An Appreciation of J. C. Bose's Pioneering Work in Millimeter Waves

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1. Abstract

The pioneering work in the area of millimeter waves, performed by J. C. Bose, a physicist from Calcutta, India, during 1894-1900, is reviewed and appraised. Various measurement techniques and circuit components, developed by him a hundred years ago, are still being used. The development of the electromagnetic horn, the point-contact detector, and the galena (semiconductor) detector of electromagnetic waves are attributed to the original research of J. C. Bose.

2. Introduction

Jagadish Chunder Bose (1858-1937) was a great experimental physicist from Calcutta, India. As a professor of physics at the Presidency College of Calcutta, India, he conducted many of his pioneering and fundamental research investigations. He thereby initiated the tradition of scientific research in India towards the end of the last century. His life story, outlook of life, and scientific views are discussed in [1-3].

During 1894-1900, Bose utilized what then were called the Hertzian waves (now called electromagnetic–millimeter–waves) to perform his pioneering research in the area of microwaves and millimeter waves. His original research papers, in this and other related areas, may be found in [4]. Although Bose's work in the millimeter-wave area has been recognized by the microwave community [5-8], the impact of his contributions on millimeter-wave and microwave technology is not adequately publicized and appreciated in the modern context. The present paper therefore discusses and appraises the work of Bose, specifically in the area of millimeter waves, with a brief reference to his work in other related areas.

3. Historical perspective

It is now recognized that the discipline of microwaves (millimeter waves) began in the year 1888, when Heinrich Hertz (1857-1894) published the results of this famous experiments in a paper entitled, "On Electromagnetic Waves in Air and Their Reflection" [9]. These epoch-making results provided experimental confirmation of the existence of electromagnetic waves in air, theoretically predicted by James Clerk Maxwell (1831-1879) in 1864. By generating, radiating, and receiving electromagnetic waves (of wavelength $\lambda \cong 66\,\text{cm}$), Hertz not only established the validity of Maxwell's theory, but also initiated the discipline of microwaves. Hertz's original experimental setup and findings are well documented in [10], and will not be further discussed here.

Hertz's work inspired a number of scientists in different countries to get involved in research with Hertzian waves during the years 1888-1900. The physicist Bose was one of them. He decided to use Hertzian waves of lengths smaller than those used by Hertz; in fact, he used Hertzian waves having $\lambda \cong 5$ mm ($f = 60\,\text{GHz}$) to experimentally verify the optical properties of electromagnetic waves, such as reflection, refraction, polarization, etc. Bose believed that it would be advantageous to use millimeter waves, due to the fact that the physical sizes of various components required for the experimental setup would be smaller. To this end, Bose succeeded in generating mm waves, and systematically used them for a variety of quasi-optical measurements. He developed many mm-wave circuit components which, in one form or another, are still being used in modern times. In fact, Bose essentially perfected a millimeter-wave transmission and reception system at 60 GHz. He improved upon and developed various devices required to generate, radiate, and receive (detect) mm-wave energy, and demonstrated that the newly discovered Hertzian waves, i.e., electromagnetic waves at mm-wave frequencies, essentially behaved like light waves. In 1897, Bose give a lecture demonstration [11] of his work on (mm-wave) electromagnetic radiation at the Royal Institution, London. Figure 1 shows a picture of Bose, along with his experimental set-up. In the following sections, Bose's various accomplishments in the millimeter-wave area are discussed. For completeness, we also include brief discussions of some of his other significant contributions, related to electromagnetic waves.

4. A 60 GHz transmission system

During the time of Hertz, electromagnetic waves were generated by spark gaps, which generally produced wide bands of frequencies. Unless the receiving arrangement was shielded carefully, signals of unwanted frequencies interfered with the measurement setup and, in addition, reflections from the room walls also produced undesirable effects.

Lodge [12] made some improvements on the above generating system, by using an external resonator to filter out some frequencies. He accomplished this by inserting a metal ball in-between the sparking elements. However, the problem with this arrangement was that the surface of the metal ball became rough after a few sparks, and it started radiating spurious waves thereafter.

Bose perfected the above setup by covering the metal ball with platinum, and interposing it between two hollow metal hemispheres. Electric oscillations were produced by sparking between the hemispheres. The improved version of Bose's radiator, shown in Figure 2, is further described in [13]. This device increased the energy of radiation. He found that the wavelength of the radiated waves from his radiator was approximately twice the distance between the sparking surfaces. He succeeded in generating and radiating electromagnetic waves having wavelength, λ, ranging from 2.5 to 5 mm. He shielded his transmitting setup first, by using a copper layer to minimize stray electric fields, and then using a soft iron box on top of it, to minimize the effects of stray magnetic fields. The part of the transmission system developed by Bose can be seen in Figure 1. It should be noted that Bose used a rectangular metal tube (waveguide) to guide the waves generated and, eventually, to radiate them through the open end. He placed a lens in front of the opening, to focus the electromagnetic energy. To minimize multiple reflections inside the transmitter box, so that alternating sparks could pass without roughing or oxidation, Bose used blotting paper, soaked in an electrolyte, to act as absorber of these waves. In order to accomplish this, he had to measure the dielectric constants of sulfur and other materials at 60 GHz; this he did, as will be discussed later. Figure 3 shows a microwave-spectrometer system, developed by Bose; the transmitting system described above is indicated by R in the figure.

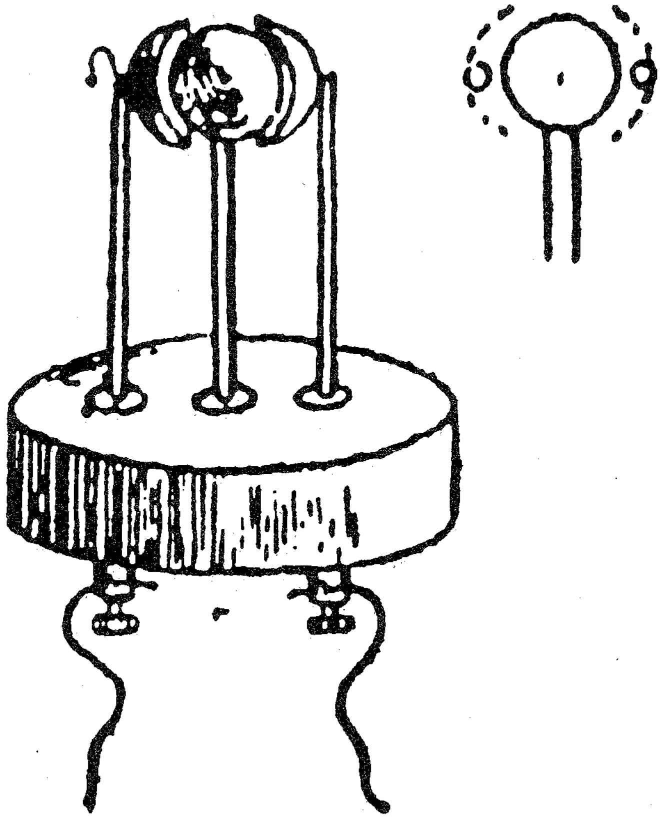

Figure 2. Spark gap arrangements for generating wavelengths of 2.5 cm to 5 mm. [4].

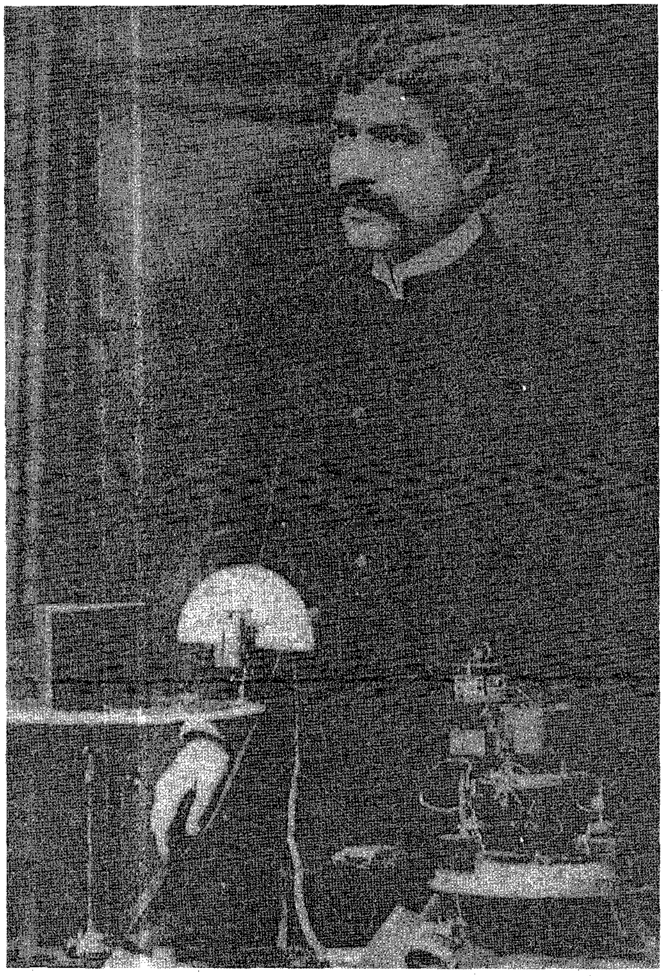

Figure 1. Professor J. C. Bose at the Friday Evening Discourse on Electric Waves before the Royal Institution (1896) [1].

The next problem faced by Bose was to verify that the radiated wave was actually of frequency 60 GHz (wavelength 5 mm), i.e., that there was a single-frequency wave radiated by the system, and not the wide band of frequencies initially generated by the sparking system. To this end, Bose developed an accurate method to determine the wavelength of millimeter waves, by using a curved optical grating [14]. A horizontal-plane sketch of the experimental setup is shown in Figure 4. The arrangement consists of a cylindrical grating, G, placed vertically on a wooden table, with its center at, C, where a receiving horn and a spiral coherer (receiver) are located. During the experiment, the radiator, R, and the receiver, S, were always kept on the focal curve, as shown. The graduated circle was used for the measurement of the angle of incidence, diffraction, etc. With the receiver placed at C, Bose used the following expression to measure the wavelength (λ) of the electromagnetic waves radiated by the source he developed:

$$(a+b)\sin\theta = n\lambda ,$$

where $(a+b)$ is the sum of the breadths of the alternate open and closed spaces in the grating, and θ is the angle between the transmitter and receiver. The results of this research were communicated to Lord Rayleigh. It is interesting to note that at the initiative of Lord Rayleigh, the University of London awarded the degree of Doctor of Philosophy to Bose, on the basis of this work [1] [Lord Rayleigh was his Physics Professor]. The quality of the research reported in [14] was so impressive that the University of London made an exception, so that Bose was not required to defend his thesis in person by appearing at the University.

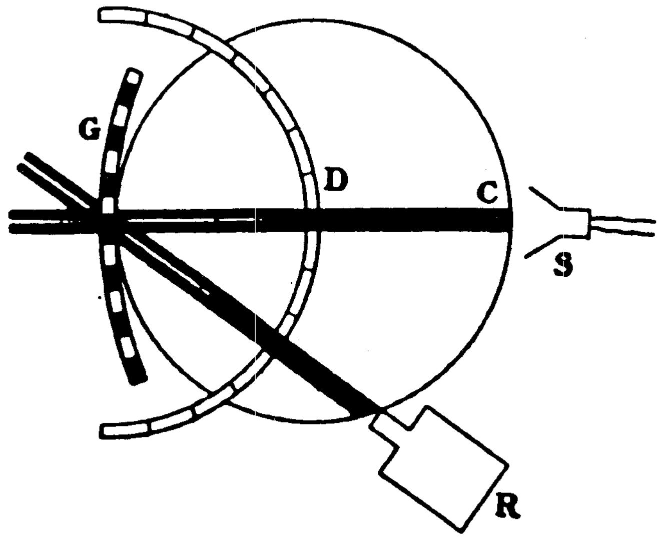

Figure 4. A sketch of the experimental setup to determine wavelength [14].

5. Development of the receiver

Professor Branly, of Catholic University College of Paris, developed a "Radio conductor." This was a glass tube filled with iron filings, as shown in Figure 5. But Branly found that the Hertzian waves, which could not produce appreciable induction in the filings, enormously reduced their resistance, sometimes even to a millionth. The resistance of the metal filings decreased when they were irradiated by millimeter waves. The problem was that after an interval when the metal filings had acted as a receiver for some time, a tap was necessary, to shake them back to their former state.

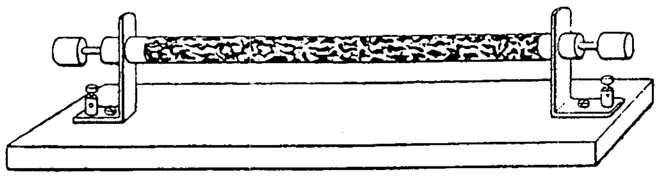

Figure 5. The conventional receiver of Hertz waves.

Lodge not only used this device, but offered an interpretation of its action as due to the fusing of minute points of contact of the filings, by the inductive effect produced by the Hertzian waves. For this reason, he renamed it a "coherer"–which, for some reason, remained with the "English-" speaking community. Branly, however, maintained the original name, with his explanation that the Hertzian waves merely modified in some way the non-conducting film upon the surface of the filings. Bose's receiver of Hertzian waves was a great advance over that of Branly and Lodge. He replaced the irregular filings by a single layer of steel springs, 2 mm in diameter and 1 cm in length. These he placed side by side in a square piece of ebonite with a shallow rectangular depression, so that the sensitive surface was 1 × 2 cm. The springs were prevented from failing by a glass slide in the front. The spiral could be compressed by means of a brass piece, which slid in and out by the action of a screw. The resistance of the circuit could therefore be

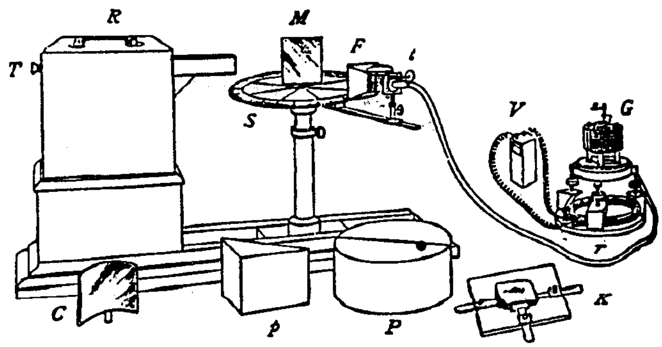

Figure 3. An electromagnetic-horn receiving antenna on a microwave spectrometer, used for quasi-optical demonstrations by Bose (1897). The transmitting antenna is a square-waveguide radiator, of wavelength 5 mm - 2.5 cm [4].

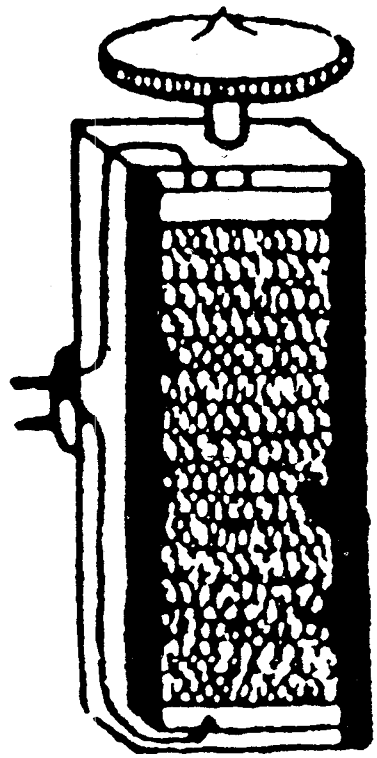

Figure 6. Bose's' microwave "semi-conducting" detector: the spiral-spring receiver [4].

gradually varied. An electrical current entered along the breadth of the top spiral and left the lowest spiral, having to traverse the intermediate spirals along a thousand regular contacts or thereabouts, as shown in Figure 6. The resistance of the receiving circuit was thus almost entirely concentrated at the sensitive contact surface. When electric radiation was absorbed by the sensitive contacts, there was a sudden decrease of the resistance, and the galvanometer was deflected. The sensitivity of the apparatus, according to M. Poincaré, "is exquisite: it responds to all the radiations in the interval of an octave. One makes it sensitive to different kinds of radiations, by varying the electromotive force, which engenders the current which traverses the receiver." Bose was successful in inventing other types of receivers that recovered automatically, without tapping. He thus made himself the best-equipped among the physicists of his time in the field of investigation.

Thus, with the most-perfect generation of mm waves under his full control, he was able to produce a well-defined beam of half-inch cross section. Furthermore, his receiver not only surpassed previous ones in sensitivity, but more importantly, in its certainty and uniformity of action.

6. Demonstration of propagation

Bose seemed to have used electromagnetic waves for signaling proposes. In 1895, in a public lecture in Calcutta, Bose demonstrated the ability of his electric rays to travel from the lecture hall, through the intervening room, and pass to a third room 75 feet (~22 m) distant from his radiator [1-3]. In fact, the waves passed through solid walls on the way, as well as through the body of the Chairman (who happened to be the Lieutenant Governor of Bengal). The waves received by the receiver activated a circuit, to make a contact that set a bell ringing, discharged a pistol, and thereby exploded a miniature mine. For an antenna, he used a circular metal plate at the top of a 6 m pole.

However, Bose was not interested in long-distance wireless transmission. Since the optical behavior of the waves could be best studied at short wavelengths, he concentrated on millimeter waves. Bose used the spectrometer setup shown in Figure 3, and some of its modified versions, extensively, to conduct a variety of quasi-optic measurements at mm-wave frequencies. It can be seen in Figure 3 that he used hollow metal tubes as waveguides, expanded the open end to form a radiator, and produced the first horn antenna. The flared rectangular guide he called a "collecting funnel" was the forerunner of the pyramidal horn.

Lord Rayleigh was so intrigued by his metal tubes that he made a trip to Calcutta to visit his laboratory. On his return, he published his work [22], in 1897, on wave propagation in waveguides.

Also, Lord Kelvin wrote to him in 1896 that he was "literally filled with wonder and admiration: allow me to ask you to accept my congratulations for so much success in the difficult and novel experimental problems which you have attacked." M. Cornu, the former president of the French Academy of Sciences, and a veteran leader in this field of physics, also wrote him early in 1897, saying that "the very first results of your researchers testify to your power of furthering the progress of science. For my own part, I hope to take full advantage of the perfection to which you have brought your apparatus, for the benefit of Ecole Polytechnique and for the sake of further researches I wish to complete" [1, p. 40].

7. Demonstration of phenomenon of refraction

Bose developed prisms made from sulfur, and made lens antennas of sulfur. For this purpose, he had to measure the index of refraction of various materials, and demonstrated the principle of total reflection. After the development of Maxwell's equations, there was some controversy as to the relation between the index of refraction of light and the dielectric constant of insulators. Bose eliminated these difficulties by measuring the index of refraction at mm wavelengths.

He determined the index of refraction at mm wavelengths by determining the critical angle at which total reflection took place. The apparatus, he called the electric refractometer, was used to measure the refractive index. This is shown in Figure 7. A rectangular aperture shielded the transmitter from the refracting cylinder and the sensitive receivers. He rotated the refracting cylinder on a turntable until he could measure the critical angle, and from the critical angle, he determined the index of refraction. He showed that the values of the refractive index differed considerably from the values measured at visible light. He used his spectrometer arrangement to measure accurately the refractive indices of a variety of solid and liquid materials at mm-wave frequencies. He also verified the relationship between dielectric constant and the refractive index. These research findings are reported in [15-17].

He also utilized the information about the refractive index to manufacture a lens of sulfur that he need at the opening of his transmitting tube, to focus the desired radiated electromagnetic energy.

8. Demonstration of the phenomenon of polarization

Bose demonstrated the effects of polarization by using three different types of polarizers:

a) Polarizers made of wire gratings;

b) Polarizers made of crystals, like tourmaline or nemalite; and

c) Jute or vegetable-fiber polarizers.

His electric-polarization apparatus is shown in Figure 8.

Bose found a special crystal, nemalite, which exhibited the polarization of electric waves in the very same manner as a beam of light is polarized by selective absorption in crystals like tourmaline. He found the cause of the polarization to be due to different electrical conductivity in two different directions. The rotation of the plane of polarization was demonstrated by means of a contriv-

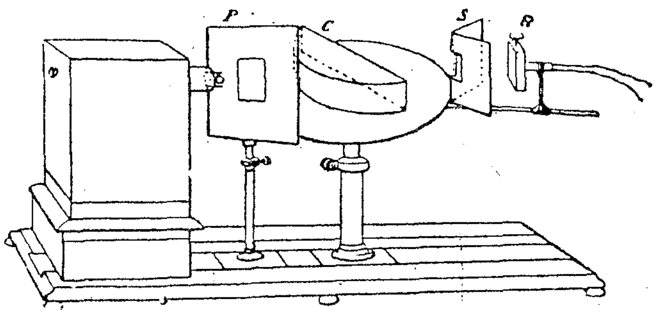

Figure 7. The electric refractometer developed by Bose [4].

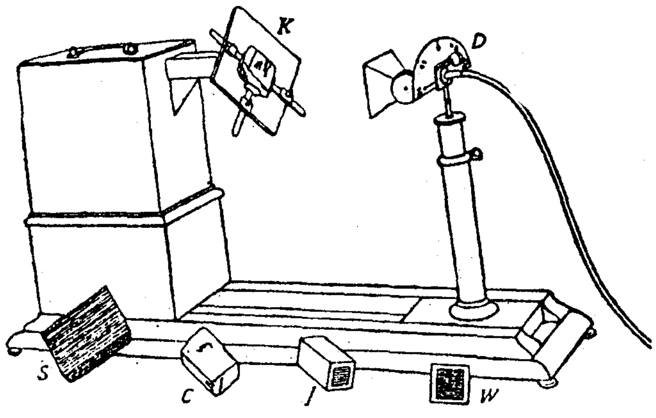

Figure 8. The polarization apparatus developed by Bose [4].

ance twisted like a rope, and the rotation could be produced to the left or right. These and other results are discussed in [18-19]. The findings of his research were communicated to the Royal Society by his teacher, Lord Rayleigh.

9. Demonstration of phenomenon similar to the photoelectric effect

Bose succeeded in detecting the effect of light in producing a variation of contact resistance in a galena receiver. One and the same receiver responded in the same way when alternately acted on by visible (light) and invisible electromagnetic radiation. He then proceeded to show the remarkable similarity of the curves of response produced under electromagnetic radiation and light. He tried to explain this phenomenon in terms of molecular strains, produced in the materials due to electromagnetic radiation. He fabricated a strain cell, to demonstrate that in providing angular torsion in a metal wire, the conductivity changed in a fashion similar to the case when the same structure was illuminated by electromagnetic radiation.

It is interesting to point out that after a Friday Evening Discourse at the Royal Institution, London, the publication *Electrical Engineer* expressed surprise that no secret was at any time made as to the construction of various apparatus, so that it was open to all the world to adopt it for practical and, possibly, money-making purposes. At that time, Bose was criticized as being impractical, and not interested in making profit from his inventions. However, Bose had his own ideas. He apparently was painfully disturbed by what seemed to him symptoms of deterioration, even in the scientific community, from the temptation of gain, and so he had made a resolution to seek no personal advantage from his inventions [1, 3, 20].

Many of the leading scientific men wished to show their appreciation of the value of Bose's work in a practical way. Their natural spokesman, Lord Kelvin, strongly realized the all-but-impossible conditions under which that work hitherto had been carried out. He wrote to Lord George Hamilton, then Secretary of State for India, "...to establish a laboratory for Bose in Calcutta. Following on this letter a memorial was sent...which was signed by Lord Lister, then President of the Royal Society, Sir William Ramsay, Sir Gabriel Stokes, Professor Silvanus Thompson, Sir William Rücker and others" [1, p. 68]. This clearly shows that Bose's work underwent a thorough scrutiny by the best intellectual minds of that time, and they not only appreciated his work, but tried to help him in every possible way they could.

10. Biological effects of mm waves

After 1900, Bose moved away from millimeter-wave research, and continued his research in the area of the electrical response of living and nonliving matter. His research on millimeter waves was carried out during 1894-1900. His research on the development of the millimeter-wave receiver naturally led him to a later topic of research, called "On Electrical Touch and the Molecular Changes Induced in Matter by Electric Waves."

We recollect that the word "coherer" was introduced by Lodge, to explain the decrease of resistance of the iron filings of the detector when irradiated by electromagnetic waves. The explanation put forward by Lodge was that the iron filings tightly bonded together when irradiated by mm waves, thereby reducing the resistance.

Bose fabricated receivers by using materials of almost all the elements of the periodic table. To his surprise, he found that when any of the elements barium, magnesium, aluminum, iron, cobalt, nickel, or copper was used in the mm-wave detector, the resistance of the detector decreased when illuminated by mm waves. However, when he used lithium, sodium, potassium, or calcium as an element in the detector, the resistance increased. These observations are shown in Figure 9. His conclusion was that this cannot be due to coherence.

He also made a sensitive receiver of iron powder. He found that its conductivity was suddenly increased by the action of electric radiation. However, the sensitivity of the receiver was lost after the first response, and it was necessary to tap it to restore the sensitivity. These observations were quite contrary to Lodge's explanation, and so the conclusion was that if the filings fused, then the resistance should decrease instead of increasing. His methodology of studying the variation of conductivity due to the effects of electric radiation on living and nonliving matter stimulated new areas of research. Particularly in plant studies, this methodology, introduced by him, is still in vogue.

Bose next discovered something very interesting, when he measured the *V-I* (voltage-current) curve of a single-point iron receiver. He wanted to study the effects of electromagnetic radia-

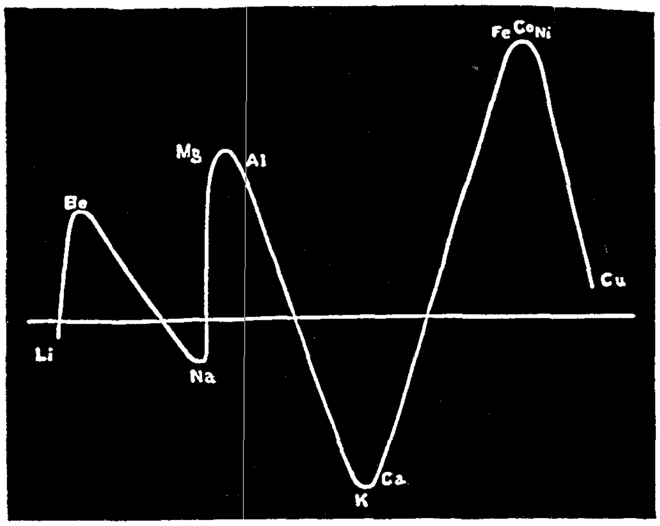

Figure 9. The periodicity of electric touch. The abscissa reports the atomic weight; the ordinate gives the electric-touch, positive or negative [1].

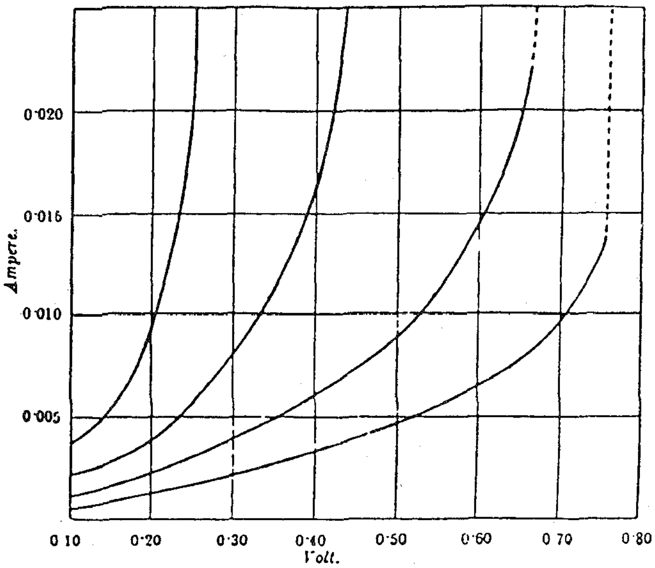

Figure 10. The *V-I* characteristics of a point-contact device [4].

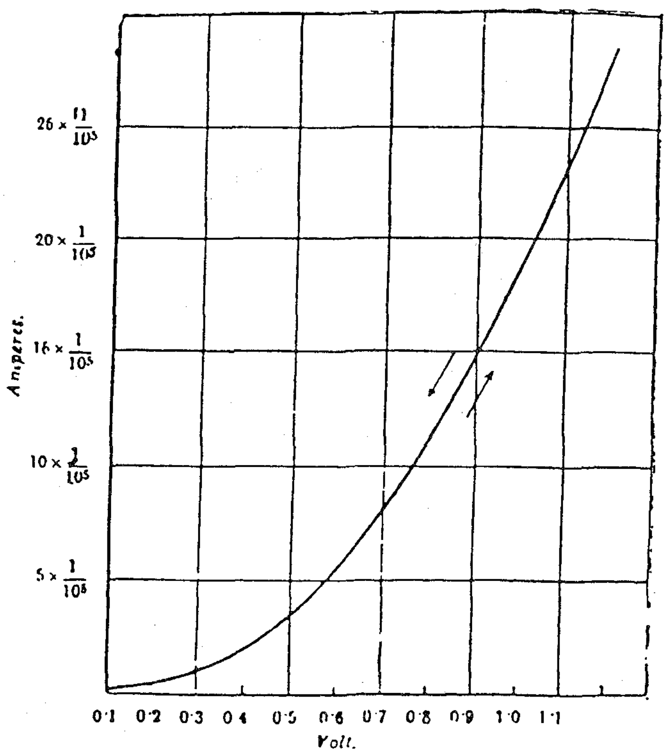

Figure 11. The characteristic curve of a self-recovering receiver of positive type [4].

tion on the single-point iron receiver. He made it a point contact, in order to reduce the conditions of the experimental sample. The change of conductivity was thus confined to the molecular layer at the point of contact. This consisted of a sharp point of iron, pressing against a convex iron surface, the pressure being capable of very delicate adjustment by means of a micrometer. He found that the resistance of the receiver was not constant, but went through a continuous decrease with increasing applied voltage. The conductivity therefore increased with the rise of voltage. Hence, he concluded that conduction, in such cases, did not obey Ohm's Law. The *V-I* characteristics of such a point-contact device are shown in Figure 10. From Figure 10, it is clear that this represents the *V-I* characteristics of a diode. In fact, the point-contact diodes used today had their humble beginnings in the work of Bose.

At the second Royal Institution Discourse in 1900, Bose demonstrated an "artificial retina." He stated that his artificial retina, or "sensitive" receiver, could see lights not only some way beyond the violet, but also in regions far below the infrared. A typical point-contact characteristic of his self-recovering receiver is shown in Figure 11. The response curve was shown to closely resemble that of a frog's retina, recorded earlier by Waller. Although Bose did not explicitly mention that the "artificial retina" was a pair of galena point contacts, it was, in fact, the first semiconductor receiver of radio waves [20, 21]. This was patented for Bose in the USA, entitled "Detector of Electrical Disturbances," Patent No. 755840, dated March, 1904. The application was filed September 30, 1901, with the assigned number 77028. Hence, Bose's galena detector was the forerunner of crystal detectors.

According to Bose,

> I found that under continuous stimulation by the electromagnetic radiation, the sensitiveness of the metallic detectors disappeared. But after a sufficient period of rest it regained once more its normal sensitiveness. In taking records of successive responses, I was surprised to find that they were very similar to those exhibiting fatigue in the animal muscle. And just as animal tissue, after a period of rest, recovers its activity, so did the inorganic receiver recover after an interval of rest.
>
> Thinking that prolonged rest would make the receiver even more sensitive, I laid it aside for several days and was astonished to find that it had become invert. A strong electric shock now stirred it up into readiness for response. Two opposite treatments are thus indicated for fatigue from overwork and for inertness from long passivity.
>
> A muscle-curve registers the history of the fundamental molecular change produced by the excitation in a living tissue, exactly as the curve of molecular reaction registers an analogous change in an inorganic substance.

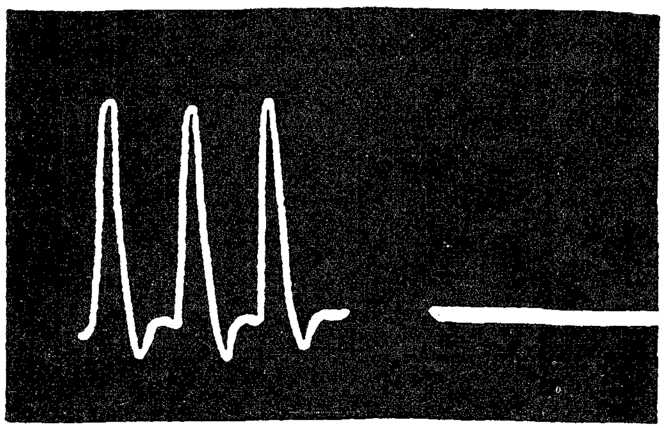

Figure 12a. The action of poison in abolishing the response of muscle.

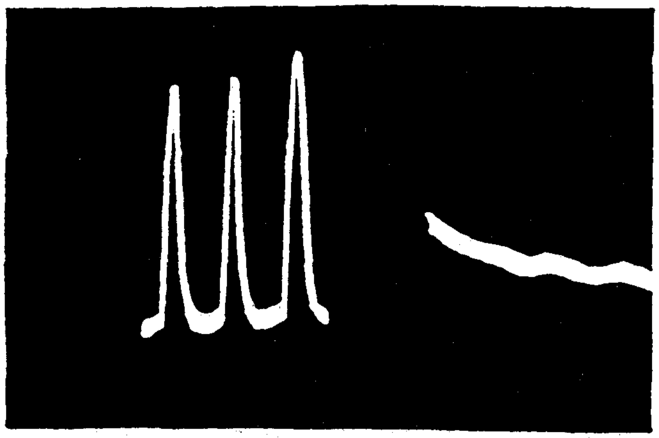

Figure 12b. The action of poison in abolishing the response of a plant.

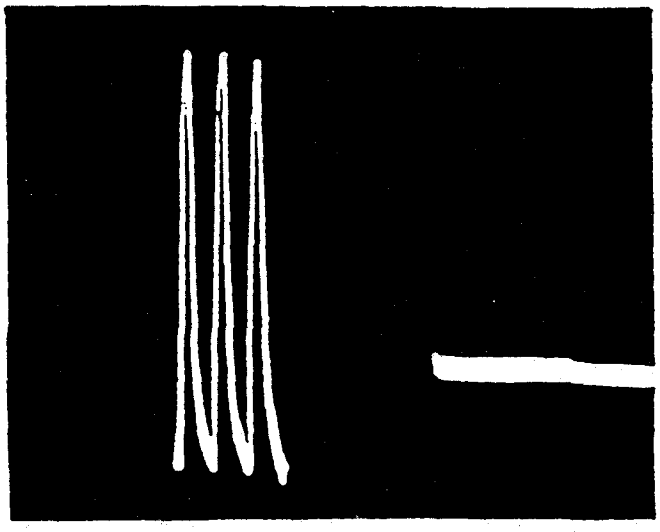

Figure 12c. The action of poison in abolishing tne response of metal.

As an example, he demonstrated that introduction of a low dose of poison acted as a stimulant, whereas a high dose killed it–which was the absence of any electrical response (which is the modern definition of death!).

In the Faraday Evening Discourse, at the Royal Institution in 1900, he showed that on application of chloroform, plant response disappeared, just as it does for an animal. With timely "blowing off" of the narcotic vapor by fresh air, the plant, just like an animal, revived and recovered, to respond anew. He also experimented with metals. He showed that a low dosage of oxalic acid on tin stimulated its response, while a large dosage "killed it," as shown in Figure 12. He concluded by saying that there was no line of demarcation between physics and physiology.

10. Conclusion

The brief description given above pertains mainly to the pioneering and significant contributions made by J. C. Bose, during 1898-1900, towards the advancement of the discipline of (microwave) millimeter-wave physics and techniques. Further details about the investigations performed, and the variety of experimental arrangements developed by him, may be found in [4]. We conclude by highlighting the following significant accomplishments of Bose during the end of the last century:

1. Generated, radiated, and received electromagnetic waves having wavelengths ranging from 2.5 mm to 5 mm.

2. Developed a mm-wave spectrometer, to investigate the reflection, refraction, diffraction and polarization of electromagnetic waves.

3. Experimentally measured the wavelength of mm electromagnetic waves.

4. Measured the refractive indices (and hence, the dielectric constants) of a variety of materials at mm-wave frequencies.

5. Contributed to the development of the microwave lens.

6. Used blotting paper soaked in electrolyte as a lossy artificial dielectric to absorb millimeter waves.

7. Along with others, used metal tubes to guide and radiate electromagnetic waves. However, Bose made the significant step of flaring the walls of a rectangular waveguide, and thereby developed the pyramidal horn, which he called a "collecting funnel."

8. Invented the "galena receiver," which was the first use of a semiconductor as a detector of electromagnetic waves.

9. Developed the point-contact detector, which was the forerunner of the diode.

11. Acknowledgment

Grateful acknowledgment is made to Mr. Dibakar Sen, of the Bose Research Institute, Calcutta, for providing a "live" demonstration of his equipment, described in Figure 3.

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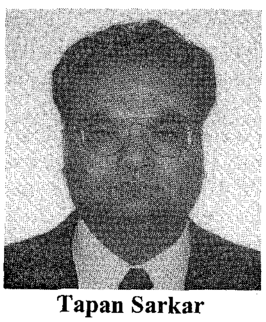
22. Lord Rayleigh, "On the Passage of Electric Waves Through Tubes," *Philosophical Magazine*, **43**, 1897, pp. 125-132.

Introducing Feature Article Authors

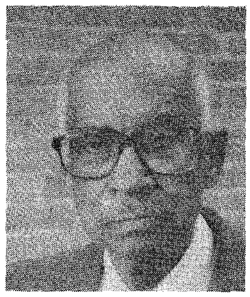


Tapan Sarkar

Tapan Kumar Sarkar received the B. Tech. degree from the Indian Institute of Technology, Kharagpur, India, the MScE degree from the University of New Brunswick, Fredericton, Canada, and the MS and PhD degrees from Syracuse University; Syracuse, New York in 1969, 1971, and 1975, respectively.

From 1975 to 1976, he was with the TACO Division of the General Instruments Corporation. From 1976 to 1985, he was with the Rochester Institute of Technology, Rochester, NY. From 1977 to 1978, he was a Research Fellow at the Gordon McKay Laboratory, Harvard University, Cambridge, MA. He is now a Professor in the Department of Electrical and Computer Engineering, Syracuse University; Syracuse, NY. He has authored or co-authored more than 170 journal articles, and has written chapters in ten books. His current research interests deal with numerical solutions of operator equations arising in electromagnetics and signal processing, with application to system design.

Dr. Sarkar is a registered Professional Engineer in the State of New York. He was an Associate Editor for Feature Articles of the *IEEE Antennas and Propagation Society Newsletter*, and he was the Technical Program Chairman for the 1988 IEEE Antennas and Propagation Society International Symposium and URSI Radio Science Meeting. He was the Chairman of the Intercommission Working Group of URSI on Time-Domain Metrology. He is a member of Sigma Xi and USNC/URSI Commissions A and B. He received one of the "best solution" awards in May, 1977, at the Rome Air Development Center (RADC) Spectral Estimation Workshop. He received the Best Paper Award of the *IEEE Transactions on Electromagnetic Compatibility* in 1979, and at the 1997 National Radar Conference. He is a Fellow of the IEEE.



Dipak Sengupta

Dipak L. Sengupta received the BSc (Honors) degree in physics, and the MSc degree in radiophysics, from Calcutta University, Calcutta, India, in 1950 and 1952, respectively. He received the PhD degree in electrical engineering from the University of Toronto, ON, Canada, in 1958.

In 1959, he was a Research Fellow in Electronics at Harvard University, Cambridge, MA. During 1963-1964, he was an Assistant Professor in Electrical Engineering, University of Toronto. From 1964-1965, he was Assistant Director for the Central Electronics Engineering Research Institute, Pilani, India. During 1959-1963 and 1965-1986, he was with the University of Michigan, Ann Arbor, conducting research at the Radiation Laboratory, and teaching in the Electrical and Computer Science Department. In 1986, he joined the University of Detroit, Mercy, as Professor and Chairman of the Department of Electrical Engineering and Physics, where he is now a Professor, since 1996. During 1992-1993, he was a Fulbright Visiting Lecturer in India. In 1996, he was a Visiting Professor at the Instituto Technologico y de

Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico. His professional interests include the areas of antennas, EMC, and navigation systems.

Dr. Sengupta is a member of Commission B of USNC/URSI, Sigma Xi, and of Eta Kappa Nu. He is listed in *American Men and Women of Science*. From 1976-1978, he served as Vice-Chairman, and then as Chairman, of the South East Michigan joint AP-S/MTT/EDS Section. During 1976-1978, he also served as Secretary of USNC/URSI Commission B. During 1981-1985, he served as an Associate Editor for the *IEEE Transactions on Antennas and Propagation*. He serves as a consultant to industrial and US government organizations.

Proceedings of the 1997 International Conference on Antenna Theory and Techniques Available

The second International Conference on Antenna Theory and Techniques (ICATT'97) was held in Kyiv, the Ukraine, May 20-22, 1997. It was sponsored by the National Antenna Association of the Ukraine and the National Technical University of the Ukraine "Kyiv Polytechnical Institute." The Chairman of ICAAT'97 was Yakov S. Shifrin, NAA President and IEEE AP-S East Ukraine Chapter Chair. The *Proceedings* of this conference are now available.

The *Proceedings* include 159 papers, totaling 375 pages. This includes the following papers by the invited speakers:

"Electromagnetics of Superconducting Structures and Its Application to the Problems of Antenna and Waveguide Technique," V. F. Kravchenko, Moscow, Russia

"Frequency Selective and Polarization Sensitive Reflector Antennas," P. Endenhofer, Germany

"Pseudorandomly Generated Estimator Banks: A New Reassembling Scheme For Improving The Threshold Performance of Second and Higher-Order Direction Finding Methods," A. Gershman, Germany

"Modern Antenna Measurements and Diagnostics Including Phaseless Techniques," Y. Rahmat-Samii and R. G. Yaccarino, USA

"Iteration Technique of the Design of Frequency-Selective Devices and the Software on This Base," A. Kirilenko, L. Rud', S. Senkevich, and V. Tkachenko, Kharkiv, Ukraine

"Optimization and Projecting Methods for Microwave Technologies UHF Systems," G. Morozov and V. Gusev, Kazan, Russia

Copies of the *Proceedings* may be ordered for $50 plus $10 for air mail shipping. The e-mail address to use in placing orders is shifrin@kture.kharkov.ua . Payments should be sent to Bank of New York, Rtg. #0210-0001-8 (New York City branch), Eastern Europe Division, One Wall Street, New York, NY 10286, Account No. 890-0222-646; Beneficiary: Real-Bank, Ukraine, Swift Code: NPKBUA2X in favor of Shifrin Yakov Acc. #023139365. Alternatively, a personal check can be sent to M. S. Yurchenko, 2110D building 17, NTUU-"KPI," Politekhnicheskaya str. 12, Kyiv 252056 Ukraine.