THE WORK OF JAGADIS CHANDRA BOSE: 100 YEARS OF MM-WAVE RESEARCH

D.T. Emerson
National Radio Astronomy Observatory[1]
949 N. Cherry Avenue
Tucson, Arizona 85721

ABSTRACT

Just one hundred years ago, J.C. Bose described to the Royal Institution in London his research carried out in Calcutta at millimeter wavelengths. He used waveguides, horn antennas, dielectric lenses, various polarizers and even semiconductors at frequencies as high as 60 GHz. Some concepts from his original 1897 papers have been incorporated into a new 1.3-mm multi-beam receiver now in use on the NRAO 12 Meter Telescope.

INTRODUCTION

James Clerk Maxwell's equations predicting the existence of electromagnetic radiation propagating at the speed of light were made public in 1865; in 1888 Hertz had demonstrated generation of electromagnetic waves, and that their properties were similar to those of light [1]. Before the start of the twentieth century, many of the concepts now familiar in microwaves had been developed [2,3]: the list includes the cylindrical parabolic reflector, dielectric lens, microwave absorbers, the cavity radiator, the radiating iris and the pyramidal electromagnetic horn. Round, square and rectangular waveguides were used, with experimental development anticipating by several years Rayleigh's 1896 theoretical solution [4] for waveguide modes. Many microwave components in use were quasi-optical - a term first introduced by Oliver Lodge. Righi in 1897 published a treatise on microwave optics [5].

Hertz had used a wavelength of 66 cm; other post-Hertzian pre-1900 experimenters used wavelengths well into the short cm-wave region, with Bose in Calcutta [6,7] and Lebedew in Moscow [8] independently performing experiments at wavelengths as short as 5 and 6 mm.

THE RESEARCHES OF J.C. BOSE

Jagadis Chandra Bose [9,10,11] was born in India in 1858. He received his education first in India, until in 1880 he went to England to study medicine at the University of London. Within a year he moved to Cambridge to take up a scholarship to study Natural Science at Christ's College Cambridge. One of his lecturers at Cambridge was Professor Rayleigh, who clearly had a profound influence on his later work. In 1884 Bose was awarded a B.A. from Cambridge, but also a B.Sc. from London University.
Bose then returned to India, taking up a post initially as officiating professor of physics at the Presidency College in Calcutta. Following the example of Lord Rayleigh, Jagadis Bose made extensive use of scientific demonstrations in class; he is reported as being extraordinarily popular and effective as a teacher. Many of his students at the Presidency College were destined to become famous in their own right - for example S.N. Bose, later to become well known for the Bose-Einstein statistics.

A book by Sir Oliver Lodge, "Heinrich Hertz

---

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

0-7803-4603-6/97/$5.00 (c) IEEE

and His Successors,” impressed Bose. In 1894, J.C. Bose converted a small enclosure adjoining a bathroom in the Presidency College into a laboratory. He carried out experiments involving refraction, diffraction and polarization. To receive the radiation, he used a variety of different junctions. The detectors were connected to a galvanometer capable of detecting 10^{-9} amps. He plotted in detail the voltage-current characteristics of his junctions, noting their non-linear characteristics. He developed the use of galena crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light. Patent rights for their use in detecting electromagnetic radiation were granted to him in 1904. In 1954 Pearson and Brattain [13] gave priority to Bose for the use of a semi-conducting crystal as a detector of radio waves. Sir Neville Mott, Nobel Laureate in 1977 for his own contributions to solid-state electronics, remarked [11] that “J.C. Bose was at least 60 years ahead of his time” and “In fact, he had anticipated the existence of P-type and N-type semiconductors.”

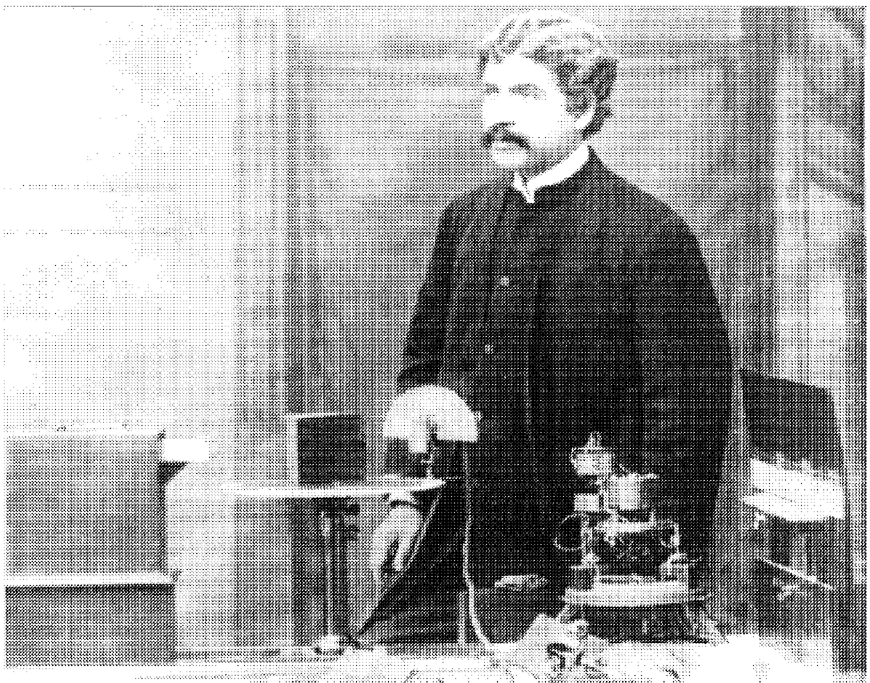
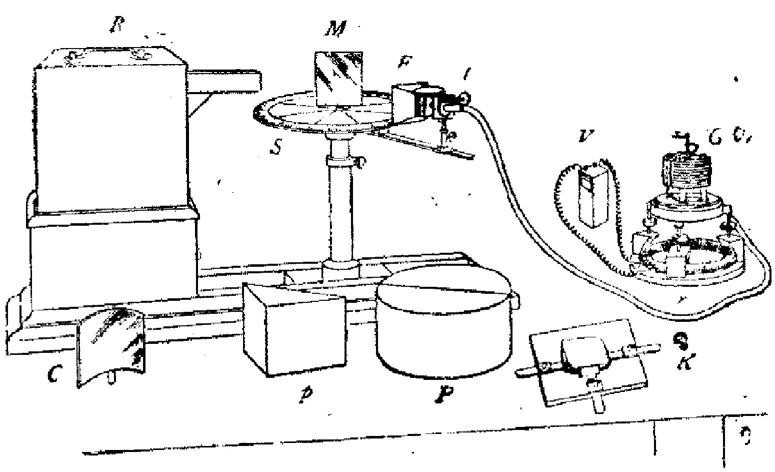


Figure 1: J.C. Bose at the Royal Institution, London, 1897. [12]



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

Figure 2: Bose’s apparatus demonstrated to the Royal Institution in London in 1897 [7]. Note the waveguide radiator on the transmitter at left, and that the “collecting funnel” (F) is in fact a pyramidal electromagnetic horn antenna, first developed by Bose.

In 1895 Bose gave his first public demonstration of electromagnetic waves, using them to ring a bell remotely and to explode some gunpowder. In 1896 the Daily Chronicle of England reported: “The inventor (J.C. Bose) has transmitted signals to a distance of nearly a mile and herein lies the first and obvious and exceedingly valuable application of this new theoretical marvel.” Popov in Russia was doing similar experiments, but had written in December 1895 that he was still entertaining the hope of remote signalling with radio waves. The first successful wireless signalling experiment by Marconi, on Salisbury Plain in England, was not until May 1897. The 1895 public demonstration by Bose in Calcutta predates all these experiments. Invited by Lord Rayleigh, in 1897 Bose reported on his microwave (millimeter-wave) experiments to the Royal Institution and other societies in England [7]. The wavelengths he used ranged from 2.5 cm to 5 mm. Figure 1 shows J.C. Bose at the Royal Institution in London in 1897; Figure 2 shows a matching diagram from one of his own papers, with a brief description of the apparatus.

By about the end of the 19th century, the interests of Bose turned away from electromagnetic waves to response phenomena in plants. He retired from the Presidency College in 1915, but was appointed Professor Emeritus. Two years later the Bose Institute was founded. He was elected a Fellow of the Royal Society in 1920. He died in 1937, a week before his 80th birthday. His ashes are in a shrine at the Bose Institute in Calcutta.

THE DOUBLE-PRISM ATTENUATOR

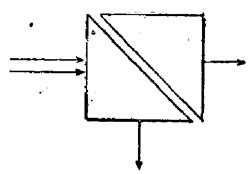


Figure 3: Bose's 1897 diagram of the prism attenuator [7].

Bose's investigations included measurement of refractive index of a variety of substances. He made dielectric lenses and prisms; examples are visible in Figures 1 and 2.

One investigation involved measurement of total internal reflection inside a dielectric prism, and the effect of a small air gap between two identical prisms; when the prisms are widely separated, total internal reflection takes place and the incident radiation is reflected inside the dielectric. When the 2 prisms touch, radiation propagates unhindered through both prisms. By introducing a small air gap, the combination becomes a variable attenuator to incident radiation. Bose investigated this prism attenuator experimentally; his results were published in the Proceedings of the Royal Society in November, 1897. Schaefer and Gross [14] made a theoretical study of the prism combination in 1910, referring to the invention and experimental work by Bose. The device has since been described in standard texts.

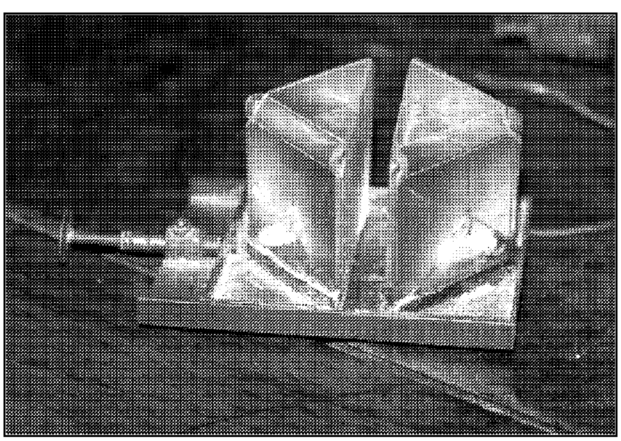


Figure 4: Bose's prism attenuator, with adjustable air gap, photographed at the Bose Institute in Calcutta in 1985.

At the National Radio Astronomy Observatory in Tucson, Arizona a new multiple-feed receiver, operating at a wavelength of 1.3 mm, has recently

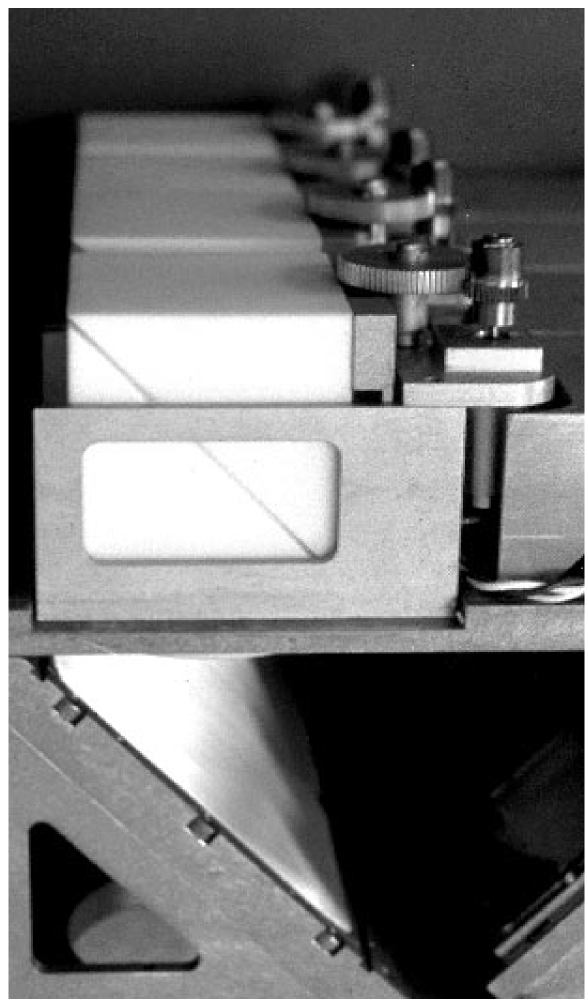


Figure 5: Four of the 8 prism attenuators used to control local oscillator injection into the NRAO 1.3-mm 8-beam receiver in use at the 12 Meter Telescope at Kitt Peak.

0-7803-4603-6/97/$5.00 (c) IEEE

been built and installed on the 12 Meter Telescope at Kitt Peak [15]. The system is an 8-feed receiver, where the local oscillator is injected into the SIS mixers optically. With an SIS mixer receiver the power level of the injected local oscillator is critical; each of the 8 mixers requires independent local oscillator power adjustment. This is achieved by adjustable prism attenuators. Figure 5 shows 4 of these 8 prism attenuators, installed on one side of the 8-feed system; this can be compared with Figure 4, which is a photograph taken at the Bose Institute in Calcutta in 1985, of an original prism system built by Bose.

CONCLUSIONS

Research into the generation and detection of millimeter waves, and the properties of substances at these wavelengths, was being undertaken in some detail one hundred years ago, by J.C. Bose in Calcutta and also by Lebedew in Moscow. Many of the microwave components familiar today - waveguide, horn antennas, polarizers, dielectric lenses and prisms, and even semiconductor detectors of electromagnetic radiation - were invented and used in the last decade of the nineteenth century. At about the end of the nineteenth century, many of the workers in this area simply became interested in other topics. Attention of the wireless experimenters of the time became focused on much longer wavelengths which eventually, with the help of the then unknown ionosphere, were able to support signalling at very much greater distances.

Although it appears that Bose's demonstration of remote wireless signalling has priority over Marconi, he was the first to use a semiconductor junction to detect radio waves, and he invented various now commonplace microwave components, outside of India he is rarely given the deserved recognition. Further work at millimeter wavelengths was almost nonexistent for nearly 50 years. J.C. Bose was at least this much ahead of his time.

ACKNOWLEDGEMENTS

I wish to thank the Bose Institute in Calcutta for help with material, and for permission in 1985 to photograph some of the original equipment of J.C. Bose, including the prism shown in Figure 4.

REFERENCES

[1] H. Hertz, "Electric Waves," Macmillan and Co. Ltd., London, 1893. (Reprinted by Dover.)
[2] John F. Ramsay, "Microwave Antenna and Waveguide Techniques before 1900," Proc.IRE., February 1958, pp.405-415.
[3] K.L. Smith,"Victorian Microwaves," Wireless World, September 1979, pp.93-95.
[4] Lord Rayleigh, "On the passage of electric waves through tubes, or the vibrations of dielectric cylinders," Phil.Mag., Vol.43, pp.125-132, Feb.1897.
[5] A. Righi, "L'Ottica delle Oscillazioni Elettriche," N. Zanichelli, Bologna, Italy; 1897.
[6] J.C. Bose, "On the determination of the wavelength of electric radiation by a diffraction grating," Proc.Roy.Soc., Vol.60;1897.
[7] J.C. Bose, "Collected Physical Papers," Longmans, Green and Co., New York, N.Y.;1927.
[8] P. Lebedew, "Ueber die Dopplbrechung der Strahlen electrischer Kraft," Annalen der Physik und Chemie, Series 3, Vol.56, No.9, pp.1-17;1895.
[9] Monoranjon Gupta, "Jagadis Chandra Bose, A Biography," Bhavan's Book University, 1952.
[10] Bimalendu Mitra, "Sir Jagadis Chandra Bose: A Biography for Students," Orient Longman, 1982.
[11] B. Mitra, "Early Microwave Engineering: J. C. Bose's Physical Researches during 1895-1900," Science and Culture, Vol.50, pp.147-154, 1984.
[12] Photograph from "Acharya Jagadis Chandra Bose, Birth Centenary, 1858-1958," published by the Birth Centenary Committee, printed by P.C. Ray, Calcutta: November 1958.
[13] Pearson and Brattain, "History of Semiconductor Research," Proc.IRE, 1954.
[14] Schaefer and Gross: Annalen der Physik, Vol 32, p.648; 1910.
[15] J.M. Payne & P.R. Jewell, "The Upgrade of the NRAO 8-beam Receiver," in "Multi-feed Systems for Radio Telescopes", Eds. D.T. Emerson & J.M. Payne, ASP Conference Series, Vol 75, p.144; 1995.