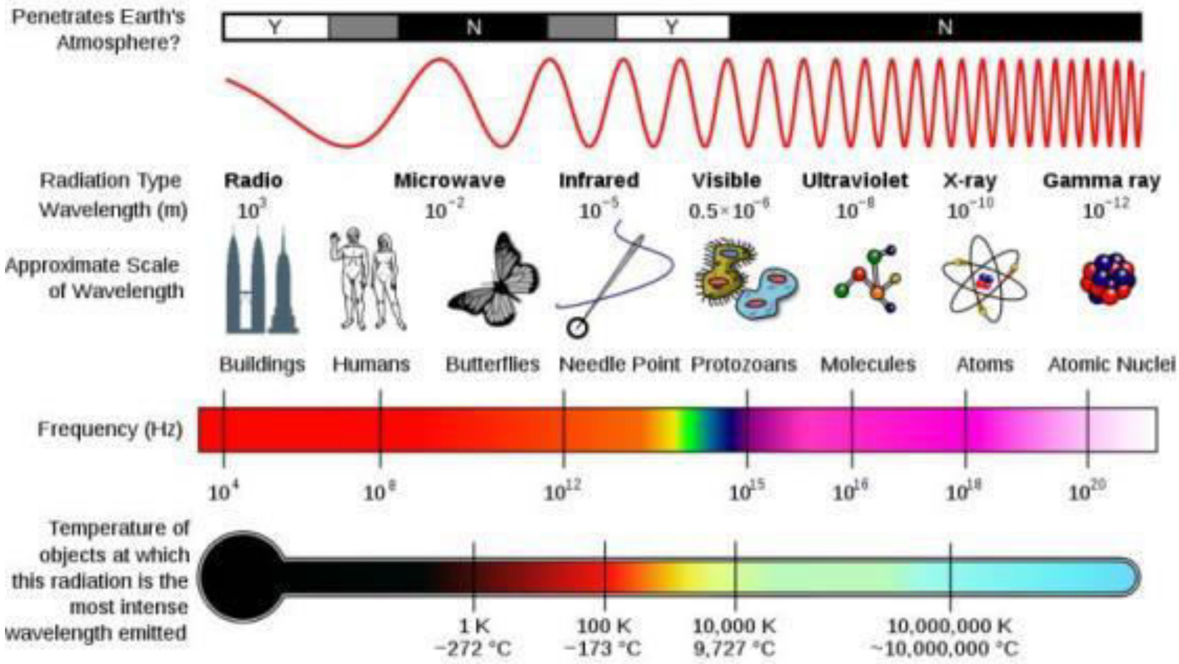

Figure 2: The Electromagnetic Spectrum

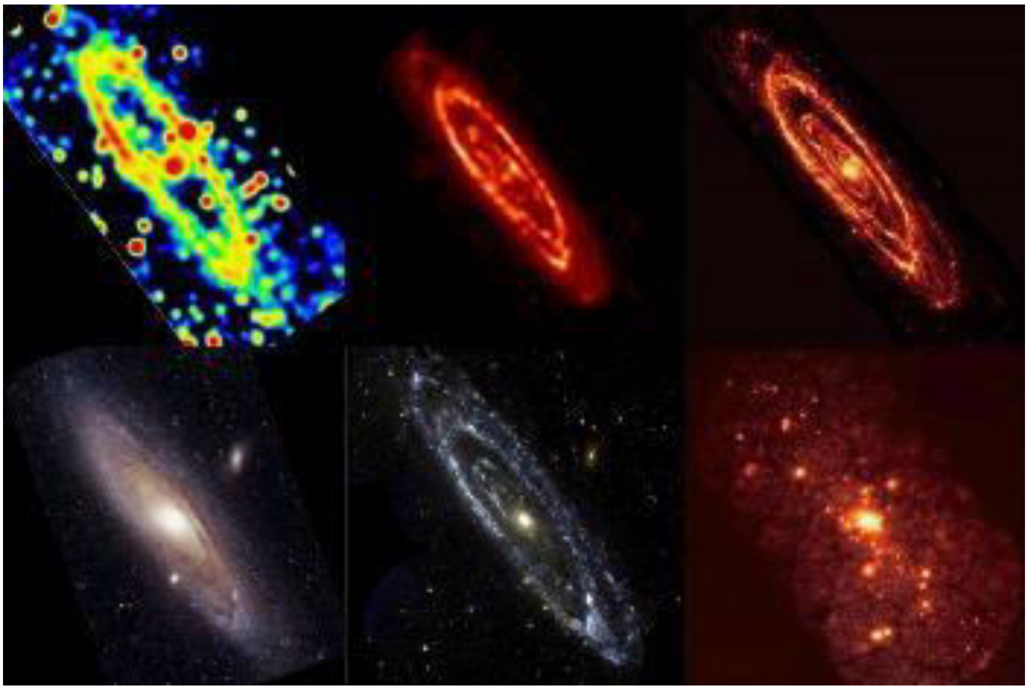

Figure 3: The Andromeda galaxy at different wavelengths – from Radio to Gamma-rays – showing different aspects of the galaxy becoming prominent at different wavelengths

However, there are some hurdles to overcome. First, we need to have the detectors for all the wavelengths. This has become possible over time with the development of technology e.g. photographic plates, charge-coupled devices, radio communication equipment. Second, not all the wavelengths from outer space reach us because of various effects in the Earth's atmosphere and ionosphere. As can be seen in figure 4, the two main Earth-based windows for astronomy turn out to be the optical window and a very wide portion of the radio window; for all the other wavelengths, we have to have space-based observing facilities. Hence it was natural that radio astronomy was the next branch to develop after optical astronomy.

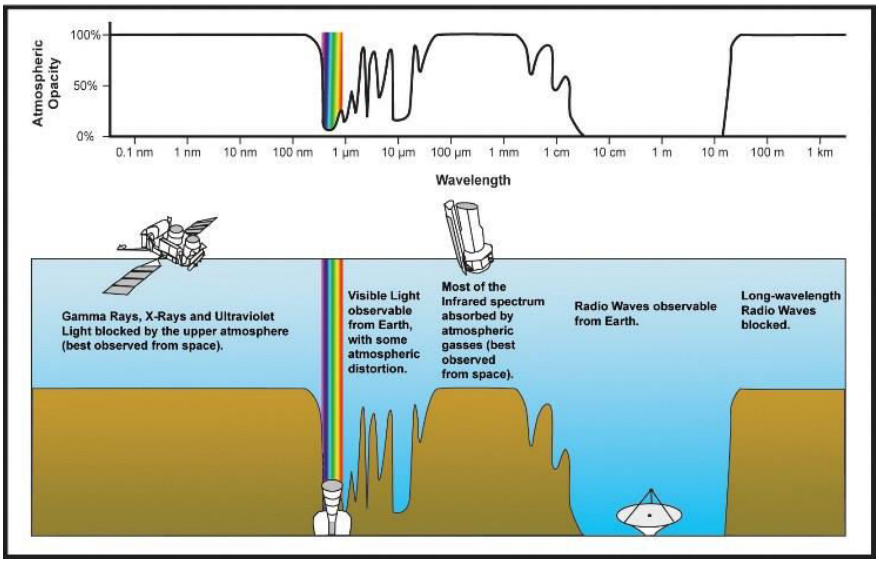

Figure 4: Multi-wavelength astronomy – Earth-based and space-based windows

2. Radio Astronomy basics

Genesis and early days : Detectors for radio astronomy came about during the1930s as an off-shoot of the developments in radio communications technology. As often happens in scientific discoveries (especially in astronomy), serendipity played a major role. Radio Astronomy has its origin in the Bell Labs, USA where, while debugging trans-atlantic communication systems to understand the cause of unwanted noise that was being picked up by the equipment, in 1931 Karl Jansky built an antenna designed to detect radio waves at a frequency of 20.5 MHz. It was mounted on a turntable that allowed it to be rotated in any direction (see figure 5). It had a diameter of 100 ft. and height of 20 ft. He was able to show that the source of noise in the communication system was not coming from any terrestrial source, but from a given direction in the sky -- from the Milky Way. With this breakthrough discovery, radio astronomy was born, and Karl Jansky is known as the father of radio astronomy.

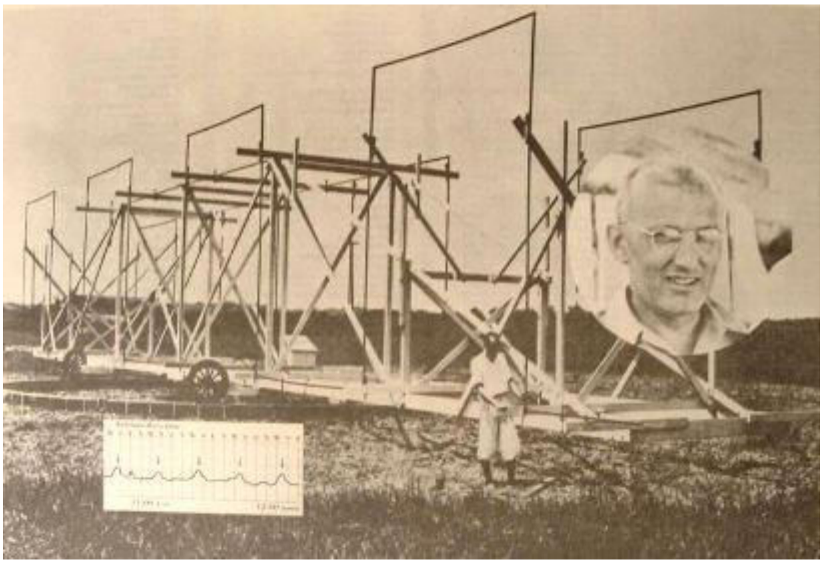

Figure 5: Karl Jansky and the first detection of radio waves from the Universe, in 1931

Basics of radio telescopes : A radio telescope antenna (figure 6) is basically like any satellite dish that we use for receiving television signals; but there is one major difference : celestial radio signals are *very* weak, so much so that we have a separate unit of flux to describe them : 1 Jy = 10^{-26} W/m^2/Hz. On this scale, the strongest celestial radio sources are about 1000 Jy, and today radio astronomy probes sources as weak as few micro Jy. Put another way, the typical input power to a radio telescope from celestial sources is ~ -100 dBm, meaning that it would take a few 100 years of continuous operation of the telescope to collect 1 milli Joule of energy. These signal levels are so weak that the typical instrumental noise levels from the receiver electronics can easily overwhelm them, making the detection of celestial sources a difficult task.

In order to overcome the above issues, radio astronomers do the following : use large antennas so as to collect as much signal as possible, use large bandwidth to increase the amount of signal (most celestial sources emit over a fairly large range of frequencies); build high quality low noise receivers to minimise the harmful effects of noise; and integrate the final signal over as long a duration of observation as possible, so as to further improve the signal to noise.

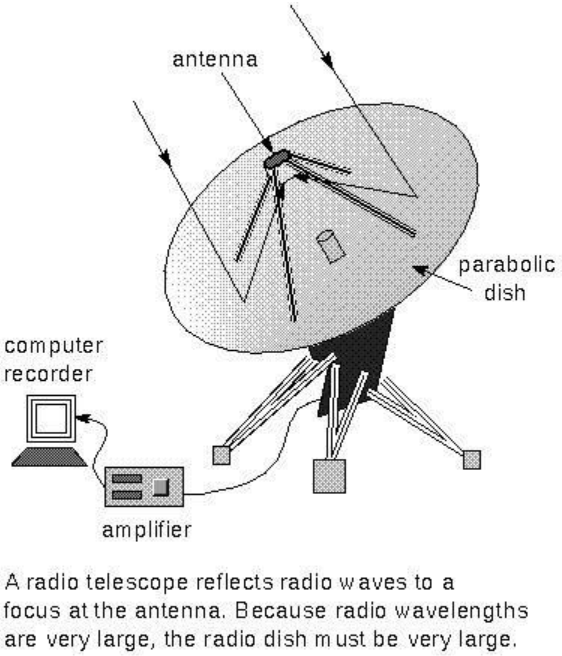

Figure 6: The basic radio telescope

<u>Single Dish vs Multi-dish Radio Telescopes :</u> From the arguments above, and our understanding that both resolution and sensitivity depend on the physical aperture size of the telescope, the goal has been to build larger and larger antennas for improved performance of the radio telescope. However, due to practical limits, fully steerable single dishes of more than about 100 m diameter are very difficult and expensive to build (see figure 7 for some examples). Now, for 100 m size radio telescope operating at a typical wavelength of 1 m (frequency of 300 MHz), the resolution (λ/D) is approximately 0.5 degree, which is very poor compared to the resolution achieved with the simplest optical telescopes !

To overcome this challenge, radio astronomers discovered the technique of aperture synthesis where, to synthesize a telescope of larger size, many individual dishes spread out over a large area on the Earth are used. Signals from such array telescopes are combined and processed in a particular fashion to generate a map of the source structure, with a resolution that is now give by λ / D_s , where D_s is the largest separation between the antennas in the array. This his allows radio telescopes to be competitive in resolution to telescopes at shorter wavelengths (like optical). Figure 8 shows some examples of some well known multi-dish aperture synthesis array radio telescopes, and figure 9 illustrates the improved resolution achieved by the use of such telescopes.



Figure 7 : the picture on the left is of the largest fully steerable single dish radio telescope in existence today – the 100-m Greenbank Telescope in USA; the other two are largest non-steerable (fixed) single dish radio telescopes : the 300-m Arecibo Radio Telescope (middle) in Puerto Rico, and the 500-m FAST observatory (right) in China

Figure 8 : the picture on the left is of the Very Large Array (VLA) radio telescope in the USA and that of the right is the Atacama Large Millimetre Array (ALMA) located in Chile.

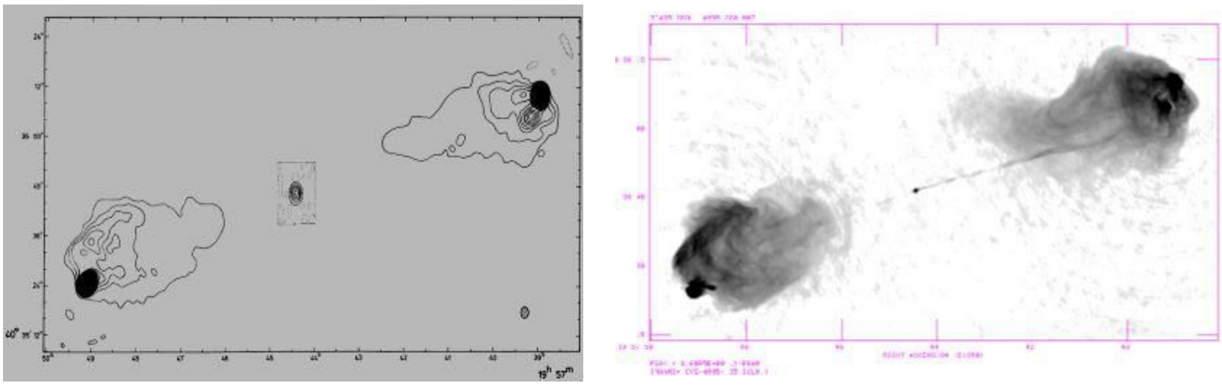

Figure 9 : Illustrating the improvement in resolution with the advent of aperture synthesis array telescopes. The image on the left is of the radio galaxy Cygnus-A made with a single dish antenna; the one on the right is an image of the same galaxy made with the Very Large Array (VLA) radio telescope in the USA.

3. Case study of a modern radio observatory : the GMRT

Introduction and basic paramters : The Giant Metre-wave Radio Telescope (GMRT) is a world class facility for studying astrophysical phenomena at low radio frequencies (50 - 1450 MHz). Completed in 1992 by the National Centre for Radio Astrophysics (NCRA), of the Tata Institute of Fundamental Research, it is an array telescope consisting of 30 antennas of 45 m diameter (see picture in figure 10), operating at metre wavelengths -- the largest in the world at these frequencies !

It is situated at a Latitude of 19 deg N and Longitude of 74 deg E, about 70 km N of Pune,   160 km E of Mumbai. Of the 30 antennas, 12 are located in a central compact array and the remaining 18 are spread out along 3 arms of Y-shaped array, going out to distances of 14 km from the centre (see figure 11). By appropriate combination of signals from all the 30 antennas, the resolution of a 28 km size antenna is achieved.

Figure 10 : A panoramic view of part of the GMRT array

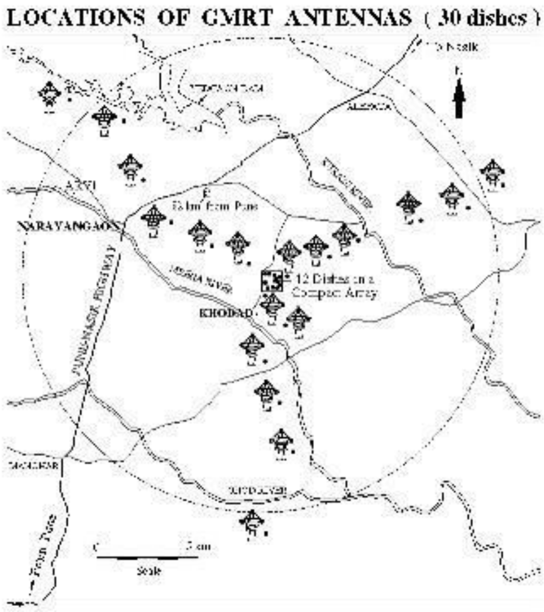

Figure 11 : Showing the layout of the GMRT array, centred near the village of Khodad and extending out to radial distances of a bit more than 14 km, along 3 arms arranged in a roughly Y-shaped configuration.

Many different sub-systems and technologies go into making an instrument like the GMRT, several of them requiring cutting-edge technologies to be developed and deployed :

1. *Mechanical sub-system*
2. *Servo sub-system*
3. *Antenna feeds (including positioning & control)*
4. *Receiver chain -- analog*
5. *Optical fibre sub-system*
6. *Receiver chain -- digital*
7. *Telemetry sub-system*
8. *"On-line" Control and Monitor sub-sytem*
9. *Off-line data processing chain(s)*

GMRT : Operations, Usage & Science : The GMRT observatory is open to international participation via a formal proposal system. Proposals are invited twice a year and reviewed by the GMRT Time Allocation Committee, and allocated time on the telescope. Observations are scheduled for 2 cycles of about 5 months each. The GMRT is typically oversubscribed by a factor of 2.5 i.e. the demand for observing time is more than the available time, and hence only the best proposals are allocated time. As shown in figure 12, The GMRT sees users from all over the world, with the distribution of Indian vs Foreign users being close to 50:50.

The GMRT is a powerful instrument to probe several astrophysical objects and phenomena, and the range of science possible with the facility is quite wide spread, covering topics such as:

1. The Sun, extrasolar planets
2. Pulsars : rapidly rotating neutron stars
3. Other Galactic objects like supernova remnants, microquasars etc
4. Other explosive events like Gamma Ray Bursts
5. Ionized and neutral Hydrogen gas clouds (in our Galaxy and in other galaxies)
6. Radio properties of different kinds of galaxies; galaxy clusters
7. Radio galaxies at large distances in the Universe
8. Cosmology and the Epoch of Reionization
9. All sky surveys such as the 150 MHz TIFR GMRT Sky Survey (TGSS)

Many interesting new results have been produced in the last 17 years or so that the GMRT has been functional. Today, more than 40 papers per year are published in international journals that use data and results from the GMRT.

Current Status & Future Prospects : The GMRT has just completed major upgrade that improves its sensitivity by a factor of up to 3 times, and also make it a much more versatile instrument. The upgraded GMRT provides near seamless frequency coverage from 120 to 1450 MHz at present (likely to be extended down to 50 MHz), with a maximum instantaneous bandwidth of 400 MHz (replacing 32 MHz of the legacy system), with improved sensitivity receivers. There are also accompanying improvements in the servo system, the monitor and control system and infrastructure facilities. These upgrades will keep the GMRT at the forefront on the global stage, as one of the most sensitive radio facility at metre wavelengths, for the next decade or so.

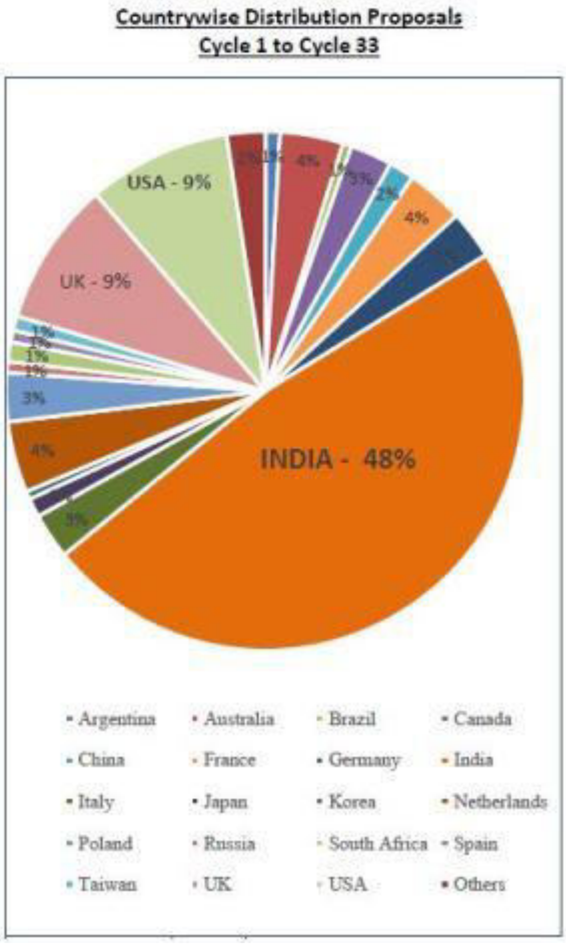

Figure 12: Proposal allocation pie-chart for the GMRT from cycles 1 to 33 (2003 to 2018), showing usage by scientists from several countries across the world, with a roughly 50% participation from Indian astronomers.

About the author

Prof. Yashwant Gupta presently heads the National Centre for Radio Astrophysics as the Centre Director. He obtained his M.S. and Ph.D. in Radio Astronomy from the University of California, San Diego in 1990, after completing his Bachelor's degree in Electrical Engineering from IIT Kanpur in 1985. In addition to research in the astrophysics of pulsars, Prof Gupta also has significant interest and involvement in instrumentation and signal processing applications in radio astronomy. He has led the recent major upgrade of the GMRT, and is also involved in the technical developments at the SKA, in addition to being the Science Director from India on the SKA Board.

To commemorate JCBose's birth centenary in 1958, the JBNSTS scholarship programme was started in West Bengal. In the same year, India issued a postage stamp bearing his portrait.

On 14 September 2012, Bose's experimental work in millimetre-band radio was recognised as an IEEE Milestone in Electrical and Computer Engineering, the first such recognition of a discovery in India

The Bank Of England has decided to redesign the 50 UK Pound currency note with an eminent scientist. Indian scientist Sir Jagadish Chandra Bose has been featured in that nomination list for his pioneering work on Wifi technology

Design and Construction of Working Replica of Sir J.C Bose 60 GHz Experiment

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1. INTRODUCTION

Sir Jagadish Chandra Bose one of the pioneered of Radio Physics, demonstrated in Calcutta, India, the generation, transmission and reception of electromagnetic waves in 1895. So Jagadish Chandra Bose first demonstrated in Presidency College, Calcutta, India, transmission and reception of electromagnetic waves at 60 GHz, over 23 meters distance, through two intervening walls by remotely ringing a bell and detonating some gunpowder. For his communication system, Sir J.C Bose pioneered in development of entire millimeter-wave components like a spark transmitter, coherer, dielectric lens, polarizer, horn antenna, and cylindrical diffraction grating. This is the first millimeter-wave communication system in the world, developed more than 100 years ago. This is the oldest Milestone achievement from the Asian continent.

Bose chose quasi-optical, millimeter-wave frequency range. The wavelengths he used ranged from 2.5 cm to 5 mm. The reason for the choice of millimeter wave by Sir J.C. Bose was primarily due to the advantage of studies of quasi-optical properties of the radio waves within his laboratory of limited size that was available to him at the Presidency College [1]. However, the components and systems developed by Sir J.C. Bose, initially at millimeter wave and subsequently at microwave, were outstanding discoveries made more than 100 years ago, in Calcutta, India, most of which are now being used, in a modernized form for Earth/space links and remote sensing and 5G communication

Sir J. C. Bose invented the Mercury Coherer (together with the telephone receiver) used by Marconi to receive the radio signal in his first transatlantic radio communication over a distance of 2000 miles from Poldhu, UK to New found land, St. Johns in December 1901. In 1895, Sir J. C. Bose gave his first public demonstration of electromagnetic waves, using them to ring a bell remotely and to explode some gunpowder. He sent an electromagnetic wave across 75 feet passing through walls and body of the Chairman, Lieutenant Governor of Bengal. Sir J. C. Bose holds the first patent worldwide to invent a solid-state diode detector to detect EM waves. The detector was built using a galena crystal. Sir J. C. Bose was a pioneer in the field of microwave devices. His contribution remains distinguished in the field and was acknowledged by the likes of Lord Kelvin, Lord Rayleigh [2-3].

The institute of Electrical and electronics Engineering (IEEE) a professional body with members from 160 countries, wants to pay the homage to Sir J.C. Bose. In 1986 IEEE forum has recognized Sir J.C Bose mm wave experiment as a millstone experiment. In November 2012 IEEE approached Muffakham Jah College of engineering and technology (MJCET) for making the first working model of Sir J.C Bose mm wave experiment to be installed at B.M Birla science museum at Hyderabad. In this paper we present the detail construction, design and working of Sir J.C Bose mm wave experiment working Replica designed by Muffakham Jah College of engineering and technology.

2. DESIGN AND CONSTRUCTION OF WORKING REPLICA

Bose's experiments were carried out at Presidency College, although for demonstrations he developed a compact portable version of the equipment, including transmitter, receiver, and various microwave components. Some of his original equipment still exists, currently at the Bose Institute. Figure 1. Shows the sir J.C Bose original mm wave setup and MJCET designed working replica. The working replica was planned, designed and executed in the physic lab, MJCET. The detail construction and working of replica as follows.

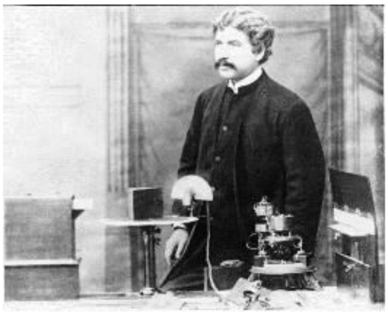

Figure 1. MJCET designed working Replica and Original J.C Bose apparatus

2.1 The Radiator

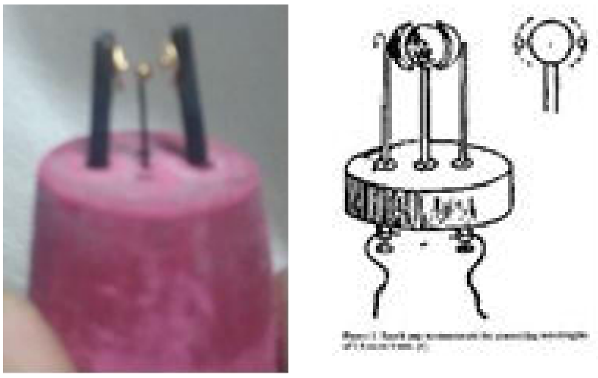

Figure 2. Sparking element of the Replica and Original Sparking element

In the working Replica the radiator consists of sparking element consist of DC power supply of 12V, 6Amps is connected across the primary of the coil, magnetic disturbances are created by applying the key which results in emission of flash of radiations form the secondary coil. The sparking elements consist of two gold spherical beads of 0.5mm diameter and one interposed sphere situated at the center of the tow beads of 1.5mm diameter. Figure 2 shows the sir. J. C Bose sparking element and MJCET designed sparking element. The working of the sparking element as follows.

- The wires of the primary coil are in connection with a small storage cell through a tapping key. The coil, a small storage cell and the key are enclosed in a tinned iron box which screens the space external from magnetic disturbances.
- Each time the key is pressed, the primary circuit of induction coil is made or broken and magnetic disturbance is produced. Therefore, pressing and releasing of key ensures flash of radiations. In front of the box the radiator tube (square). The radiating apparatus has a square tube of 1 sq. inch. cross section.

2.2 Spiral Spring receiver

Single layer of steel springs of 2 mm diameter and 1 cm length are placed in square piece of Ebonite with a shallow rectangular depression (Sensitive surface = 1cm x2 cm). Glass slide is used to prevent springs falling out. Springs are compressed by brass piece which slides in and out using screw therefore the resistance can be varied. When radiation is generated by sensitive contacts, there is sudden decrease in resistance and galvanometer was deflected. It responds (sensitive) to different types of radiations by varying the electromotive force which give rise to current that reaches recei ver and galvanometer shows deflection. Figure 3 shows the design of spiral spring receiver of Sir J.C Bose and working replica.

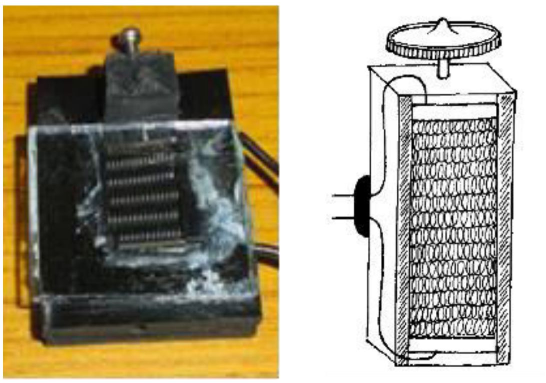

Figure 3 Spiral spring receiver of working replica and Original Sir J.C Bose receiver

2.3 Determination of Wavelength of and Cylindrical Grating

The grating made of equidistant metallic strips, which are vertical and parallel. The diameter of the cylindrical grating is 100 cm. A piece of thin sheet ebonite is bent in the shape of a portion of a cylinder and kept in that shape by screwing against upper and lower circular guide pieces of wood. Against the concave side of the ebonite are stuck strips of rather thick tinfoil at equal intervals. Figure 4 shows the design of cylindrical grating of working Replica.

The diffracted waves follow the equation. *(a+b) sin θ = n λ*
Where, (a+b) is sum of breadths of strip and space in the grating. (6mm)

θ is angle of diffraction

n is order of diffraction

λ is wavelength

 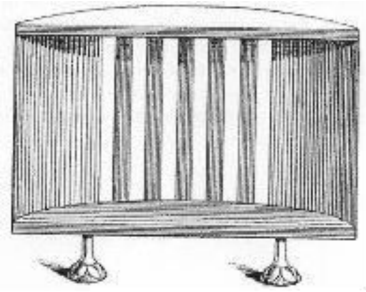

Figure 4 Design of Original cylindrical grating and working Replica

The measurement of the frequency of mm waves produced by our experimental setup has been recorded with spectrum analyzer at Research Center Imarat DRDO. Hyderabad and frequency of the replica was around 60 GHz. This frequency is similar to the frequency generated by Sir J.C Bose in his experiment. This is an achievement for the developers of the replica to attain same frequency as the original. Figure 5 shows the recording frequency spectra of working replica produced by RCI.

Figure 5 Photograph of 60GHz frequency generated by working replica

3. QUALITY TEST

The quality test of receiver was conducted at physics laboratory MJCET. The experiment repeated by pressing radiator key 50 times. For each time key press, the galvanometer reading was recorded. The report of quality test is given in figure 6 and it was found that Replica receiver absorbs radiation. It also gives the variation of signal changes recorded galvanometer which is in the range of 10 units to 30 units.

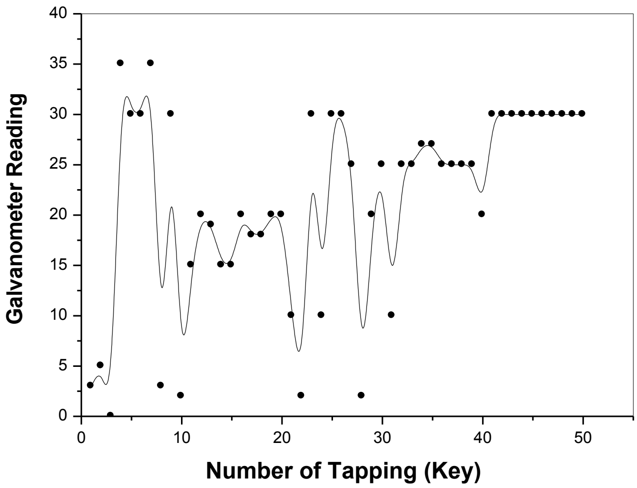

Figure 6 Variation of Galvanometer deflections with number of tapping

4. CONCLUSION

The following conclusion were drawn from the present experiment

- MJCET successfully designed and demonstrated working replica of Sir J.C Bose 60 GHz mm wave experiment
- The sparking elements consists of two spherical beads of 0.5mm diameter and one interposed sphere situated at the center of the tow beads pf 1.5mm diameter
- The spiral spring receiver designed with Single layer of steel springs 2 mm diameter and 1 cm length placed in square piece of Ebonite with a shallow rectangular depression (Sensitive surface = 1cm x2 cm). The quality test confirms the accurate signal detection of spiral spring receiver.
- The frequency of the Replica was measured and it is around 60 GHz. This frequency is similar to what Sir J.C Bose had generated in his experiment. This is an achievement for the developers of the replica to attain same frequency as the original.

5. ACKNOWLEDGEMENT

MJCET would like to thank IEEE, India for providing financial support of this project. MJCET also thank *Sri. Gopala Krishna Kuppa*, Chair, India Work Group on 1451-99 standards for valuable inputs which were incorporated to improve performance and give accurate signal detection. We wish to thank *Dr. Janhagirdar*, RCI, Hyderabad for providing spectrum analyzer for signal measurement. The authors also like to thank *Dr. Basheer Ahmed*, Advisor cum Director MJCET for encouragement and support.

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Sir Jagadish Chandra Bose
Biologist, Biophysicist, Botanist, Physicist, Archaeologist and Polymath

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Sir Jagadish Chandra Bose was a Biologist, Biophysicist, Botanist, Physicist, Archaeologist and polymath. He has pioneered the investigation of radio and microwave optics, made significant contributions to plant science, and laid the foundations of experimental science in the Indian subcontinent. IEEE named him one of the fathers of radio science.

Jagadish was born in Munshiganj (Bikrampur), present day in Bangladesh on 30th November 1858. His father, Bhagawan Chandra worked as a deputy magistrate and assistant commissioner in Faridpur, Bardhaman and other places. He was a leading member of the Brahmo Samaj. He was a firm believer in learning and knowing one's mother tongue prior to any foreign language and therefore Bose's early education started in a vernacular school. Jagdish's education started in same school.

Bose joined the Hare School in 1869 and then St. Xavier's School at Kolkata. In 1875, he passed the Entrance Examination (equivalent to school graduation) of the University of Calcutta and was admitted to St. Xavier's College, Calcutta. At St. Xavier's, Bose came in contact with Jesuit Father Eugene Lafont, who played a significant role in developing his interest in natural sciences. He received a BA from the University of Calcutta in 1879.

Bose wanted to go to England to compete for the Indian Civil Service. However, his father, a civil servant himself, canceled the plan. He wished his son to be a scholar, who would "rule nobody but himself." Bose went to England to study Medicine at the University of London. However, he had to quit because of ill health. The odour in the dissection rooms is also said to have exacerbated his illness.

Then Jagdish secured admission in Christ's College, Cambridge to study natural sciences. He received a BA (Natural Sciences Tripos) from the University of Cambridge and a BSc from the University of London in 1884, and a DSc from the University of London in 1896. Among Bose's teachers at Cambridge were Lord Rayleigh, Michael Foster, James Dewar, Francis Darwin, Francis Balfour, and Sidney Vines.

Bose returned to India in 1885, carrying a letter from Fawcett, the economist, to Lord Ripon, Viceroy of India. On Lord Ripon's request, Sir Alfred Croft, the Director of Public Instruction, appointed Bose officiating professor of physics in Presidency College. The principal, C.H. Tawney, protested against the appointment but had to accept it. The British still believed that Indians were gifted in sciences but lacked the capability to deal with exact sciences.

Bose was not provided with any facilities for research. On the other hand, he was a "victim of racialism" with regard to his salary. In those days, an Indian professor was paid Rs. 200 per month, while a European drew Rs. 300 per month. Since Bose was officiating, he was offered a salary of only Rs. 100 per month. With a remarkable sense of self-respect and national pride, he decided on a new form of protest. He refused to accept the salary check. In fact, he continued his teaching assignment for three years without any salary. Finally, both the Director of Public Instruction and the Principal of the Presidency College fully realized the value of Bose's skill in teaching and also his lofty character. As a result, his appointment was made permanent with retrospective effect. He was given the full salary for the previous three years in lump sum. Very soon Bose became popular professor among students and Simultaneously he started research on electromagnetic waves.

During the decade1960s; Scottish scientist James Clerk Maxwell had published his landmark paper, `A Dynamical Theory of the Electromagnetic Field', in which Maxwell's equations demonstrated that electric and magnetic forces are two complementary aspects of electromagnetism. He shows that the associated complementary electric and magnetic fields of electromagnetism travel through space, in the form of waves, at a constant velocity of light. He also proposes that light is a form of electromagnetic radiation and that waves of oscillating electric and magnetic fields travel through empty space at a speed that could be predicted from simple electrical experiments.

After Maxwell, German physicist Heinrich Hertz published the results of his experiments on electromagnetism and shown the existence of electromagnetic waves in free space in 1890s. Subsequently, British physicist Oliver Lodge, who had demonstrated their similarity to light and vision including reflection and transmission. Hertz and post-Hertzian experiments used wavelength in cm. and short cm. wave region. in August 1894 (after Hertz's death) Lodge's work was published in book, `The work of Hertz and his successors', caught the attention of scientists in different countries, including Bose in India.

To conduct research on electromagnetism, Bose had converted a small enclosure of 24 square foot space, adjoining a bathroom in the Presidency College into a laboratory. He invented generator, transmitter and receiver for microwave region of electromagnetic spectrum there. He devised equipment’s for the research with the help of one untrained roadside tinsmith.

Bose made public demonstration of his invention at Town Hall of Kolkata, in November 1895. Bose ignited gunpowder and rang a bell at a distance using radio waves. Lieutenant Governor Sir William Mackenzie witnessed Bose's demonstration.

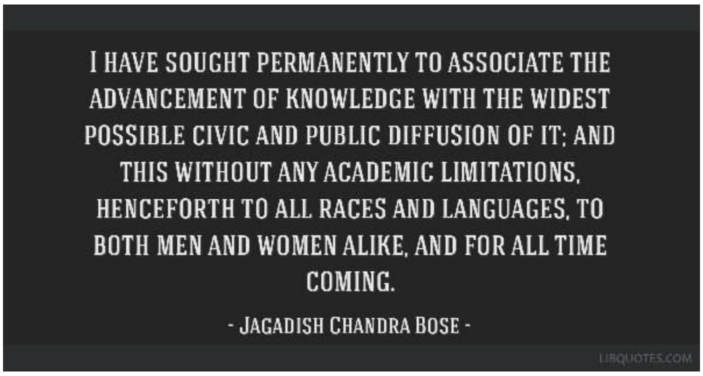
The spark gap transmitter used a spark gap radiator made of three tiny 3 mm metal balls excited by high voltage from an induction coil to generate microwaves at 60 GHz. The transmitter was enclosed inside the metal box to prevent sparks from the coil's interrupter from disturbing the action of the receiver, and the microwaves emanated from the waveguide i.e. metal tube. The receiver point contact detector was placed inside a waveguide receiving antenna, very much like the transmitting antenna with a matching polarizing grid.

Bose had also carried out experiments to study refraction, diffraction and polarization for same electromagnetic waves. Bose also developed spiral-spring detector and coherer. He publishes scientific papers on his research in 1995 and communicated to the Royal Society of London. Bose was invited by Royal Institution to give the prestigious Friday evening discourse on 29th January 1897. There he openly displayed the construction and workings of his microwave apparatus.

Sir J C Bose’s work is commemorated by IEEE, as the oldest milestone achievement from Asia.

About the author

Mr. Sudhir Phakatkar is working in GMRT, TIFR as an Electronics Technician for 29 years. He is also serving on the committee of Khodad Rural Science Center. He is very active in science popularization among in students and laymen. As a part of it, he wrote two books in Marathi, namely - Radio Durbin and Vidnyanyatri Dr. Govind Swarup. Mr. Phakatkar wrote a column in the Sunday supplement of a Marathi newspaper on research organizations of India as well as several articles on scientific subjects for Marathi Science Magazines. Three more books by him are in the production.



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