Sir J. C. Bose's Diode Detector Received Marconi's First Transatlantic Wireless Signal of December 1901 (The "Italian Navy Coherer" Scandal Revisited)

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The true origin of the "mercury coherer with a telephone" receiver that was used by G. Marconi to receive the first transatlantic wireless signal on December 12, 1901, has been investigated and determined. Incontrovertible evidence is presented to show that this novel wireless detection device was invented by Sir. J. C. Bose of Presidency College, Calcutta, India. His epoch-making work was communicated by Lord Rayleigh, F.R.S., to the Royal Society, London, U.K., on March 6, 1899, and read at the Royal Society Meeting of Great Britain on April 27, 1899. Soon after, it was published in the Proceedings of the Royal Society. Twenty-one months after that disclosure (in February 1901, as the records indicate), Lieutenant L. Solari of the Royal Italian Navy, a childhood friend of G. Marconi's, experimented with this detector device and presented a trivially modified version to Marconi, who then applied for a British patent on the device. Surrounded by a scandal, this detection device, actually a semiconductor diode, is known to the outside world as the "Italian Navy Coherer." This scandal, first brought to light by Prof. A. Banti of Italy, has been critically analyzed and expertly presented in a time sequence of events by British historian V. J. Phillips but without discovering the true origin of the novel detector. In this paper, the scandal is revisited and the mystery of the device's true origin is solved, thus correcting the century-old misinformation on an epoch-making chapter in the history of semiconductor devices.

Keywords*—*Detection of first transatlantic wireless signal, Italian Navy coherer, Marconi's 1901 transatlantic wireless experiment, mercury coherer with a telephone, origin of the Italian Navy coherer, self-restoring coherer, semiconductor diode detector.

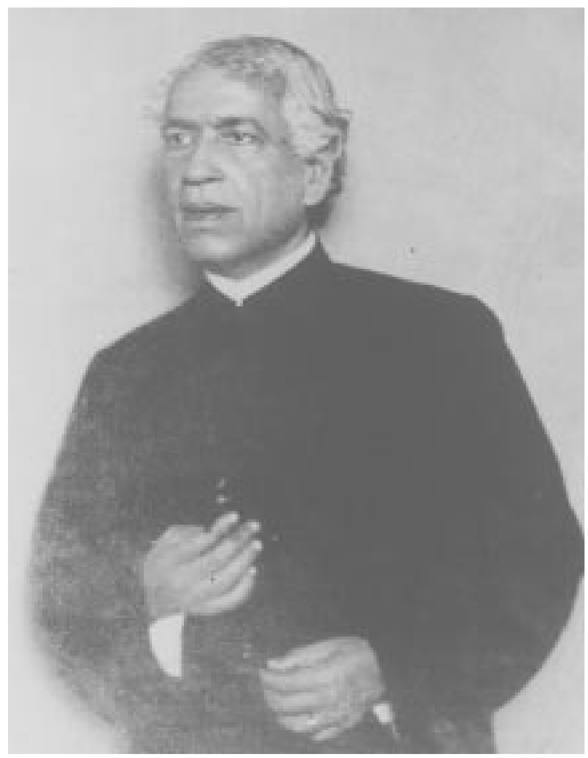

Fig. 1. Sir J. C. Bose.

I. INTRODUCTION

In his epoch-making transatlantic wireless communication experiment, G. Marconi received the first transatlantic wireless signal at Signal Hill, St. John's, Newfoundland, in the afternoon of December 12, 1901 [1]–[3]. The signal in the form of successive Morse code letter "S" was heard using a temporary makeshift receiving system consisting of a wire antenna flown 400 ft up by a kite and connected to a new "mercury coherer" detector in series with a telephone headset. This revolutionary detector device was invented by Sir J. C. Bose, professor of physical sciences, Presidency College, Calcutta, India (Fig. 1), and the invention was first reported in the April 27, 1899, meeting of the Royal Society, London, U.K. [4], [5]. However, the circumstances under which Marconi got hold of this detector device and successfully used it in his experiment to hear the first transatlantic wireless signal is surrounded by a scandal, which was expertly outlined recently by British historian V. J. Phillips [6] without discovering the true origin of the device.

Marconi, as the scandal reveals, received this "mercury coherer detector" in the summer of 1901 from his childhood

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friend, Lieutenant L. Solari of the Royal Italian Navy, and then filed a patent application for it in England in his own name shortly thereafter. When, how, and where Solari got this detection device is the central theme of this paper on this turn-of-the-century scandal. The true origin of the invention of this historically important wireless detector device has not come to light in the past narratives of this scandal. This paper follows the trails carefully and reveals for the first time the real inventor of the detector. Those amazing facts are presented next.

To present the startling historical account in a clear, straightforward fashion, the principal individuals are first introduced in Section II. Bose's invention and its descriptions are presented in Section III.

Marconi's descriptions of his reception of the first transatlantic wireless signal made at several places immediately following the experiment are given in Section IV. The scandal surrounding Marconi's use of the Bose detector device began unfolding with the Marconi Company's response to a letter of Lodge in *The Times* of London [7] and came to an ugly head with the publication of Prof. A. Banti's article in the technical journal *L'Elettricista,* the translated version of which appeared in the English publication *The Electrician* [8]. Subsequent developments of the scandal have been expertly narrated by Phillips, and all these are presented in Section V. Marconi's further experimental activities and Marconi–Fleming correspondence prior to Marconi's Royal Institution lecture of June 13, 1902, are described in Section VI to capture a glimpse of the inner workings of Marconi's thoughts and actions during the unraveling of the scandal.

Marconi's descriptions of how he procured the "mercury coherer with a telephone detector" device through his friend Solari, the narratives of his transatlantic experiments, and his conscious efforts to downplay the scandal are excerpted in Section VII from his Royal Institution lecture of June 13, 1902, and critically analyzed. Three later narratives on the reception of the first transatlantic wireless signal are presented next in Section VIII for comparison with Marconi's above-mentioned prior statements before the Royal Institution. The Marconi–Solari trail on the detector is followed in Section IX to trace its origin from Solari's two publications, which are reproduced in full. This is followed by the tracking, in Section X, of the bogus Tommasina trail put forward by the Italian sources to confuse the true origin of the detector device and where the previous narratives, so far, rested. The historical timeline is revisited in Section XI to reveal the true source of the detector Marconi used to receive the first transatlantic signal. The Marconi–Bose relationship is explored in Section XII, followed by pertinent concluding remarks in Section XIII.

II. Cast of Characters

To present the subject matter in clear historical perspective, it is advantageous to introduce the central cast of characters in this intriguing story.

- *Lord Rayleigh (1842–1919):* Cavendish Professor of Physics (1879–1885) succeeding J. C. Maxwell at Cambridge University, U.K. Nobel Laureate in Physics (1904), later chancellor of Cambridge University. Taught physics at Cambridge to J. C. Bose of Presidency College, Calcutta, India, and thereafter patronized Bose's pioneering research works.
- *Sir J. C. Bose (1858–1937):* Professor of physical sciences, Presidency College, Calcutta, India. Invented the mercury coherer with a telephone detector in 1898 and presented it to the Royal Society of Great Britain on March 6, 1899. Marconi used this coherer to hear the first transatlantic wireless signal on December 12, 1901, at Signal Hill, Newfoundland.
- *G. Marconi (1874–1937):* Wireless wizard. Nobel Laureate in Physics (1909). Conducted world's first transatlantic wireless communication experiment and received the first signal at Signal Hill, St. John's, Newfoundland, in the afternoon of December 12, 1901, with the mercury coherer with a telephone detector invented by Bose.
- *Sir J. A. Fleming (1849–1945):* Professor of electrical engineering, University College London. Technical advisor to the Marconi Company. A student of J. C. Maxwell's at Cambridge. Helped Marconi design the first high-power wireless transmitter at Poldhu, Cornwall, England, for the transatlantic experiment.
- *Sir O. J. Lodge (1851–1940):* Wireless pioneer of the United Kingdom. Coined the word "coherer" to describe the iron-filings-filled tube detector of wireless waves of Branley that he improved upon. His famous Oxford lectures of 1894 inspired Bose to initiate research in wireless and in particular in the areas of millimeter waves and "self-decohering" detectors, later known as diode detectors.
- *Lord Lister:* Pioneer of antiseptic surgery. President of the Royal Society, London, when Bose's paper on the invention of the "mercury coherer with the telephone" was presented and read on April 27, 1899.
- *Major S. F. Page:* Managing director of the Marconi Company during the 1900–1902 period.
- *R. N. Vyvyan*: Marconi's technical assistant. Built the first phase of the world's first high-power wireless transmitter at Poldhu, Cornwall, England, that sent the first transatlantic wireless signal to Signal Hill, Newfoundland.
- *Prof. S. P. Thompson:* Most vocal inquisitor of Marconi's in England. A friend of Sir Lodge, he was a professor of electrical engineering in the London City and Guilds College.
- *Lieutenant (later Marquis) L. Solari:* Of the Royal Italian Navy. Marconi's "hatchet man" and close childhood friend. Worked on Bose's invention of the mercury coherer and presented a modified version to Marconi, for which Marconi applied for a British patent.

- *Prof. A. Banti:* The editor of *L'Elettricista*, who brought the mercury coherer scandal out in the open in May 1902.
- *Corporal Signalman P. Castelli:* Claimed by Prof. Banti to have "invented" the mercury coherer, much to the embarrassment of Marconi and Solari.
- *Captain Q. Bonomo:* Castelli's superior in the Italian Navy during the 1900–1902 period.
- *Admiral Morin:* The Italian minister of marine. An inadvertent accessory to deliberate deception and confusion created and managed by Solari in Marconi's interest.
- *Signor E. Guarini:* Alleged in 1903 that it was neither Castelli nor Solari but Prof. T. Tommasina of Genoa, Italy, who "invented" the mercury coherer. Both Marconi and Solari denied using his alleged "invention."
- *Prof. T. Tommasina:* A professor of physics in Genoa, Italy. The "bogus inventor" of the iron-mercury-iron coherer. Marconi never claimed that Prof. Tommasina had invented the mercury coherer that he used. Solari by his own admission never heard of Tommasina's work when he experimented with Bose's invention and presented the design to Marconi.

III. Sir J. C. Bose's Invention of the "Mercury Coherer with a Telephone" Detector

Bose had been studying the behavior of newly discovered electromagnetic waves in the millimeter-wave region since 1894 and was experimenting with various kinds of detector devices for these waves. A comprehensive account of this work appeared in a book published in 1927 [5]. Descriptions of his pioneering work in the microwave and millimeter-wave regions have appeared periodically in many places [9]–[11]. The fact that Bose holds the world's first patent on solid-state diode detectors [12] has been known [10]. It is not known at all, however, that the first transatlantic wireless signal was detected by Marconi on December 12, 1901, using the "mercury coherer with the telephone" (semiconductor diode detector device) invented by Bose in 1899 [4]. This paper, published in the *Proceedings of the Royal Society,* London, has been reproduced in full in this special issue.[1] The excerpts of this historic paper, where the iron-mercury-iron or iron-mercury-carbon contacts device descriptions are given, is reproduced below [4]:

> I next proceeded to make a systematic study of the action of different metals as regards their cohering properties. In a previous paper[2] I enumerated the conditions which are favorable for making the coherer sensitive to electric radiation. These are the proper adjustment of the EMF and pressure of contact suitable for each particular receiver. The EMF is adjusted by a potentiometer slide. For very delicate adjustments of pressure I used in some of the following experiments an [*sic*] U-tube filled with mercury, with a plunger in one of the limbs; various substances were adjusted to touch barely the mercury in the other limb. A thin rod, acting as a plunger, was made to dip to a more or less extent in the mercury by a slide arrangement. In this way the mercury displaced was made to make contact with the given metal with gradually increasing pressure, this increase of pressure being capable of the finest adjustments. The circuit was completed through the metal and mercury. Sometimes the variation of pressure was produced by a pressure bulb. In the arrangement described above the contact is between different metals and mercury—metals which were even amalgamated by mercury still exhibited sensitiveness to electric radiation when the amalgamation did not proceed too far. In this way I was able to detect the cohering action of many conductors including carbon. For studying the contact-sensitiveness of similar metals I made an iron float on which was soldered a split-tube in which the given metal could be fixed, a similar piece of metal being adjusted above the float, so that by working the plunger or the pressure bulb the two metals could be brought into contact with graduated pressure. The other arrangements adopted were the contact of spirals compressed by micrometer screw, and filings similarly compressed between two electrodes.

Bose then describes the use of telephone to detect the reception of the signal in the self-cohering and decohering actions (what is now known as the diode detection action) of the Fe–Hg–Fe and Fe–Hg–C and other contact systems:

> Another coherer was found apparently irresponsive to radiation, there being the merest throb (sometimes even this was wanting) in the galvanometer spot, when a flash of radiation fell on the receiver. Thinking that this apparent immobility of the galvanometer spot may be due to response, followed by instantaneous recovery, the galvanometer needle being subjected to opposite impulses in rapid succession, I interposed a telephone in the circuit; each time a flash of radiation fell on the receiver the telephone sounded, no tapping being necessary to restore the sensitiveness. The recovery was here automatic and rapid.

Excerpts from the original handwritten manuscript of Bose are reproduced in Fig. 2.

Marconi's use of this invention to detect the first transatlantic wireless signal is revealed in a gradual sequence of events, presented next.

IV. The First Transatlantic Wireless Signal

The basic facts about Marconi's famous transatlantic wireless communication experiment of December 1901 (Fig. 3) are well known and well documented. However,

[1] See pp. 244–247.

[2] "On polarization of electric ray," *J. Asiatic Soc. Bengal,* May 1895.

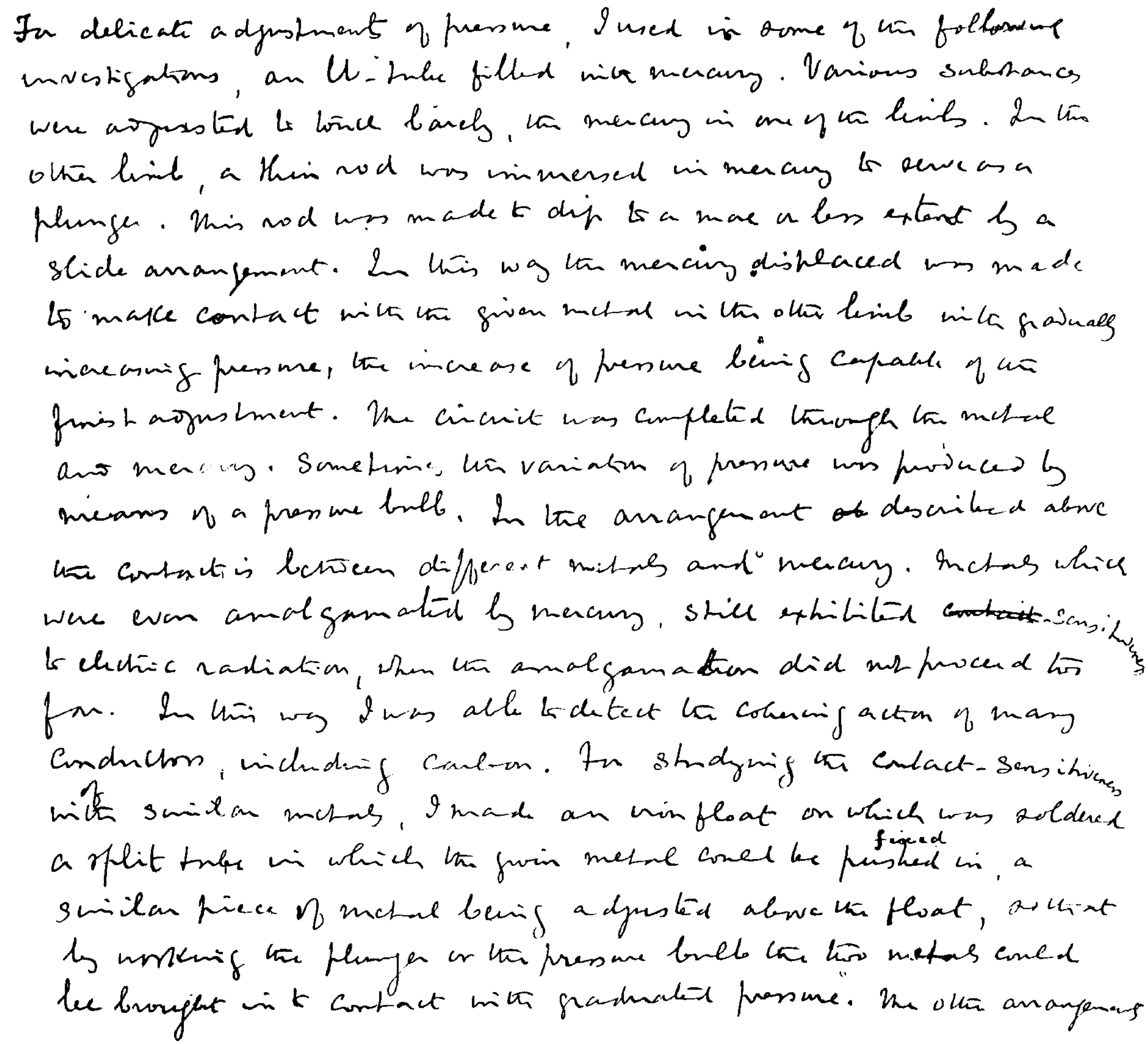

For delicate adjustment of pressure, I used in some of the following investigations, an U-tube filled with mercury. Various substances were adjusted to touch barely, the mercury in one of the limbs. In the other limb, a thin rod was immersed in mercury to serve as a plunger. This rod was made to dip to a more or less extent by a slide arrangement. In this way the mercury displaced was made to make contact with the given metal in the other limb with gradually increasing pressure, the increase of pressure being capable of the finest adjustment. The circuit was completed through the metal and mercury. Sometimes, the variation of pressure was produced by means of a pressure bulb. In the arrangement described above the contact is between different metals and mercury. Metals which were even amalgamated by mercury, still exhibited sensitiveness to electric radiation, when the amalgamation did not proceed too far. In this way I was able to detect the coherer action of many conductors, including carbon. For studying the contact-sensitiveness of similar metals, I made an iron float on which was soldered a split tube in which the given metal could be fixed in, a similar piece of metal being adjusted above the float, so that by working the plunger or the pressure bulb the two metals could be brought into contact with graduated pressure. The other arrangement

Fig. 2. Bose's handwritten manuscript.

the origin and description of the detecting device that was used to receive the first transatlantic wireless signal in the form of prearranged Morse code letter "S" are not clearly known. To ascertain precisely what detector device Marconi used to receive the first transatlantic wireless signal and to trace its true origin, it is first necessary to follow Marconi's precise statements regarding this reception, made at various places soon after the experiment.

Soon after the first experiment, Marconi arrived in New York City, and the American Institute of Electrical Engineers (AIEE, which, after merging with the Institute of Radio Engineers in 1963, became the present IEEE) quickly honored him at its Annual Dinner, held on January 13, 1902. C. Steinmetz, president of the AIEE, with A. G. Bell, the past president, were among many prominent others in attendance [13]. Marconi, in his speech, described the first transatlantic wireless signal reception in the following words.

> As I did not want to wait until repairs were effected at Cape Cod, I thought it might be useful in some way to get the English station to transmit with its full power, and the messages to be received on this side by means of a temporary installation; and as I did not think it prudent to try such a distance as three thousand miles at once. I thought that this temporary installation, this first shot of getting messages across the Atlantic, should be tried on the Island of Newfoundland, at St. John's, which is about two thousand land miles from England. Instead of poles, as are generally used for permanent work, kites and balloons were employed to elevate the aerial wires, the necessity of which I think you are pretty well acquainted with. These kites or balloons gave a great deal of trouble, as, owing to the tempestuous weather which prevailed in Newfoundland, last December, it was found almost impossible to raise the kites or balloons to the required height. However, I am glad to say, that at certain intervals, on December 12 and 13, the kites were for a short time got into satisfactory position, and my assistants and I had the great satisfaction of receiving a number of the prearranged signals from

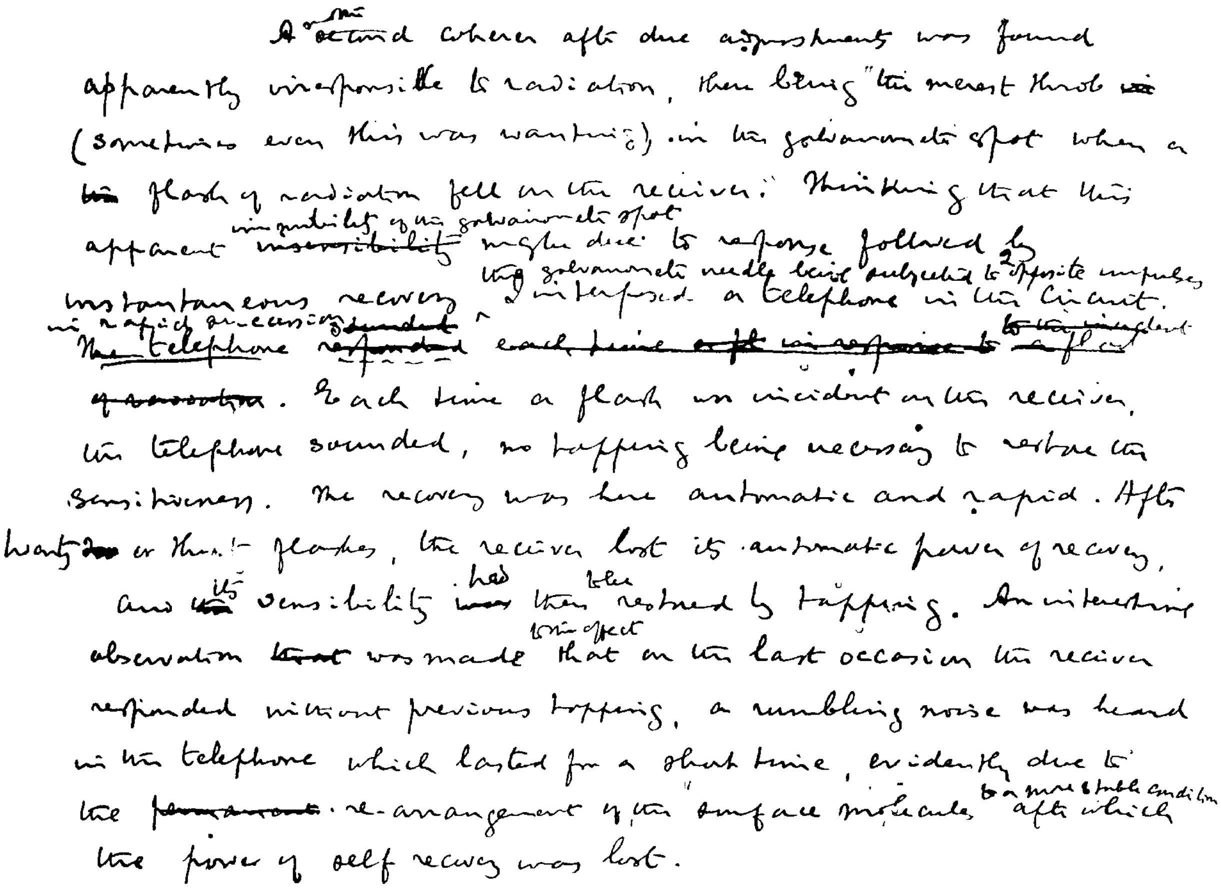

A same coherer after due adjustment was found apparently irresponsive to radiation, there being "the merest throb (sometimes even this was wanting) in the galvanometer spot when a flash of radiation fell on the receiver." Thinking that this apparent immobility of the galvanometer spot might be due to response followed by instantaneous recovery, the galvanometer needle being subjected to 2 opposite impulses in rapid succession, I interposed a telephone in the circuit. Each time a flash was incident on the receiver, the telephone sounded, no tapping being necessary to restore the sensitiveness. The recovery was here automatic and rapid. After twenty or thirty flashes, the receiver lost its automatic power of recovery, and its sensibility had then to be restored by tapping. An interesting observation was made that on the last occasion the receiver responded without previous tapping, a rumbling noise was heard in the telephone which lasted for a short time, evidently due to the re-arrangement of the surface molecules to a more stable condition after which the power of self recovery was lost.

Fig. 2. *(Continued.)* Bose's handwritten manuscript.

Cornwall, at the right time and at the prearranged speed. (Applause and cheers.)

Marconi continued:

> Time has not permitted me—I have said this before—to make any reference to the history of wireless telegraphy. I wish you to know how much the success of my work has depended upon the work of my predecessors and my present assistants. I have built very greatly on the work of others; and before concluding, I would like to mention only a few of the names; I may omit some, but these occur to me at present. They are Clerk Maxwell, Lord Kelvin, Prof. Henry and Prof. Hertz. (Applause.) I do not know if you are all aware of it; I think it has been well published in the daily press, with more or less accuracy, that these messages were received on the telephone which was actuated by the impulses translated through it from a coherer which was influenced by the electric rays coming from England, and I wish to mention the name of Prof. Alexander Graham Bell in that connection. (Applause.) If it had not been for the invention of the telephone, I do not know whether at this day we would have received signals across the Atlantic. They might have been received later, with a great deal more power. An ordinary recording instrument was not sufficiently sensitive to work at that distance, but, by the aid of the telephone, it did work.

We notice here that Marconi did not reveal the use of a self-recovering mercury coherer (in reality, a semiconductor contact diode, as will be discussed later) in conjunction with the telephone. One can assign that to the need of "business secrecy."

While Marconi was still at Signal Hill, Newfoundland, in December 1901, he gave his first interview to a reporter, R. S. Baker, who claimed to have "accurately described" the experiment in the *McClure's Magazine* [14] of February 1902. The relevant portion of the description of Marconi's reception of the first transatlantic wireless signal is presented below:

> At noon on Thursday (December 12, 1901) Marconi sat waiting, a telephone receiver at his ear, in a room of the old barracks on Signal Hill. To him it must have been a moment of painful stress and expectation. Arranged on the table before him, all its parts within easy reach of his hand, was the delicate receiving instrument, the supreme product of years of the inventor's life, now to be submitted to a decisive test. A wire ran out through the window, thence to a pole, thence upward to the kite which could be seen swaying overhead. It was a bluff, raw day; at the base of the cliff 300 feet below thundered a cold sea; oceanward through the mist rose dimly

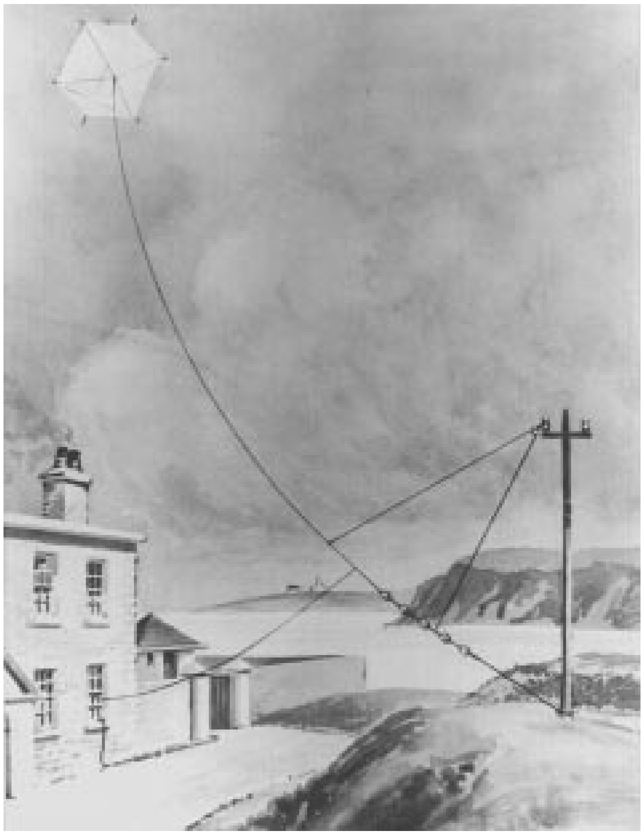


Fig. 3. Artist's rendering of the first transatlantic wireless signal reception.

the rude outlines of Cape Spear, the easternmost reach of the North American Continent. Beyond that rolled the unbroken ocean, nearly 2000 miles to the coast of the British Isles. Across the harbor the city of St. John's lay on its hillside wrapped in fog: no one had taken enough interest in the experiments to come up here through the snow to Signal Hill. Even the ubiquitous reporter was absent. In Cabot Tower, near at hand, the old signalman stood looking out to sea, watching for ships, and little dreaming of the mysterious messages coming that way from England. Standing on that bleak hill and gazing out over the waste of water to the eastward, one finds it difficult indeed to realize that this wonder could have become a reality. The faith of the inventor in his creation, in the kite-wire, and in the instruments which had grown under his hand was unshaken.

"I believed from the first," he told me, "that I would be successful in getting signals across the Atlantic."

Only two persons were present that Thursday noon in the room where the instruments were set up—Mr. Marconi and Mr. Kemp. Everything had been done that could be done. The receiving apparatus was of unusual sensitiveness, so that it would catch even the faintest evidence of the signals. A telephone receiver, which is no part of the ordinary instrument, had been supplied, so that the slightest clicking of the dots might be conveyed to the inventor's ear. For nearly half an hour not a sound broke the silence of the room. Then quite suddenly Mr. Kemp heard the sharp click of the tapper as it struck against the coherer; this, of course, was not the signal, yet it was an indication that something was coming. The inventor's face showed no evidence of excitement. Presently he said:

"See if you can hear anything, Mr. Kemp."

Mr. Kemp took the receiver, and a moment later, faintly and yet distinctly and unmistakably, came the three little clicks—the dots of the letter S, tapped out an instant before in England. At ten minutes past one, more signals came, and both Mr. Marconi and Mr. Kemp assured themselves again and again that there could be no mistake. During this time the kite gyrated so wildly in the air that the receiving wire was not maintained at the same height, as it should have been; but again, at twenty minutes after two, other repetitions of the signal were received.

Thus the problem was solved. One of the great wonders of science had been wrought. But the inventor went down the hill toward the city, now bright with lights, feeling depressed and disheartened—the rebound from the stress of the preceding days. On the following afternoon, Friday, he succeeded in getting other repetitions of the signal from England, but on Saturday, though he made an effort, he was unable to hear anything. The signals were, of course, sent continuously, but the inventor was unable to obtain continuous results, owing, as he explains, to the fluctuations of the height of the kite as it was blown about by the wind, and to the extreme delicacy of his instruments, which required constant adjustment during the experiments.

Once again, it is noticed that Marconi did not reveal what detector he actually used, but it is absolutely clear that he used the telephone to listen to the first transatlantic wireless signal. Although news reporter Baker's technical description may not be very accurate, reading the descriptions, it will be eminently clear to a wireless engineer skilled in the art of wireless signal reception at that time that the detector must be a self-recovering coherer. Marconi's more comprehensive description of the first transatlantic experiment will be described in a later section. Marconi's subsequent descriptions of the reception of the first transatlantic signal throughout his later life and the description of the same by his technical assistant, Vyvyan, will also be examined for consistency and accuracy.

Marconi returned to England on January 30, 1902, and immediately embarked on his second experiment aboard the SS *Philadelphia* to corroborate the success of his first experiment. The transmitting antenna along with the transmitter strength at Poldhu remained the same but this time, Marconi used a tuned receiving antenna system aboard the ship and continually received the signals at regular intervals and recorded the maximum distances at which signals could be received during the day and night. The maximum distance over which signals could be clearly received was 700 mi during the day and 1550 mi at night.

It was proven beyond doubt that wireless waves could bend to the curvature of the earth and reach the new continent.

After the second experiment, Marconi triumphantly returned to England toward the end of April 1902.

V. Unfolding of the Scandal

The first hint at the fact that Marconi received the first transatlantic signal at Signal Hill, Newfoundland, with the "mercury coherer with a telephone" came from a rebuttal by Marconi Company managing director Major S. F. Page in *The Times* of London in response to a letter written by Lodge. This publication, reproduced below, speaks for itself [7]:

> *Atlantic Wireless Telegraphy*—The following letter on the recent alleged achievement of Mr. Marconi appeared in the *Times* on 20th inst. from the pen of Dr. Oliver Lodge, at the University of Birmingham:—"It is rash to express an opinion either way as to the probability of the correctness of Mr. Marconi's evidently genuine impression that he has obtained evidence on the other side of the Atlantic of electrical disturbances purposely made on this side, but I sincerely trust that he is not deceived. He has probably been using as detector the very simple device depicted in my little book on the subject published by *The Electrician,* p. 27; and I know how sensitive this plan is, for with it messages could be easily heard across the Bristol chanel at Weston-super-Mare with a pole only 12 ft high; hence I am not indisposed to credit the assertion that with great power on one side a faint trace could be perceived on the other side even of the Atlantic. The danger of referring even hypothetically to such subjects lies in the fact that needless financial disturbances are sometimes brought about; but, as I have expressed myself critically on some of the early achievements of Mr. Marconi, which from the first were erroneously heralded before the British public as scientific novelties, I should not like to be behindhand in welcoming, even prematurely, the possibility of so immense and barely expected an increase of range as now appears to be foreshadowed. Proof, of course, is still absent, but by making the announcement in an incautious and enthusiastic manner Mr. Marconi has awakened sympathy and a hope that his energy and enterprise may not turn out to have been deceived by the unwonted electrical dryness of the atmosphere on that wintry shore."
>
> In response to Prof. Lodge's letter Major Flood Page says:—"Prof. Oliver Lodge is altogether wrong in his suggestion that Marconi was 'using as detector the very simple device depicted in my little book on the subject.' If this 'simple device' described in a 'little book,' had been the means by which Marconi had received communication from a distance of 2170 statute miles, it would not have made the fact of the communication less wonderful, but Mr. Marconi was using something that principal Lodge has never yet seen. Every advance in scientific industry is always met with doubt, and cavillers are numerous. It is so in this case. It was the same when Marconi communicated at a distance of 14 miles, of 50, and still more of 200 miles, and so it will be until such communication across the Atlantic and further has become a matter of daily use, of hourly experience."
>
> A Laffan dispatch from New York says, "*The Electrical Review,* prints a telegram from Signor Marconi in which he fully confirms the success of his experiments, and adds that he intends to read a paper on the subject before a scientific society as soon as possible."
>
> *The Times* St. John's correspondent on 22nd inst., telegraphed that "the Canadian Government has offered Mr. Marconi every facility to operate on Canadian territory, and has invited him to Ottawa. He has accepted, and goes there on Tuesday." [35]

It needs to be mentioned here that during the first few years, after Marconi arrived in England from Italy in February 1896, and was experimenting with wireless signaling with the help of the British Post Office, most of the scientists of the day in England were not aware of what actually Marconi had invented and discovered. Accordingly, they were expressing opinions that nothing new was being offered by Marconi. The most notable of Marconi's opponents then was Lodge. What Marconi had discovered was revolutionary and simple. By attaching the transmitted Hertzian waves (electromagnetic radiation at radio frequencies) to the ground and using a receiving antenna tuned to the transmitter antenna, Marconi was able to communicate over larger and larger distances with wireless waves. Further, Marconi was first in inventing the Morse code modulator of Hertzian waves. For this discovery and the invention, Marconi is correctly known worldwide as the father of long-distance wireless communication [15].

While Marconi was conducting his follow-up experiment aboard the SS *Philadelphia* across the Atlantic Ocean, word got around in Italy that Marconi received the first transatlantic wireless signal using a new device called the "mercury coherer" with a telephone. Prof. Banti, editor of the Italian publication *L'Elettricista,* published an article [8] claiming that the device was "invented" by one P. Castelli, a signal man of the Italian Navy, and was not Marconi's device. From Marconi's side, it was claimed first that the device was "invented" by Solari, Marconi's childhood friend and also of the Italian Navy, and was presented to Marconi. Marconi then applied for a patent for this device in his own name [16]. Banti's article soon reached England, where Marconi bashing was already in progress. Without knowing Marconi's precise discoveries, and reacting to the news of Marconi's spectacular success, Prof. S. P. Thompson, one of Marconi's prominent inquisitors of the time, began writing letters in a weekly British publication, *Saturday Review*. Phillips has given a comprehensive account of those exchanges [6].

In the first round of exchanges, Thompson's charge [17] was that Marconi had utilized Lodge's work without giving him due credit; on that charge, Marconi gave an excellent rebuttal [18] immediately after returning to England from the second decisive transatlantic tests aboard the SS *Philadelphia*. In the second round of exchanges, Thompson made a vitriolic attack [19] with Banti's statement that the self-restoring mercury coherer was "invented" by Castelli [8]. Marconi once again gave a good rebuttal [20], without discussing the detection device. He charged that Thompson should wait until Marconi had the opportunity to present his results in a forthcoming lecture at the Royal Institution [21]. It may be remarked here that not knowing the precise device that Marconi used in receiving the first transatlantic wireless signal, and apparently having overlooked Bose's work, Thompson did not discover that Marconi used Bose's invention, so prominently displayed in the most prestigious of British publications [4].

These public exchanges in the newspaper disturbed Marconi tremendously. The following correspondence of Marconi with his technical advisor, Prof. J. A. Fleming, just prior to his second reply [20] poignantly captured the issues of the moment.

VI. Fleming–Marconi Private Correspondence

Fleming, the first professor of electrical engineering at the University College London, was appointed a technical advisor to the Marconi Company in December 1899 at 300 British pounds a year. Fleming designed the high-power wireless transmitting plant at Poldhu, Cornwall, England (when this work started, his compensation was increased to 500 British pounds a year).

The design and testing of the transmitting plant was completed by October 1901, but a strong gale destroyed the antenna system erected at Poldhu. Marconi's technical people very soon erected a temporary fan-shaped aerial, and Marconi was ready to embark upon the first transatlantic experiment in December 1901, previously described.

Although Fleming was aware of Marconi's transatlantic wireless communication venture from the very beginning, it was carefully kept secret to the outside world. After Marconi's second experiment aboard the SS *Philadelphia*, which conclusively proved that wireless waves bend to the curvature of the earth and can reach across the Atlantic, and it was announced that Marconi would soon disclose his experimental results in a lecture at the Royal Institution, Fleming wrote to Marconi two letters requesting him to mention his own contributions to the experiment in the Royal Institution lecture, as subsequently revealed in the follow-up correspondence. These two letters, of April 19, 1902, and May 14, 1902, have not been found in the archives and probably did not survive because, most likely, Fleming later destroyed their copies before he bequeathed his papers to the library of the University College London. Fleming was also unhappy, as we would learn many years later from his autobiography [22], that although promised by Marconi, Fleming was not told when the Poldhu wireless station began sending the first transmissions in December 1901.

The two follow-up exchanges reproduced below provide a glimpse of the Marconi–Fleming relationship at a critical time. (See Figs. 4 and 5 for the handwritten correspondence.)

Haven Hotel, Sandbanks,
Near Poole.
May 19, 1902

Telegrams,
Expanse, Poole.

Dear Dr. Fleming,

Many thanks for your interesting letter of the 14th inst. I am very glad to learn of the progress made with the various devices and arrangements which will be necessary for Poldhu. I hope to go there next Wednesday and shall proceed to get the condenser circuits in tune with the big aerial and also to test the strength of the signals between Poldhu and this station.

With reference to what you ask me in your letter of the 19th April, re. my Royal Institution lecture, it is needless for me to say that I had and have every intention to make reference to your work and assistance in connection with the Poldhu plant and I would have done so long ago at other lectures had I not refrained from doing so at your own request.

At the same time you will understand that I have to be careful as to what I say considering the very hostile attitude of certain persons like S. P. Thompson who wish to deny me credit for any and every important invention or detail which I may have originated.

I am sure you have no doubt as to my sincere and high appreciation of your work but at the present juncture it would greatly facilitate my statements re. your assistance in the transatlantic experiments if you could also see your way as a scientific man to protect me in some manner as you have done in the past from the violent and very often unfair attacks to which I have been lately so much exposed.

I would feel extremely obliged if when opportunity presents itself you could give me credit for the essential receiving arrangements which I have devised for use in conjunction with large power plants, the tuning of the different circuits in the transmitters and receivers, the determination of the shape and size of the aerials and the special forms of oscillation transformers which have proved so successful in practice etc.

Hoping to hear from you soon
I remain,
Yours sincerely,
G. Marconi

Dr. J. A. Fleming FRS
University College
London.

P.S. If you write tomorrow—address here, if during the next three days—Poldhu. G. M.

Fleming sent the following reply two days later:

University College, London
Gower Street W.C.
May 21, 1902

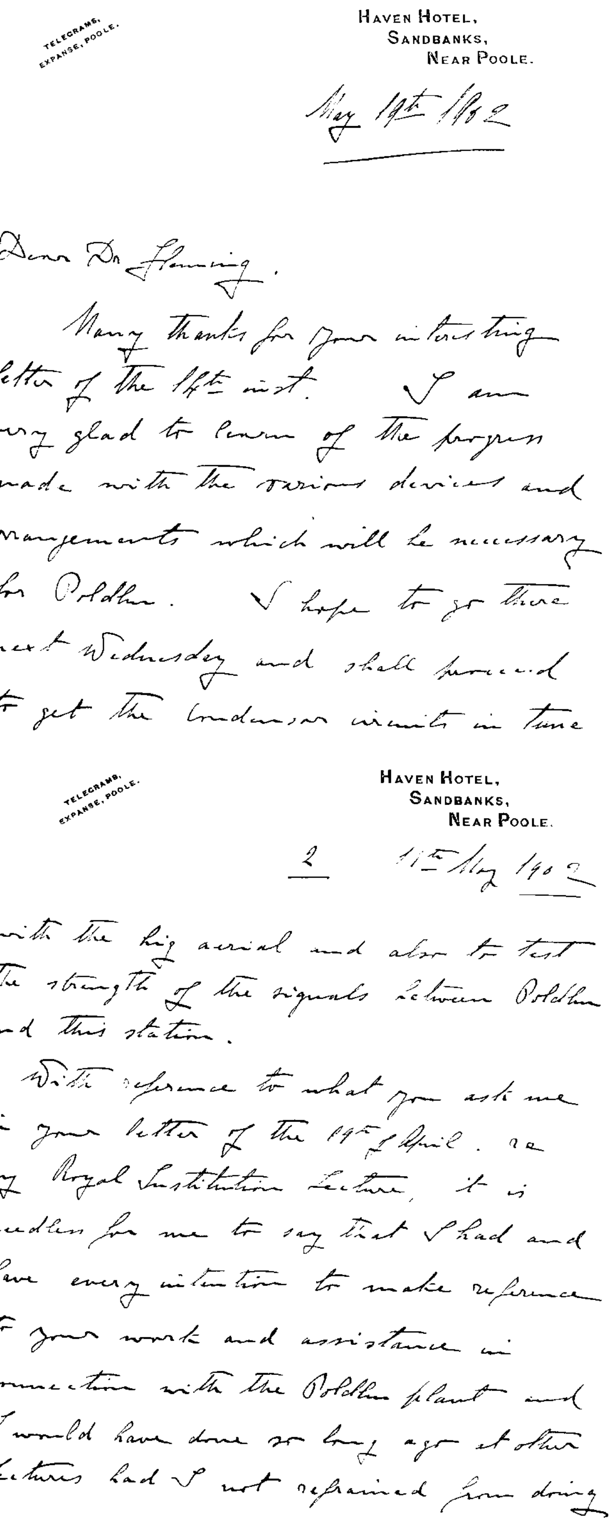
Dear Mr. Marconi,

I thank you for your letter of 19th inst. and for your kind promise to make a reference at your forthcoming lecture to the assistance I have rendered you in the erection of the Power Stations for your Transatlantic telegraphy. You may be quite sure that a generous mention at the Royal Institution of my work for you will not only please me and my friends very much but will call for an equally public acknowledgment on my part of the fact that the achievement is essentially due to *your* inventions. I shall have the opportunity at a lecture I am to give at the College source held here during the Coronation week, and I shall be guided in what to say by the line taken in your lecture a fortnight before. I quite understand that you have to be cautious just now on your public utterances, and there is no doubt that your success has made many opponents desire to take credit from you or ascribe it to someone else.

I did not consider it advisable for me to say anything on patent questions apropos of Thompson's articles because I feel that these very delicate matters may have to be discussed one day in a Court of Law and the less said about them now the better. That however need not prevent you and me from freely acknowledging in general terms our relative shares in the work in which we are both engaged and you may rely on me on that. I shall not fail to repay any kindness that you may show me at the earliest possible occasion in the way you desire.

I am
Yours very truly,
J. A. Fleming

It is eminently clear that Marconi was rattled by Thompson's false accusation that Marconi was using the mercury coherer allegedly "invented" by an unknown technician, Castelli. It is possible to speculate that Fleming may have known that Bose was the true inventor of the "mercury coherer with the telephone" because on an earlier occasion, Fleming and Bose presented papers to the Royal Society at the same session, and Fleming must have been following Bose's work, but he did not mention it anywhere explicitly.[3]


TELEGRAMS, EXPANSE, POOLE.

HAVEN HOTEL,
SANDBANKS,
NEAR POOLE.

May 19th 1902

Dear Dr Fleming.

Many thanks for your interesting letter of the 14th inst. I am very glad to learn of the progress made with the various devices and arrangements which will be necessary for Poldhu. I hope to go there next Wednesday and shall proceed to get the condenser circuits in time

TELEGRAMS, EXPANSE, POOLE.

HAVEN HOTEL,
SANDBANKS,
NEAR POOLE.

2 19th May 1902

with the big aerial and also to test the strength of the signals between Poldhu and this station.

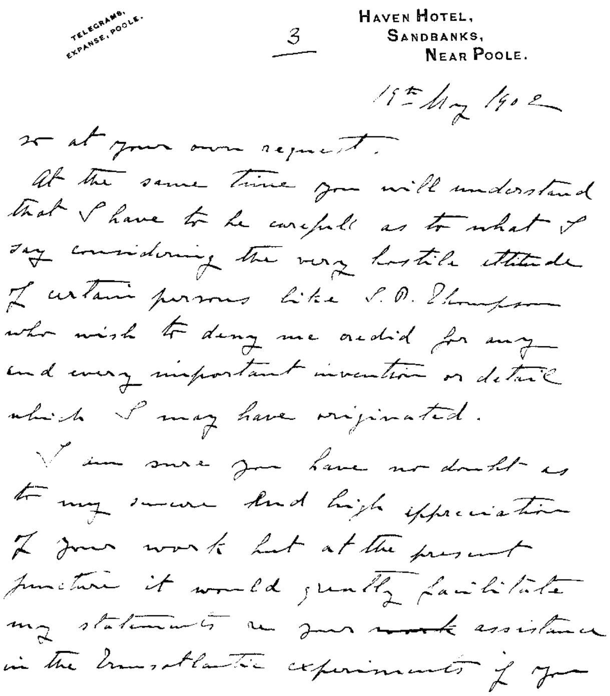
With reference to what you ask me in your letter of the 19th of April re my Royal Institution Lecture, it is needless for me to say that I had and have every intention to make reference to your work and assistance in connection with the Poldhu plant and I would have done so long ago at other lectures had I not refrained from doing

Fig. 4. Marconi's correspondence to Fleming.

VII. Marconi's Lecture at the Royal Institution

On June 13, 1902, Marconi presented the results of his two transatlantic experiments in a lecture at the Royal Institution of Great Britain. Part of that lecture [21] that dealt with the reception of the first transatlantic wireless signal is reproduced below for closer examination of the statements made therein.

[3] On January 28, 1897, Bose personally presented his seminal paper [23] at the Royal Society meeting in London after a presentation by Fleming and Dewar.


TELEGRAMS: EXPANSE, POOLE.

3

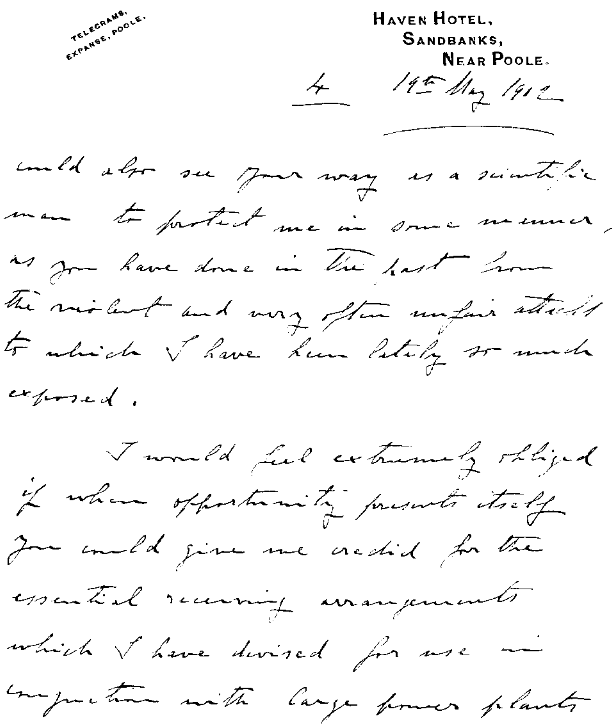
HAVEN HOTEL,
SANDBANKS,
NEAR POOLE.

15th May 1902

so at your own request.

At the same time you will understand that I have to be careful as to what I say considering the very hostile attitude of certain persons like S. P. Thompson who wish to deny me credit for any and every important invention or detail which I may have originated.

I am sure you have no doubt as to my sincere and high appreciation of your work but at the present juncture it would greatly facilitate my statements re your ~~work~~ assistance in the transatlantic experiments if you


TELEGRAMS: EXPANSE, POOLE.

HAVEN HOTEL,
SANDBANKS,
NEAR POOLE.

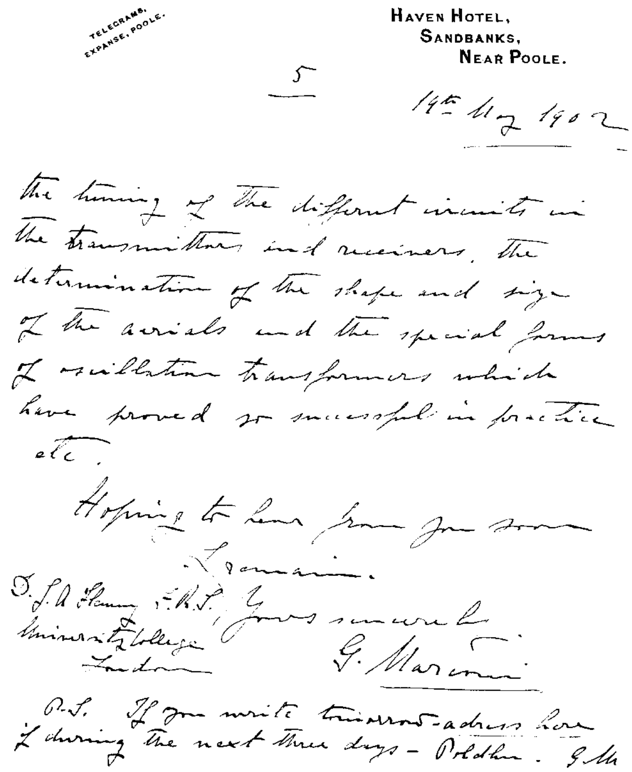
4 14th May 1902

could also see your way as a scientific man to protect me in some manner, as you have done in the past from the violent and very often unfair attacks to which I have been lately so much exposed.

I would feel extremely obliged if when opportunity presents itself you could give me credit for the essential receiving arrangements which I have devised for use in conjunction with large power plants

Fig. 4. *(Continued.)* Marconi's correspondence to Fleming.

Other self-restoring coherers were proposed by Profs. Tommasina, Popoff, and others, but one which has given good results when syntonic effects were not aimed at was (according to official information communicated to me) designed by the technical personnel of the Italian Navy. This coherer, at the request of the Italina Government, I tested during numerous experiments. It consists of a glass tube containing plugs of carbon or iron with between them a globule of mercury. Lieutenant


TELEGRAMS: EXPANSE, POOLE.

HAVEN HOTEL,
SANDBANKS,
NEAR POOLE.

5

14th May 1902

the tuning of the different circuits in the transmitters and receivers, the determination of the shape and size of the aerials and the special forms of oscillation transformers which have proved so successful in practice etc.

Hoping to hear from you soon

I remain.

Dr. J. A. Fleming F.R.S.
University College
London

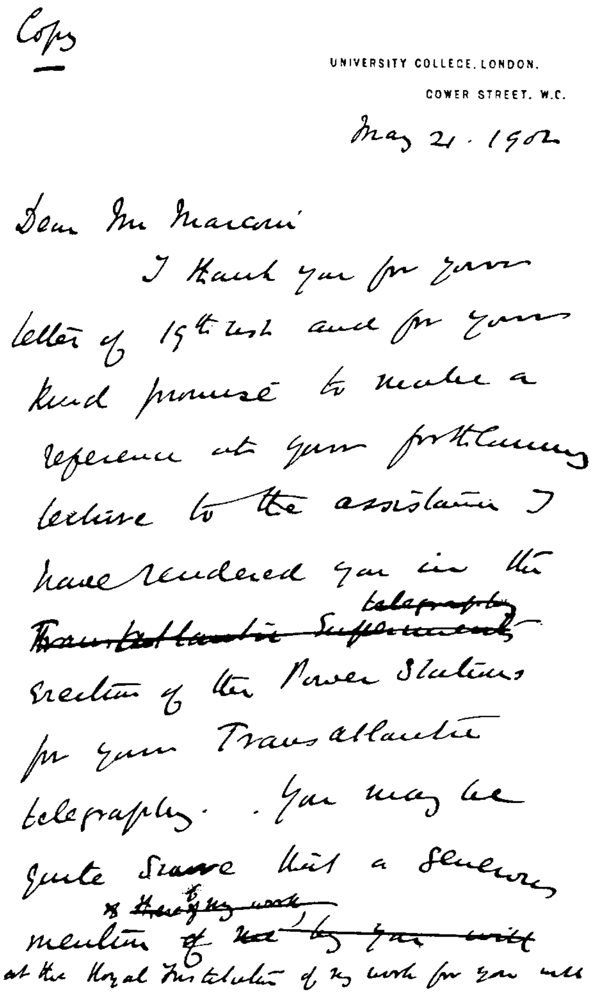
Yours sincerely
G. Marconi

P.S. If you write tomorrow address here if during the next three days - Poldhu. G.M.

Fig. 4. *(Continued.)* Marconi's correspondence to Fleming.

Solari, who brought me this coherer, asked me to call it the "Italian Navy Coherer." Recently, however, a technical paper gave out that a signalman in the Italian navy was the inventor of the improved coherer, and I was at once accused in certain quarters of suppressing the alleged inventor's name. I therefore wrote to the Italian Minister of Marine, Admiral Morin, asking him to make an authoritative statement, to which I could refer in the course of this address, of the views of the Italian Admiralty on the matter. The head of the Italian Navy was good enough to reply to me by a letter, dated the 4th inst., in which he makes the following statement, which I have translated from the original Italian:—"The coherer has been with good reason baptized with the name of 'Italian Navy Coherer,' as it must be considered fruit of the work of various individuals in the Royal Navy and not that of one." These nontapped coherers have not been found to be sufficiently reliable for regular or commercial work. They have a way of cohering permanently when subjected to the action of strong electrical waves or atmospheric electrical disturbances, and have also an unpleasant tendency toward suspending action in the middle of a message. The fact that their electrical resistance is low and always varying, when in a sensitive state, causes them to be unsatisfactory for the reasons I have already enumerated when worked in connection with my system of syntonic wireless telegraphy.

These coherers are, however, useful if employed for temporary tests in which the complete accuracy


Copy

UNIVERSITY COLLEGE, LONDON.
GOWER STREET. W.C.

May 21. 1902

Dear Mr Marconi

I thank you for your letter of 19th inst and for your kind promise to make a reference at your forthcoming lecture to the assistance I have rendered you in the ~~Transatlantic Experiment~~ telegraphy erection of the Power Stations for your Transatlantic telegraphy. You may be quite sure that a generous ~~* though my work~~ mention ~~of me by you will~~ at the Royal Institution of my work for you will

Fig. 5. Fleming's reply.

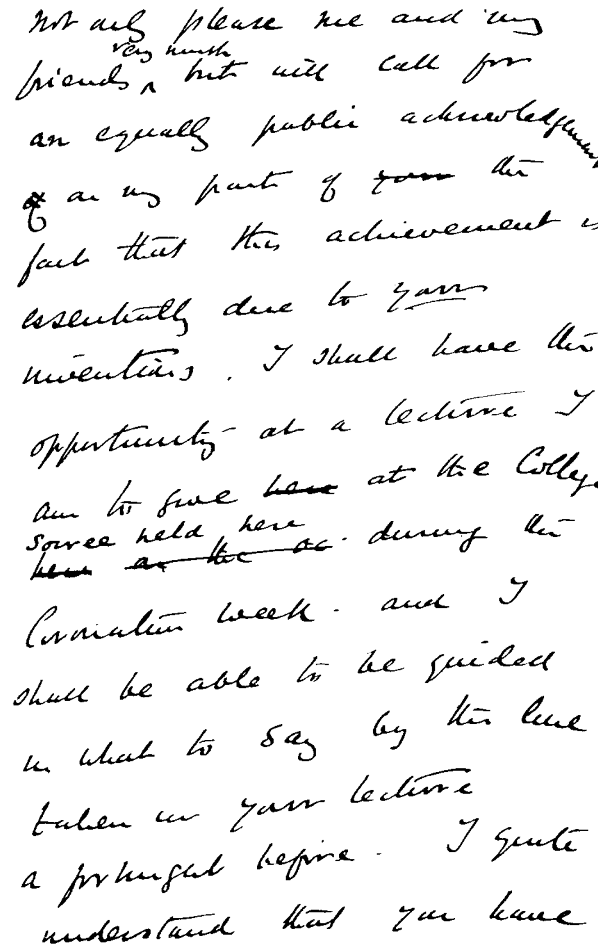

not only please me and my very much friends, but will call for an equally public acknowledgment ~~of~~ as any part of your the fact that this achievement is essentially due to your inventions. I shall have the opportunity at a lecture I am to give ~~here~~ at the College Soiree held here ~~here on the~~ &c. during the Coronation week and I shall be able to be guided in what to say by the line taken in your lecture a fortnight before. I quite understand that you have

Fig. 5. *(Continued.)* Fleming's reply.

of messages is not all-important, and when the attainment of syntonic effects is not aimed at. They are especially useful when using receiving vertical wires supported by kites or balloons, the variations of the height of the wires (and, therefore, of their capacity) caused by the wind making it extremely difficult to obtain good results on a syntonic receiver.

By using coherers containing very fine filings the necessary condition of nonconductivity when in a sensitive state is obtained. Coherers have lately been tried which will work to a certain extent satisfactorily without the necessity of employing any tapper or decoherer in connection with them. Nearly all are dependent on the use of a carbon microphonic contact or contacts which possess the curious quality of partially re-acquiring spontaneously their high resistance condition after the effect of the electrical oscillations has ceased. This enables one to obtain a far greater speed of reception than is possible by means of a mechanically-tapped coherer, the inertia of the relay and tapper which are used in connection with it being necessarily sluggish in their action. In all these self-decohering coherers a telephone which is affected by the variations of the electric current, caused by the changes in conductivity of the coherer is used in place of the recording instrument. It has not yet been found possible, so far as I am aware, to actuate a recording instrument or a relay by means of a self-restoring coherer. The late Prof. Hughes was the first, I believe, to experiment with and receive signals on one of these coherers associated with a telephone. His experiments were carried out as early as 1879, and I regret that this pioneer work of his is not more generally known.

This is the most significant historical document describing Marconi's statements on his first transatlantic wireless signaling experiment, and as such needs to be critically analyzed. As already discussed, the "mercury coherer with a telephone" detector was the invention of Bose that Marconi had actually used. Marconi failed to acknowledge that because he had already applied for a patent in his own name for a trivially modified version of Bose's invention (instead of Bose's mercury-filled U-tube, Marconi used a globule of mercury in a linear glass tube). It should be noticed here that Marconi makes it clear that he knew of Prof. Tommasina's work, and Marconi clearly states that the "mercury coherer with a telephone" was *not* Tommasina's invention. Needless to say, Marconi is absolutely clear also that Castelli, the

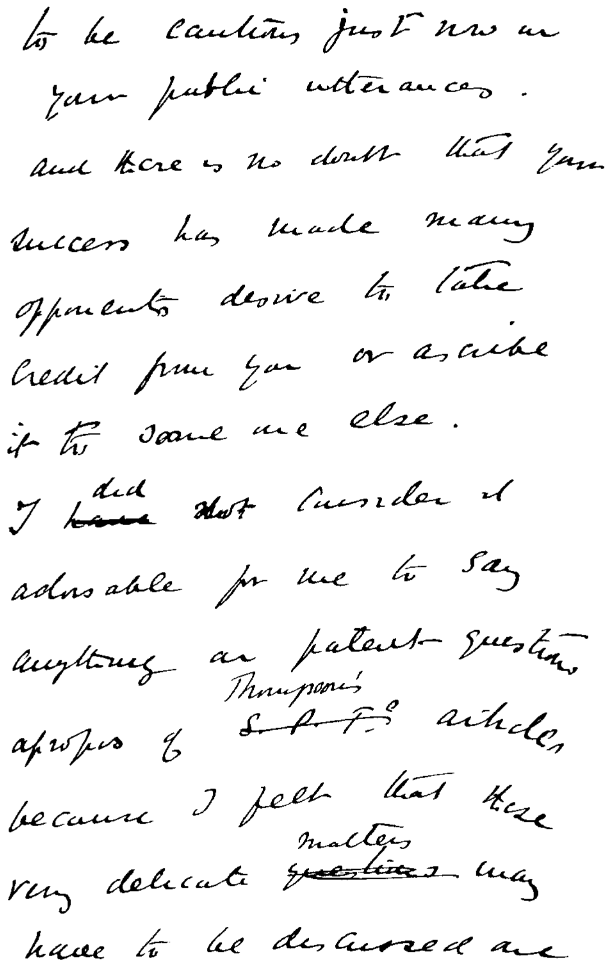

to be cautious just now in
your public utterances.
And there is no doubt that your
success has made many
opponents desire to take
credit from you or ascribe
it to some one else.
I did not consider it
advisable for me to say
anything on patent questions
apropos of Thompson's articles
because I felt that these
very delicate matters may
have to be discussed one

Fig. 5. *(Continued.)* Fleming's reply.

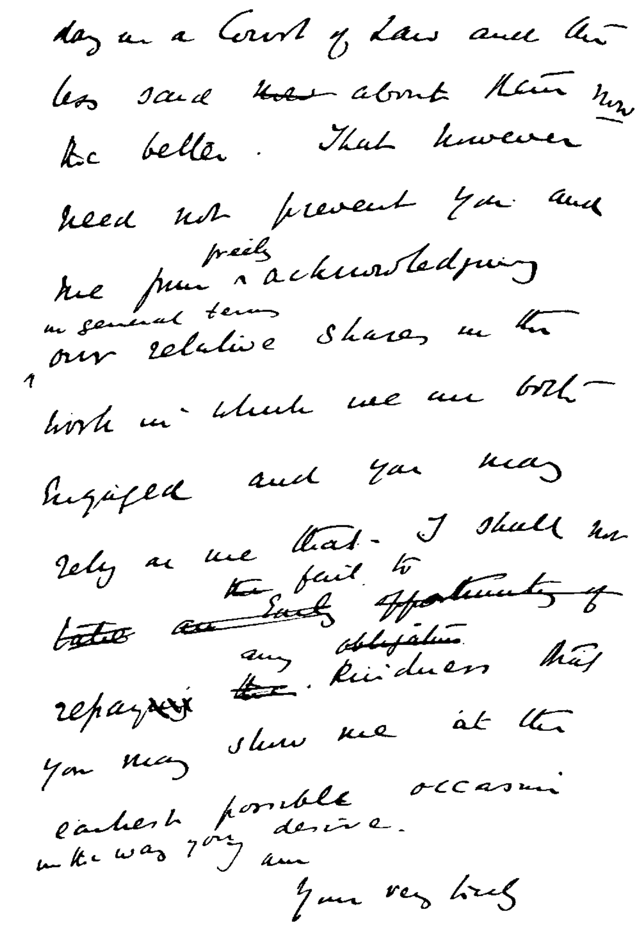

day in a Court of Law and the
less said about them now
the better. That however
need not prevent you and
me from freely acknowledging
in general terms
our relative shares in the
work in which we are both
engaged and you may
rely on me that I shall not
fail to
repay any kindness that
you may show me at the
earliest possible occasion
in the way you desire.
I am
Yours very truly

Fig. 5. *(Continued.)* Fleming's reply.

technician, was also *not* the inventor. Marconi deliberately created a smoke screen by involving officials of the Italian Navy and also creating a bogus confusion that other kinds of detectors were also used to receive the first transatlantic signal.

Knowing full well that the telephone was invented by Bell in 1876 [24], that the late Prof. Hughes did not experiment with the mercury coherer, and that Hughes' experiments were conducted before Hertz verified the existence of the wireless waves, Marconi raised more clouds of dust to confuse the real situation to distract his antagonists. It needs to be noticed here that Marconi stated that the mercury coherer was designed by people in the Italian Navy but failed to mention who was the real inventor. These revelations, however, made it clear that Marconi did *not* invent the device for which he applied for the following patent [16]:

> Improvements in Coherers or
> Detectors for Electrical Waves
>
> I, Guglielmo Marconi, of 18 Finch Lane in the City of London, Electrician, do hereby declare the nature of this invention to be as follows:
>
> Coherers made according to this invention consist of a drop of conducting liquid lying between two conductors. I employ a glass tube having in it two plugs whose distance apart can be adjusted with the liquid between them. Preferably one plug is of steel and the other is of carbon, whilst the liquid is mercury. Dated this 9th day of September 1901.

Much to his embarrassment, Marconi had to face the humiliation of modifying this patent application to state that he was patenting a device that he received as a "gift" from the Italian Navy [25] and did not invent.

> The Castelli Coherer
>
> Special interest attaches to the recent publication, so long delayed, of Patent Specification No. 18 105 of Sept. 1901. This is the specification which was originally filed by Marconi in his own name, and which, closely following upon certain correspondence in the *Saturday Review* and in *The Times* between Sr. Marconi and his associates on the one part, and Dr. Silvanus Thompson on the other, was amended on July 16th, 1902 (see *Official Journal of the Patent Office,* p. 961, and *Electr. Rev.,* July 25, p. 153), "by converting it into an application for a patent for an invention communicated to him from abroad by the Marquis Lingi [*sic*] Solari, of Italy." The whole substance of this invention is practically contained in the first sentence of the specification, which reads as follows:—"Coherers made according

> to this invention consist of a drop of conducting liquid lying between two conductors." [25]

VIII. Later Statements on the First Transatlantic Wireless Signal Detector

To divert attention away from growing criticisms that Marconi had been using others' work without giving them due credit and to quench the curiosity and criticisms as to who was the real inventor of the "mercury coherer with the telephone," Marconi created a deliberate confusion in his Royal Institution lecture that several kinds of detectors were in fact used by him to detect the first transatlantic signal. That statement [21], however, did not coincide with his earlier statement at the AIEE Annual Dinner [13] before the most distinguished American audience. As we shall see now, Marconi's later statements do confirm repeatedly that it was the device that detected the first transatlantic wireless signal, thus reaffirming that Marconi was quite disturbed by the public criticism initiated by his own countrymen (Italians). In 1903, Marconi wrote in his weekly publication *Marconigram* [26]:

> The critical moment had come, for which the way had been prepared by six years of hard and unremitting work, despite the usual criticisms directed at anything new. I was about to test the truth of my belief.
>
> In view of the importance of all that was at stake, I had decided not to trust entirely to the usual arrangement of having the coherer signals record automatically on a paper tape through a relay and Morse instrument, but to use instead a telephone connected to a self-restoring coherer. The human ear being much more sensitive than the recorder it would be more likely to hear the signal.

Near the end of Marconi's life, in 1936, in an authorized Marconi biography [2], O. Dunlap quoted the following Marconi statement:

> I ran my wire though a window in the barrack, thence to an old telephone pole, where it was attached to the kites. For this especial experiment I had devised an especially sensitive coherer of a new type and instead of depending on the ordinary Morse Inker for printing the signals I had substituted a telephone receiver, believing that I could then detect much fainter signals, should the wave effects be very light.

In the above statements, Marconi, near the end of his life, says, "I had devised an especially sensitive coherer of a new type," whereas in his June 13, 1902, Royal Institution lecture quoted in Section VII, Marconi said that the self-restoring coherer was "designed by the technical personnel of the Italian Navy" and went on to mention "Lieutenant Solari, who brought me this coherer."

One can see the striking discrepancy between Marconi's two statements. There is mention neither of Solari nor of the Italian Navy in [2]. Marconi, in this book [2], whose proof he thoroughly read in 1936, did not call the device the "Italian Navy coherer."

Vyvyan, Marconi's technical assistant, first started construction of the wireless transmitter at Poldhu, Cornwall, that transmitted the first transatlantic wireless signal. In his book [3], written a quarter-century later, he definitely confirmed that the self-restoring mercury coherer was the device that made the detection possible. Vyvyan, however, did not disclose who was the real inventor of that device. He only stated that it was "of Italian Navy Design."

> The kite was rising and falling in the wind throughout the experiments and varying the electrical capacity of the aerial. It was impossible to use, therefore, any form of syntonic apparatus and Marconi was obliged to employ the next best means at his disposal. He therefore used a highly sensitive self-restoring coherer of Italian Navy design, simply connected in series with a telephone and the aerial, and with this simple receiving apparatus on Thursday, December 12, 1901, he and one of his two assistants heard the faint S signals.

It is now eminently clear that neither Marconi nor his assistants nor his biographer—and, in fact, no one else so far—had disclosed or identified the real and true inventor of the "mercury coherer with a telephone" that played such a revolutionary role in the history of the technological revolution.

IX. Following the Marconi–Solari Trail

To ascertain the true origin of the mercury coherer that Marconi received from Solari, it is necessary now to follow Solari's public statements carefully. There exist two publications of Solari's in the English journals in the form of letters to the editor. One is dated July 3, 1902 [27], which was followed by a response from Thompson [28] and was then followed by Banti's publication [29] claiming that Castelli and Solari "independently invented" the mercury coherer. The other Solari letter was of July 10, 1903 [30], in response to a letter published by one E. Guarini [31]. Both of these Solari letters are of major historical significance and are reproduced in full in time sequence.

In these letters, Solari says that he never received the mercury coherer from Castelli, nor did he know of Captain Bonomo's work when he, Solari, brought the mercury coherer to Marconi in the summer of 1901. Solari also said that he never heard of Tommasina's work until after Marconi's Royal Institution lecture of June 13, 1902. He says emphatically that he did not invent the mercury coherer. Then from where did Solari get it?

Solari gives the hint that he got the "mercury coherer with a telephone detector" from the English literature but falls short of telling that it is from the 1899 *Proceedings of the Royal Society*. He then tries to mislead the reader by pointing to irrelevant publications, as Phillips has pointed out [6]. Solari's first letter [27], which follows, asserted that neither Solari nor Castelli was the inventor of the "mercury coherer":

Mr. Marconi and the Italian Government
To the Editor of *The Times*

Sir—Upon my arrival on the 13th ult. from Italy, where, after a considerable period spent in the study of wireless telegraphy in Mr. Marconi's English stations, I have for some months past been engaged in supervising the installations of Marconi apparatus on Italian warships and at land-stations controlled by the Italian Navy. I learnt with deep regret that Professor Silvanus Thompson has thought fit in the columns of a weekly review to accuse Mr. Marconi of having made use in an undue manner of a mercury coherer, the property of the Italian Government, and the name of the inventor of which he is alleged to have deliberately concealed.

I am glad to be able, by the order of my Admiral and with the express authorization of my Government to state that the coherer in question, which was not, as alleged, the invention of Castelli, was offered to Mr. Marconi by myself, acting upon the instructions of my Minister, in consideration of the deep affection and gratitude cherished by the Italian Navy for our illustrious inventor. Mr. Marconi in accepting this offer, inquired of me with insistence by what name the new coherer ought to be designated. It was I who suggested to him that it should be called the "Italian Navy Coherer," although the model brought over to England by me had, in fact, been devised in the stations under my own immediate supervision, with which stations the above mentioned naval signalman Castelli had nothing whatever to do. This suggestion received the approval of my Government, which was communicated to Marconi subsequently in an official letter signed by the Minister of Marine and dated the 4th ult., from which letter I see that Mr. Marconi read an extract in the course of his discourse at the Royal Institution on the 13th ult. By way of confirmation of the above statement, so far as it affects my own position in the matter, I may mention that I am in possession of official authorization to take out patents for the said coherer in my own name, and I would, furthermore, call attention to the following passage, which I take from a letter addressed under date May 26 last by the director of the stations in which this signalman was employed to Professor Banti, the editor of *L'Elettricista:*—"To my sincere and intense regret the researches of Lieutenant Solari were not communicated to me at the time when I was conducting the experiments at Leghorn." And if any one should wonder what can be the explanation of my delay in taking out patents for this invention of my own, I may say that I have always been dissuaded from such a recourse by my recollection that the idea of the employment of mercury had been suggested to me by something which I had read in some English publication which I found myself unable to trace, as well as by certain researches of Ridberg. I have now, however, succeeded in tracing the former to Fahie's "History of Wireless Telegraphy," published in September, 1899, which shows (see p. 320, par. 10) that so early as March 2, 1897 (i.e., about three years prior to any employment by me of mercury for purposes of wireless telegraphy). Mr. Marconi himself had already patented "The use of Mercury in sensitive imperfect electrical contacts."

What I have said finally clears up, I think, an incident occasioned by a just scruple on my part and by an excessive delicacy on the part of Mr. Marconi. It will also, I hope, make clear that it is unnecessary, as it is unasked and superfluous, that any one outside the service of his Majesty the King of Italy, and least of all a foreign professor, should take upon himself the protection of a subordinate official of the Italian Navy, whose rights, as those of every man, of whatever rank, in the Royal Service in Italy, are perfectly safe in the hands of his official superiors, who may be trusted to accord them the most scrupulous protection.

I think I have shown in the clearest possible way how groundless have been these accusations brought against Mr. Marconi whose position in the matter could not have been more considerate or more correct, and in conclusion, I am happy to attest publicly that whilst no attacks made by so unscrupulous a controversialist as Professor Thompson has shown himself to be could alter in any sense the affectionate esteem in which Mr. Marconi is held by the people of Italy, and whilst I was glad to be able to demonstrate to Mr. Marconi by the offer of the Mercury coherer the affection in which he is held by the Italian Navy, still more do I rejoice to recognize that this great inventor has no need of the cooperation of any one, and that the new discovery of the magnetic detector, recently announced to the world, has demonstrated once more to the most severe critic that it is not the work of any one but himself that confers glory upon my illustrious fellow-countryman, but a personal genius so weighty that it makes ridiculous any controversy upon his merit. Thanking you for the courtesy of space in your columns for this statement.

I am yours faithfully,
Marchese Solari, Royal Italian Navy.
Flagship Carlo Alberto, Weymouth, July 1.

Phillips pointed out [6] that Solari's reference to Marconi's use of mercury in the above-mentioned letter is not related to self-restoring coherers, and hence that reference is clearly fraudulent.

One year later, in June 1903, Guarini published an article [31] in which he dismissed the earlier claims of Banti that Castelli was the "inventor" of the mercury coherer and introduced the name of Prof. Tommasina of

Genoa as having priority in the "invention." Banti by now had disappeared from the scene. The Guarini letter is reproduced below in full:

The Real Inventor of the Mercury Coherer
E. Guarini

An animated controversy has been recently carried on in the German, American and especially English technical and even daily press as to the real inventor of the mercury coherer which Marconi used for his first transatlantic experiments in December, 1901.

Let us recapitulate the facts: In the course of a lecture before the Royal Society in London Marconi stated that he had used for the reception of the signals "S" the mercury coherer of the Royal Italian Navy, invented by the naval lieutenant Solari. This declaration was taken advantage of by Marconi's adversaries—and he had as many admirers—who disputed his merits in connection with the transatlantic experiments and transferred the honor to Solari. But the latter modestly declined these honors and the merits attributed to him, declaring himself a simple disciple of Marconi. Then Dr. Banti, director of *L'Elettricista,* intervened in a very animated article, pointing out that in reality it had been invented by a sub-officer, Sig. Castelli.

The question now seemed to be settled in favor of Sig. Castelli, when Prof. Tommasina, a modest and distinguished savant of Geneva, and well known by his interesting experiments and researches in connection with wireless telegraphy, placed at our disposal quite a series of new data of such a nature as to warrant the reopening of the discussion. The result of an investigation into these documents is that neither Lieut. Solari nor Sig. Castelli, but Prof. Tommasina is the inventor of the mercury coherer which was used to inaugurate the wireless transatlantic telegraphy, a fact that has been ignored by most writers on the subject.

Indeed, in the publication *Telegraphia senza fili,* by the naval captain Quintino Bonomo (Rome, 1902) in the chapter on the "Summary of Experiments carried out between September 1, 1900, and May 18, 1901," p. 11, the following passage occurs: "It was our intention to carry out a complete set of studies with Marconi's apparatus before experimenting with the methods proposed by Popoff and Tommasina, when a desire expressed by the semaphorist Castelli induced us to carry out an experiment—independent of those already commenced—with telephonic reception by means of a little tube of his construction. The result was excellent, and the little tubes devised by Castelli, with electrodes of iron or carbon with one or more globules of mercury, were not only extremely sensitive, but also decohered perfectly. . . ."

Now the facts are these: After his first "Note sur les Cohereurs à Charbon" ("Note on Carbon Coherers"), March 13, 1899, Prof. Tommasina communicated a note to the *Comptes Rendus* de l'Acadèmie des Sciences of Paris of May 1, 1899, "Sur la Production de Chaines de Dèpots Electrolytiques," &c. (On the Production of Electrolytic Chains and Deposits," &c), which begins with these words: "In my researches relating to coherers with single contact, after having obtained very sensitive ones by means of a drop of mercury placed in a glass tube between two brass electrodes of cylindrical shape. . . ." Furthermore, in a supplement to the abstract of the "Archives de la Sociètè de Physique et des Sciences Naturelles" of Geneva will be found in a communication by Prof. Tommasina, dated May 3, 1900, wherein he claims priority to Popoff in connection with the use of the telephone, and he mentions, amongst the different decohering coherers, a coherer consisting of a drop of mercury between two carbon electrodes.

Therefore, while the Italian Navy was making experiments with the Marconi system—unsuccessful experiments, according to Capt. Bonomo—*L'Elettricista* of Milan published in its issue of July 7, 1900, p. 418, a resume of Prof. Tommasina's communication of May 3, under the title "Nuovo Esperienzo sulla Autodecoerazione." Certainly Sig. Castelli would have read the article and had hastened to profit by it. In his records on his experiments—we are told by Prof. Tommasina—there are to be found all his experiments relating to the mercury coherer, including those with iron electrodes (which are not attacked by mercury), and which gave excellent results. Prof. Tommasina prefers those of carbon, and that because the mercury oxidises and then loses its sensibility and the regularity of its action.

From the foregoing, we therefore conclude that it is Prof. Tommasina, and not Lieut. Solari nor Sig. Castelli, who is entitled to share with Marconi the honor of having inaugurated transatlantic telegraphy with the aid of the mercury coherer combined with a telephone.

Solari, in response to Guarini's new revelations, again reiterated that the device that he experimented with was not what Tommasina had disclosed or worked with. As it is clear from the following full text of his letter, Solari certified the claim on behalf of Tommasina as being bogus [30]:

The Real Inventor of the Mercury Coherer
To the Editor of *The Electrician*

SIR: In *The Electrician* of June 19, there appears an article by Signor Emilio Guarini, concerning the priority of the mercury coherer, in which it is alleged that in the course of a lecture delivered before the Royal Society in London, Marconi stated that he had employed, for the reception of "S" signals across the Atlantic, a mercury coherer of the Royal Italian Navy, invented by Lieut. Solari.

I should be interested to see an attempt to produce a verbatim quotation of any such statement, but appreciating the difficulty of sifting out the truth from a mass of sensational articles, each of which seems content to take its facts from a predecessor of similar character, I shall merely point out that what Mr. Marconi stated (at the Royal Institution on June 13, 1902, and not at the Royal Society, where the subject was not mentioned) was, that it was I who brought to him the coherer which, upon my proposal, sanctioned by the Minister of Marine, Admiral Morin, in an official letter, dated June 4, 1902 (see p. 9 of Report published by the Royal Institution in June, 1902) was named the Royal Italian Navy Coherer.

In consequence of a controversy raised by ill-informed persons, I published in *The Times*, in July 1902, a letter in which I stated that I had at no time personally advanced a claim to priority in the invention of the Mercury coherer since I was under the impression that the idea of employing mercury in the manner in question had been suggested to me by passages in scientific publications which, in consequence of the lapse of time, it was difficult for me to trace precisely, and I instanced accordingly only one or two examples. To the present claim of Prof. Tommasina, therefore, I can only reply that I am very glad to add his name to those of the other investigators who preceded me in the application of mercury as a self-decohering body, and among whom should not be forgotten Wilson who patented the first mercury coherer in London in the year 1897. In any case, however, the coherer called the "Royal Italian Navy Coherer" is constructed in an entirely different manner from those suggested by Wilson and by Tommasina, and is the fruit of a long series of experiments which brought to light the importance of certain special and extremely delicate arrangements calculated to increase the efficiency of this radio-conductor.

For my own part, then, I wish to remark that my present intervention in the controversy is occasioned solely by inexact statements which have received publicity in the past, and is directed toward the making clear of what share in the matter is due to my own experiments guided by my readings in scientific publications, to which, so far as has been possible, I have endeavored to refer just merit, differing here in my proceeding from those who would credit the idea of the mercury coherer to the brilliant devising of any one person. On the other hand, even before the controversy on the subject arose, I attached no great importance to the invention in question, since, as a result of the prolonged labor which I devoted to it, and which represented, perhaps, a larger than any other individual contribution, I was the first to recognize to what a small degree this coherer satisfies the exigencies of a practical commercial radiotelegraphic service.

With regard, again, to the first radio-telegraphic transmission across the Atlantic, it seems to me that there can be no doubt that the one and only admissible testimony on that point is that of Mr. Marconi, since the said communication having been effected by himself alone, it must be allowed to himself to state the methods he employed. I fail to understand how or why persons who were not present at the experiment in question should affect to accept in part and not in their entirety the statements made at the Royal Institution on June 13, 1902, by Mr. Marconi, who on that occasion, after having affirmed the efficiency of the powerful transmission obtained from the station at Poldhu, proceeded to render in the clearest manner public justice to the greater or less sensibility of the various receivers employed in Newfoundland (and not of the mercury coherer exclusively)—receivers which contributed to establish even more certainly the possibility of radio-telegraphic communication across the Atlantic, but which was, on the contrary, only reached on December 20, 1902, by means of Mr. Marconi's own new receiver, the magnetic detector.—Yours, &c.,

Rome, July 5. Marquis Luigi Solari

From Solari's above-mentioned publication, it is clear that neither Castelli nor Tommasina was the inventor of the "mercury coherer with a telephone." Solari clearly states as well, that he, Solari, did not invent it, nor of course did Marconi. Solari also claimed to be suffering from selective amnesia and did not remember which English publication he got the idea from. At this point one may recall Marconi's reference in his Royal Institution lecture [21] to Hughes' 1879 work and see that Solari never referred to Hughes' work (Hughes did not work [32] with the mercury coherer) whereas it was Solari who brought the mercury coherer to Marconi in the summer of 1901. Therefore, the notion that this detector device was invented in the Italian Navy is eminently fraudulent.

In fact, with the prior knowledge of Bose's publication in the *Proceedings of the Royal Society* [4], if one reads this last letter of Solari's [30], one will notice clearly that he was hinting at the Bose publication when he wrote:

> I shall merely point out that what Mr. Marconi stated (at the Royal Institution on June 13, 1902, and not at the Royal Society, where the subject was not mentioned).

The most important aspect of Marconi's first transatlantic wireless experiment was the detection of the signal in Newfoundland in the afternoon of December 12, 1901. Why did Marconi *not* mention "the subject" at the Royal Society? Could it be because he was using Bose's invention, which was published in the *Proceedings* of that very society?

X. Following the Tommasina Trail

Marconi never in his lifetime said that Tommasina might have invented the mercury coherer that he used to detect the first transatlantic signal on December 12, 1901, at Signal

Hill, Newfoundland. In fact, in his Royal Institution lecture of June 13, 1902, Marconi did mention Tommasina's name with many others as having done work on self-coherers but very clearly did not at all associate Tommasina's name with the "Italian Navy Coherer" [21]. If Tommasina had anything to do with the mercury coherer that Marconi used, Marconi, who was the foremost experimenter with wireless communication at that time, should have known Tommasina's work at that time.

Solari never claimed that his work of 1901, which leads to his giving the mercury coherer to Marconi in the summer of 1901, originated from Tommasina's work. Solari's letter of July 3, 1902, had no mention of Tommasina. Only after Guarini pointed out some detector work of Tommasina did Solari, clearly surprised, write back to add Tommasina's name to the detector work, but he did clearly say that the mercury coherer that he gave to Marconi was definitely not Tommasina's work. Solari even claimed that he, Solari, did not invent the mercury coherer.

Banti, who first exposed the scandal without knowing the full story, never mentioned Tommasina's work with the so-called Italian Navy coherer. Banti disappeared from the scene when Tommasina's alleged work with the mercury coherer was brought out by Guarini. Banti obviously never said that Castelli, whose work was allegedly taken by Solari but not mentioned by him, derived his knowledge from Tommasina.

Guarini *never* claimed that Solari derived his knowledge from Tommasina about the mercury coherer that Marconi used.

Prof. Tommasina never claimed that Solari or Marconi or Castelli might have derived the knowledge about the mercury coherer from him.

Having said all that, it is necessary to examine what Tommasina had actually done on the mercury coherer prior to December 12, 1901.

Guarini refers to Tommasina's earliest work [31], which is as follows:

> Electrolytic Coherers—A very sensitive coherer may be constructed by enclosing a drop of mercury in a glass tube between two cylindrical brass electrodes. This fact was discovered by T. Tommasina, and led him to investigate the properties of liquids with reference to electromagnetic waves. For this purpose he immersed a copper disc and a pendulum bob in distilled water. Both conductors had previously been coated with a film of electrolytic copper and well washed. On passing a current through the two electrodes, a black deposit was formed on the disc, which grew until a chain of particles, probably cupric oxide, joined the two electrodes. On increasing the distance between them, the current was not interrupted, but the chain grew until it again united both electrodes, even when 3 cm apart. The chain followed the pendulum bob on displacing the latter to the right or to the left. The chain is sometimes invisible. If a small incandescent lamp is inserted in the circuit, and the bob suddenly removed to 3 cm, the lamp remains alight even before a visible chain is formed. When the distance between the electrodes is very small, a chain may be formed simply by the action of electromagnetic waves, and the author has constructed a coherer on that principle, with a very thin layer of distilled water. [33]

There is no mention anywhere that Tommasina ever used a telephone as a listening device in conjunction with his mercury-related coherer. The remark that refers to a work that was done many months after Bose's work stated clearly that Tommasina did not work with iron or carbon contacts. Tommasina's subsequent writings, as pointed out by Phillips [6], did not establish any claim of Tommasina's work with the mercury coherer that Marconi used. It becomes apparent that Tommasina had followed in May 1900 Bose's work, a year after it was published by the Royal Society, London in April 1899 [4].

If the so-called Italian Navy coherer originated from Tommasina, then how is it that Banti, who declared "the end of a scandal" in July 1902 [29], did not mention that?

Further, whatever experiment he had done with the mercury, it was done after March 6, 1899, when Bose's paper was communicated to the Royal Society by Lord Rayleigh. Therefore, any claim that Tommasina might have invented the mercury coherer, which neither Solari nor Castelli nor Marconi had known about as of June 13, 1902, is absolutely without merit and is, in fact, fraudulent.

XI. Revisiting the Historic Timeline

At this point, it is instructive to revisit the accurate timeline on the true origin of the "mercury-iron contact with a telephone" detector device and critically examine its alleged origin in Prof. Tommasina's work. As we have already seen, Solari vehemently denied that he got the device from Castelli [27]. Solari also said that he was never aware of Tommasina's work. When Solari did become aware of Tommasina's work, he stated clearly that Tommasina did not work with the device that Solari gave to Marconi [30] for use in detecting the first transatlantic wireless signal.

As Phillips pointed out [6], on June 4, 1903, more than seventeen months after the first transatlantic experiment, Tommasina claimed to have received a letter from the Italian Minister of Marine that his work was known to them and that his priority in the invention of these coherers was not contested. If the integrity of the honorable Italian Minister of Marine is not to be questioned, then it is fair to conclude that he can be trusted to have communicated Tommasina's work to Marconi before Marconi delivered his lecture on June 13, 1902. Marconi clearly stated (quoted earlier in this paper) that the device he used to receive the first transatlantic wireless signal was not invented by Tommasina. Therefore, subsequent claims attributed to Tommasina by others or as claimed by Tommasina himself are totally fraudulent.

Phillips examined Tommasina's publications and asserts [6] that Tommasina's work with the telephone [6], [31] took place in May 1900, more than a year after Bose's work was reported to the *Proceedings of the Royal Society*, and in almost certainty was triggered by Bose's published work.

XII. Marconi and Sir J. C. Bose

Was Marconi then an intellectual thief? The initial accusation by his own countryman Banti was just that. But his accusation did not stand further scrutiny. Marconi was a great benefactor of mankind, and, as we are about to explore below the professional relationship that existed between Bose and Marconi, it becomes eminently clear that Marconi had cleverly utilized Bose's work in his long-distance signaling work as Bose had intended it to be so utilized by him or possibly others.

Going back to 1896, Marconi arrived in England from Italy with his mother, A. Jameson Marconi, in February of that year. Soon, with the help of his influential cousins, he got the British Post Office interested in his work. Sir W. Preece, chief engineer of the British Post Office, was the patron who sponsored the field experiments, the story of which is very well known [1]–[3]. Marconi's discoveries were not accepted initially by the British learned men of the day like Lodge, and Marconi faced their severe criticisms. An obvious contributor to this was the fact that Marconi never went to college, and his scientific credentials were suspect and in fact challenged. At this critical juncture, Bose was a distinguished scientist of the day, having studied at the Cavendish Laboratory of Cambridge University under Lord Rayleigh and having earned the D.Sc. degree from the University of London with high praise and recommendations from Lord Rayleigh. Bose already worked with wireless telegraphy in the microwave and millimeter-wave regions prior to Marconi and reported his advanced scientific work in the various learned forums of the United Kingdom. Marconi, who was more than 17 years younger than Bose, received high praise, confidence, and support from Bose [34] publicly, which Marconi desperately needed at that time to establish his credibility in the face of opposition from distinguished persons like Lodge. In the March 1897 issue of *McClure's Magazine* H. W. J. Dam had captured [34] this early Bose–Marconi relationship through his interviews with these two great scientists. This article, though written for a lay audience, is reproduced in full in the appendix to capture the correct rhythm of the events. Dunlap, in his official biography of Marconi [2], used the following extract from the article:

> Marconi, himself, was credited with "opening new doors in the electric wing of the temple of truth." Dr. Jagadis Chunder Bose, the Hindoo, Professor of Physics in the Presidency College at Calcutta, and distinguished student of electrical radiation, foresaw, "all the special sciences marching abreast along the old Roman road of science which leads no one knows whither." And he espied an obstacle—a great high wall blocking the way in all directions. Upon the wall, as upon the wall in the palace of Babylon, he perceived "a strange and as yet unintelligible inscription—the mysterious word 'ether.'" [34]
>
> "What new and great discoveries lie beyond this wall no one knows," said Dr. Bose; "But more than one high authority believes that these discoveries will startle the twentieth century more greatly than the nineteenth has been startled. To suggest in the crudest possible fashion, how the ether is at present regarded by scientists, imagine that the whole universe, to the uttermost stars is a solid mass of colorless jelly; that in this jelly the stars, solar systems and space-worlds are embedded like cherries in a mold of fruit jelly. . . .
>
> "In short, this jelly or ether is a universal substance so thin that it permeates everything in space on earth. Only by its quivering, only by the waves in it, which light rays and electric rays excite, are these rays enabled to travel and produce their various results.
>
> "Strange to say, considering the number of brilliant electricians today, and the enormous amount of interest in electrical phenomena, it has been left to a young Italian scientist, Marconi, to frame the largest conception of what might be done with electric waves and to invent instruments for doing it."
>
> One ship drives east, and another west,
> With the self-same winds that blow;
> 'Tis the set of the sails, and not the gales,
> Which decide the way we go.
>
> Like the winds of the sea are the ways of fate,
> As we voyage along through life;
> 'Tis the will of the soul that decides its goal
> And not the calm or the strife.
>
> Rebecca Williams. [2]

Marconi wrote the foreword for the Dunlap book [2], and Dunlap in appreciation of Marconi's interest in his book wrote:

> Appreciation
>
> It has been the good fortune of the author to have had Guglielmo Marconi's friendly interest in the writing of this story. For his kindness in thoroughly reading the final proofs that the book would be accurate in facts about wireless and historically correct in personal detail, the author is deeply indebted.
>
> Trails of research have led far, from the nooks of old magazine shops to the time-yellowed newspaper files now tucked away in dark chambers. Recognition must be given to the observers and reporters, especially those of *The New York Times*, *McClure's Magazine* and the *Scientific American*, who at the turn of the century reported the drama of Marconi and his wireless. Those interviewed directly and by correspondence have been many, and to all

> who have been so helpful, sincere appreciation is expressed.

As Dunlap acknowledged, Marconi had personally reviewed the book. It is curious to speculate whether Marconi had anything to do with the modified quotation from the *McClure's Magazine* about "opening new doors in the electric wing of the temple of truth." That seems to have been attributed to Bose, referring directly to Marconi, whereas in the actual article [34], the author Dam does not directly attribute it to Bose and used it to describe rapid progress in science in general, and not particularly Marconi's contributions. An expression of this kind had most likely to have originated from Bose but since Dunlap had explicitly quoted the paper, this disparity is intriguing knowing that Marconi had read and corrected the book manuscript. Was Marconi valuing Bose's support at the most critical time when Marconi needed it?

XIII. Concluding Remarks

Only Marconi and G. S. Kemp, his assistant, knew what device was actually used to capture and listen to the first transatlantic wireless signal. By the time Marconi gave his lecture at the Royal Institution, he was already under attack by his own countryman [8], and Marconi, through his careful choice of words, caused deliberate confusions and, using clear diversionary tactics, shifted attention to works of Hughes, who was already dead at that time. Only when all the facts were assembled and analyzed did the truth come out.

It is embarrassingly obvious that the British learned men of the day like Lodge or Thompson never discovered Bose's work, which was so prominently displayed in the most prestigious publication of the then British empire. It is clear that they never read this esteemed publication. Even if they did read it, they did not connect Bose's work with Marconi's use of Bose's detection device.

As for Marconi, perhaps R. S. Baker of *McClure's Magazine* put it best. To quote Baker [14]

> He took the coherer of Branley and Calzecchi, the oscillator of Righi, he used the discoveries of Henry and Hertz, but his creation like that of the poet who gathers the words of men in a perfect lyric, was none the less brilliant and original.

To this we now must include the sentence: He used Bose's "mercury coherer with a telephone" detector to receive the first transatlantic wireless signal.

Appendix[4]

A. The Mysteries of the Ether—An Interview with Dr. Bose

A year has elapsed since Röntgen gave us the new photography. Today, on the same general lines, we are confronted with something more wonderful, more important, and more revolutionary still—the new telegraphy. Two gentlemen have come to London at the same time from different countries to tell the same story, namely, that telegraphy needs no wires, and that through walls, through houses, through towns, through mountains, and, it may possibly happen, even through the earth, we can send dispatches to any distance with no other apparatus than a sender and a receiver, the communication taking place by means of electric waves in the ether.

The English language uses the word "ether" in two totally different senses. The first is as the name of a colorless liquid, easily vaporized, the vapor of which is used to allay pain. This liquid has nothing whatever to do with the present subject, and should be put entirely out of the mind. The second use of the word is as the name of a substance colorless, unseen, and unknown, we will say—except in a theoretical sense—which is supposed to fill all space. The original conception of this substance is as old as Plato's time. Newton, Descartes, all the beacon lights of science through the ages, have assumed its existence, and all modern physical students accept it. The ether theory of the formation of worlds must be familiar to many. In fact, up to 20 years ago, as the men of today who were then in college will remember, the word "ether" was a familiar name, a harmless necessary conception, a great convenience in bridging a tremendous void in science which nobody knew anything about or ever would know anything about, so far as could then be seen.

But the electrical advance in the last 20 years has been most extraordinary. Invention and experiment have daily, if not hourly, thrown open new doors in the electrical wing of the temple of truth. And now, at the close of the nineteenth century, the great mass of new facts concerning light, electricity, inaudible sound, invisible light, and the Lenard and Röntgen rays; the eager inquiry, based upon new discoveries, into the properties of living matter, crystallization, the transference of thought, and the endeavor to establish scientifically the truth of certain great religious concepts—all the special sciences thus represented, marching abreast of one another along the old Roman road of science, which leads no one knows whither, have come upon a great high wall blocking the way completely in all directions. It is an obstacle which must be conquered in whole or in part before science can go any farther. And upon the wall, as upon the wall in the palace of Babylon, is a strange and as yet unintelligible inscription—the mysterious word "ether." What new and great discoveries lie beyond this wall, no one knows; but more than one high authority believes that these discoveries will startle the twentieth century more greatly than the nineteenth has been startled.

To suggest, in the crudest possible fashion, how ether is at present regarded by scientists, let the reader imagine that the whole universe, to the uttermost stars, is a solid mass of colorless jelly; that in this colorless jelly the stars, solar systems, and space-worlds are embedded, like cherries in a mold of fruit jelly for the table; that this jelly, though it is at present believed to have density and rigidity, is so inconceivably thin that it soaks completely through all the cherries and through everything upon them; that the

[4] Reprinted from H. J. W. Dam, "Telegraphing Without Wires: A Possibility of Electrical Science," *McClure's Magazine*, vol. VIII, no. 5, Mar. 1897.

minute atoms composing the cherries are so large when compared with the thinness of the jelly that each atom is surrounded by the jelly just as the whole cherry is surrounded; that the jelly is continuous, without a point in the whole universe at which there is a single break in its continuity; that, consequently, if we tap the glass containing the jelly on the table a quiver will run through the jelly completely: the cherries will not quiver, but the quiver will run through them, the jelly which has soaked into them carrying the quiver through them as easily as through the spaces between the cherries; that, in short, this jelly or ether is a universal substance so thin that it permeates everything in space and on earth—glass, stone, metal, wood, flesh, water, and so on—and that only by its quivering, only by the waves in it which light rays, electric rays, and Röntgen rays excite, are these rays enabled to travel and produce their various results. Light enables us to see. But all the light which comes to us from any object and enables us to see that object comes by means of waves in the ether. These light waves pass through glass; that is, the wave continues right through the glass in the ether which lies between the particles of glass. From causes yet undefined, the ether carries light rays through certain substances, but will not carry Röntgen rays through those substances. Röntgen rays, on the other hand, are carried through substances which stop light. Electric rays, or electric rays of a low rate of vibration, differ in some respects from both light and Röntgen rays in the substances which they can traverse. Electric rays of high oscillation show other differences still. Other classes of rays or waves which remain to be discovered, and which will also have different properties, will doubtless be found to receive different treatment from the ether, the sum and substance of the whole matter being that the comparatively new research for new rays has now concentrated the whole scientific world's attention on the ether, its different treatment of different rays affording today a means of studying it that has never been enjoyed before.

The density of the ether has been calculated from the energy with which the light from the sun strikes the earth. As there are 27 ciphers after the decimal point before the figures begin, its density is of course less than anything we can imagine. From its density its rigidity has been calculated, and is also inconceivably small. Nevertheless, with this small rigidity and density it is held to be an actual substance, and is believed to be incompressible, for the reason that otherwise it would not transmit waves in the way it does. As it is believed to fill all the interplanetary space, many profound and searching experiments have been made to determine whether, as the earth moves in its orbit through space at the rate of 19 miles per second, it passes through the ether as a ship goes through the water, pressing the ether aside, or whether the ether flows through the earth as water flows through a sieve forced against it. Through the elusive character of the substance none of these experiments have as yet produced any very satisfactory results. It has been found, however, that the ether enclosed in solid bodies is much less free in transmitting waves than the ether in the air. Thus glass, alone, transmits light waves at the rate of about three miles per second. The ether in the glass transmits them at a rate 40 000 times greater, or about 120 000 miles per second, while the ether in the air transmits them at the rate of 192 000 miles per second. The reason why the ether in the glass and other solids transmits more slowly than that outside is a mystery at present; but, as said before, this is one of a mass of gathered facts which have now placed science in a position from which it is possible to attack the mystery of the ether.

Fig. 6. Dr. Jagadis Chunder Bose.

Electric waves were discovered by an American, Joseph Henry, in Washington, D.C., in the year 1842. He did not use the phrase "electric waves"; but he discovered that when he threw an electric spark an inch long on a wire circuit in a room at the top of his house, electrical action was instantly set up in another wire circuit in his cellar. There was no visible means of communication between the two circuits, and after studying the matter he saw and announced that the electric spark set up some kind of an action in the ether, which passed through two floors and ceilings each 14 inches thick, and caused induction—set up what is called an induced current—in the wires in the cellar. This fact of induction is now one of the simplest and most commonplace

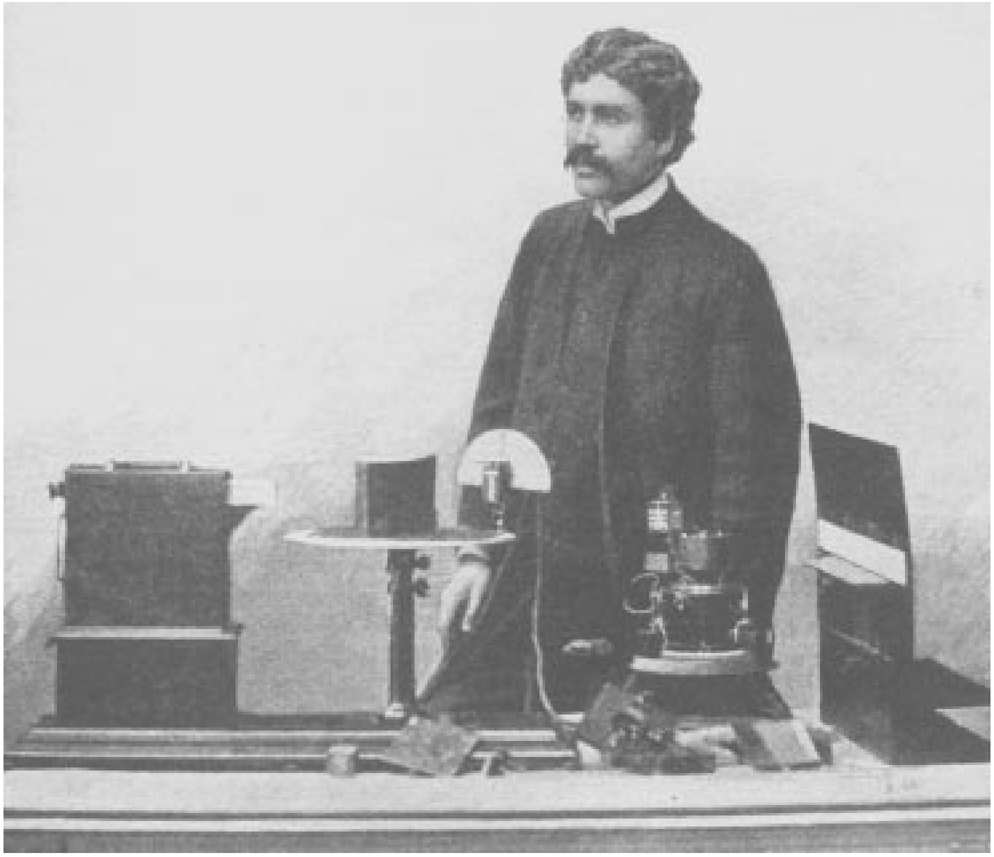


Fig. 7. Dr. Bose and his new apparatus for the study of electric radiation.

phenomena in the work of electricians. Edison has already used it in telegraphing to a flying train. Hertz, the great German investigator, developed the study of these waves, and announced that they penetrated wood and brick but not metal. Strange to say, however, considering the number of brilliant electricians in the more western countries today, and the enormous amount of interest in and experimental investigation of electrical phenomena therein, it has been left to a young Italian, Guglielmo Marconi, to frame the largest conception of what might be done with electric waves and to invent instruments for doing it. Marconi's story will be told with the utmost simplicity and care. But it sounds like a fairy tale, and if it had not for a background four grave and eager committees representing the British Army, the British Navy, the British Post Office, and the British Lighthouse Service, which are now investigating it, it might well be doubted.

Before introducing Marconi, however, the attention of the reader is called, for several good reasons, to his immediate predecessor in London, Dr. Jagadis Chunder Bose. Dr. Bose is a Hindoo, and is at present the Professor of Physics in the Presidency College, Calcutta. He is a graduate of Cambridge, with the degree of Master of Arts, and has been honored with the degree of Doctor of Science by the University of London, as a recognition of certain inventions regarding electric waves which have won him the highest praise in the Royal Society, the British Association, and elsewhere. It should be said at once that Dr. Bose has no interest in the new telegraphy. Though he has been named as its discoverer, he has done little more in it than was announced by Hertz in 1888. He has done great work in his own field, but it is that kind of detail work which is only understood and appreciated by other investigators, and in the matter of telegraphy his statements are here given largely as a preparation for and corroboration of those of Marconi.

Dr. Bose, as he sits in the drawing room of his temporary London home in Maida Vale, is a man of medium height, 36 years old. His father was a distinguished scholar and mathematician. His manner is modest and very reserved. He dislikes publicity in the extreme. To be interviewed for publication, and to have his delicate, complex, and ultratechnical work described in the nontechnical language of a popular magazine is something from which he shrinks visibly. Consequently, though he submits to the ordeal of an interview, he disclaims all responsibility for the statements made in it and the language in which these statements are expressed. If any man of science, therefore, reads this article, it is understood that he is to base no opinion or criticism upon it; but if he is interested in Dr. Bose's work, he is requested to refer to the *Journal of the Royal Society* for December 1895, and June 1896, and the *Journal of the British Association* meeting of this year. The ethereal waves of courtesy between speaker and writer having vibrated to the conclusion of this happy understanding, Dr. Bose says:

"My special work for the last three years has been the study of electrical radiation; more particularly the comparatively slow electric waves, varying between about one-quarter and about one-half an inch in length. My results were represented in the complete apparatus which I had the honor of describing before the British Association, an apparatus for the verification of the laws of reflection, refraction, selective absorption, interference, double refraction, and polarization of these waves. I also contributed a paper to the Royal Society in December 1895, on the determination of the indices of refraction of various substances for the electric ray, and another in June of this year [1896] on the determination of the wave length of electric radiation by means of a diffraction grating. These have been duly reported and discussed in the scientific journals, and I fear would not be appreciated or understood outside of their circle."

This is too evident a fact to be disputed, and the conversation is turned to the wave-telegraphing in Calcutta.

"That," said Dr. Bose, "was simply an incident in the course of a popular lecture, an illustration of the ability of electric rays to penetrate wood and brick. My radiator was a small platinum ball between two small platinum beads, connected with a two-volt storage battery. By pressing a key the ball was made to spark and start an electric wave which progressed outward through the ether in the air. Popularly speaking, an electric wave in the ether, though it moves in all directions, progresses outward like a wave produced by dropping a stone in a pond. The water wave can be seen. An electric wave is, of course, invisible. Supposing a cork on the surface of the pond at any distance from the place where the stone was dropped, the cork, when the wave reaches it, will bob up and down. Now, though we cannot see the electric wave, we can devise an arrangement which indicates the presence of the wave as the cork does. This mechanical arrangement detects and records the passage of the wave."

"This is the whole idea simply expressed; an electric radiator and a receiver for the waves. My receiver was in a room 75 feet distant from the radiator, with three walls of brick and mortar, eighteen inches thick, between them. The electric wave thus induced penetrated the walls and traversed this distance with sufficient energy, when it was converted, to fire a pistol and ring a bell, these being the simplest and best evidences of its reception that I could devise."

"Do you mean to say that the wave, outgoing in all directions, had this effect when a very small part of it reached the receiver?"

"No. A large portion of it was concentrated, as rays of light are concentrated, by a lens placed close to the radiator. This received a large portion of the wave and bent all the rays which fell upon it into parallel lines, thus making a beam proceeding outward in a straight line through the walls to the receiver. I have made and used various concentrating lenses, the best materials being sulphur, ebonite, and pitch."

"Instead of ringing a bell or firing a pistol, could a telegraph message have been sent with it and received through the walls?"

"Certainly; there would be no difficulty about that."

"What is the law describing the intensity or power of the wave at any given distance?"

"Exactly the same as the law of light. Generally speaking, these electric waves act like rays of light."

"Do you mean to say, then, that you could telegraph in this way through houses as far as you could send a beam of light, say with a search-light?"

"I would not like to say it in these terms, but, generally speaking, such is the fact."

"How far could this ether dispatch, so to speak, be sent?"

"Indefinitely. That depends on the exciting energy. At Salisbury Plain, I am told, electric rays were sent, with a parabolic reflector a quarter of a mile through the ether in the air, and then reproduced as Morse signals by a relay."

"But in telegraphing through houses—across a block of houses, for instance—supposing the lens and reflector properly aimed at the receiver, what would stop the rays?"

"Metal stops the waves I have been working with. Also water. They will penetrate wood, brick, glass, granite, rock, earth, and retain their properties."

"How far have they been successfully sent?"

"Through the air? I believe a mile. Through three walls? A distance of 75 feet, so far as I know."

"What is their relation with the Röntgen rays?"

This brought up the whole question of the differences in rays. Without committing Dr. Bose to exact language it may be said that the rays with which he is working are of comparatively slow vibrations, representing about 50 billion oscillations per second. Those ether vibrations which lie between 200 and 400 trillions of vibrations in a second are heat rays, producing the sensation of warmth. Above 400 trillions and as far as 800 trillions per second the vibrations are light rays, producing the sensation of light. According to their rapidity, these light rays produce a gradation of colors. The lowest numbers of light vibrations give our eyes the sensation of red, and the scale mounts through the yellows, greens, and blues, to the violets. When the number of vibrations passes 800 trillions per second they become invisible. The human eye is limited in its perceptive power to vibrations between 400 and 800 trillions. Below and above these numbers lie the regions of what are called "invisible light rays." The same is true of the ear. Sound is conducted by air vibrations. When these vibrations are below 16 per second or above 32 000 per second, they make no impression on our ear drums and our consciousness. These are the so-called regions of "inaudible sound."

"I think the Röntgen rays," said the doctor, "lie above 800 trillions of vibrations per second."

"And what other unknown forces also lie in that upper region?"

"That remains for the future to develop. It is impossible to forecast what new facts the study of the ether is destined to give us. It is a tremendous field, from which we may expect new facts and new forces."

"New forces?"

"That is merely a phrase. Force is a confusing word. Say new forms of energy, enabling us to accomplish results now impossible—results now unthought of and unthinkable."

"Then the ether—"

Fig. 8. Signor Marconi and his earlier apparatus for telegraphing without wires.

"Is the great field of the future, a field whose products no one can imagine or attempt to conceive."

"Have you ever considered thought impulses generated by the brain, with reference to their radiation and reception by other brains, over small or great distances?"

"I have."

"What is your opinion with reference to thought transference?"

"I must decline to express it. There is no experimental basis upon which to make a satisfactory statement."

Dr. Bose would say no more for publication. Opinions and convictions as to the unexplored regions of physical phenomena are the luxury of every scientific thinker, but he does not express them except under the seal of confidence. It was a delight, however, to hear this wise man of the East, thinking and speaking the language of exact science, discuss the region of the occult. That theosophy and Christian science will shortly hug the ether to their breasts as the undoubted vehicle of their claimed marvels is entirely certain. The present difficulty with regard to thought phenomena is that the human body is not a machine and cannot be used in an exact way to exact ends in experiments. That someone ingenious enough to accomplish this will ultimately appear is highly probable, however, and that the silent influence of brain on brain will in time be measured under mathematical conditions is as reasonable to expect as it would be rash to deny.

B. The New Telegraphy—Interview with Signor Marconi

Guglielmo Marconi, whose name will doubtless be often heard in the years which lie before us, is a young Anglo–Italian. He was born in Bologna, Italy, and will be 22 years old next April. His father is an Italian gentleman of independent means, and his mother is an English lady connected with several well-known English families. He is a tall, slender young man, who looks at least thirty, and has a calm, serious manner and a grave precision of speech, which further give the idea of many more years than are his. He is completely modest, makes no claims whatever as a scientist, and simply says that he has observed certain facts and invented instruments to meet them. Both the facts and the instruments are new, and the attention they are at present exciting is extraordinary.

This attention is largely due to the enterprise and shrewdness of Mr. W. H. Preece, the able chief of the electrical department of the British postal system. Marconi's invention is a year old, but he could obtain no satisfactory recognition of it in his own country. Mr. Preece, however, had for a long time been at work upon the problem of telegraphing through the air where wires were not available. Last year the cable broke between the mainland and the island of Mull. By setting up lines of wire opposite each other on the two coasts, he was enabled to telegraph by induction quite successfully over the water and through the air, the distance being four miles and a half. He sent and received in this way 156 messages, one of them being 120 words in length. Ordinary Morse signals were used, the dispatches being carried by the ether in the air. In a late lecture at Toynbee Hall, Mr. Preece admitted that Marconi's system, which is electrostatic, far surpassed his own, which is electromagnetic. He expressed the fullest faith in Marconi, describing his inventions as new and beautiful, scientifically speaking, and added that he (Mr. Preece) had been instructed by the postal department to spare no expense in testing them to the fullest degree. It will be understood, therefore, that it is due to Mr. Preece that Marconi has received the fullest recognition in England and that engineers from four different departments of the English government are now supervising his work.

Marconi was educated at Leghorn, Florence, and Bologna, and has more recently been following his special

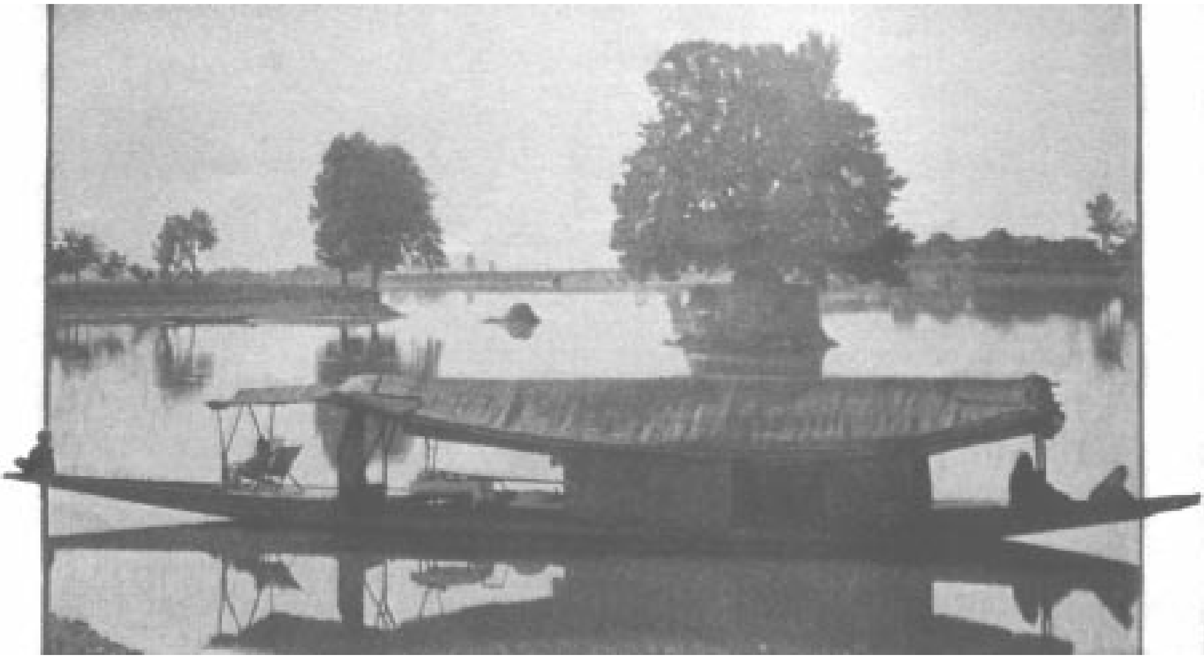


Fig. 9. Dr. Bose's houseboat.

study at his home in the last named city. He speaks English perfectly, and said, in his London home, in Westbourne Park: "For ten years past I have been an ardent amateur student of electricity, and for two years or more have been working with electric waves on my father's estate at Bologna. I was using the Hertz waves from an apparatus which you may photograph, a modified form of the apparatus for exciting electric waves as used by Hertz. My work consisted mainly in endeavoring to determine how far these waves would travel in the air for signalling purposes. In September of last year, working a variation of my own of this apparatus, I made a discovery."

"What was the discovery?"

"I was sending waves through the air and getting signals at distances of a mile, or thereabouts, when I discovered that the wave which went to my receiver through the air was also affecting another receiver which I had set up on the other side of the hill. In other words, the waves were going through or over the hill."

"Do you believe that the waves were going through the hill?"

"That is my present belief, but I do not wish to state it as a fact. I am not certain. The waves either went through the hill or over it. It is my belief, based on many later experiments, that they went through."

"And what was the thickness of the hill?"

"Three-quarters of a mile."

"And you could send a dispatch with Morse signals through this hill or over it to someone on the other side?"

"With ease."

"What followed?"

"What followed was the conception and completion of my special invention, the instruments I have been using at Salisbury Plain in the presence of the Royal engineers. I find that while Hertz waves have but a very limited penetrative power, another kind of waves can be excited with the same amount of energy, which waves, I am forced to believe, will penetrate anything and everything."

"What is the difference between these and the Hertz waves?"

"I don't know. I am not a scientist, but I doubt if any scientist can yet tell. I have a vague idea that the difference lies in the form of the wave. I could tell you a little more clearly if I could give you the details of my transmitter and receiver. These are now being patented, however, and I cannot say anything about them."

"How high an alternation were you using?"

"About 250 million waves per second."

"Do these waves go farther in air than Hertz waves?"

"No. Their range is the same. The difference is in penetration. Hertz waves are stopped by metal and by water. These others appear to penetrate all substances with equal ease. Please remember that the amount of exciting energy is the same. The difference is in the way they are excited. My receiver will not work with the Hertz transmitter, and my transmitter will not work with the Hertz receiver. It is a new apparatus entirely. Of course the waves have an analogy with the Hertz waves and are excited in the same general way. But their power is entirely different. When I am at liberty to lay my apparatus and the phenomena I have observed before the scientists, there may be some explanation, but I have been unable to find any as yet."

"How far have you sent a telegraphic dispatch on the air?"

"A mile and three-quarters. We got results at two miles, but they were not entirely satisfactory. This was at Salisbury Plain, across a shallow valley between low hills."

"What battery were you using?"

"An eight-volt battery of three amperes, four accumulators in a box."

"Did you use a reflector?"

"Yes. It was a roughly made, copper parabolic reflector with a mistake of an inch in the curve. I shall not use one in future, however. A reflector is of no value."

"Nor a lens?"

"Nor a lens."

"Why not?"

"Because the waves I speak of penetrate everything and are not reflected or refracted."

After Professor Röntgen's distances of a few yards and limitations as to substances this was rather stunning. Marconi, however, was entirely serious and visibly in earnest in his statement.

"How far have you verified this belief?"

"Not very far, but far enough, I think, to justify the statement. Using the same battery and my transmitter and receiver we sent and received the waves, at the General Post Office building, through seven or eight walls, over a distance of one hundred yards."

"How thick were the walls?"

"I can't say. You know the building, however. It is very solidly constructed."

"And you sent an ordinary telegraphic dispatch by those signals?"

"No. We did not do that, though we could have done so. We were working with agreed signals, and we obtained the taps which we sought and repeated them till there was no room for doubt."

"Do you think that sitting in this room you could send a dispatch across London to the General Post Office?"

"With instruments of the proper size and power, I have no doubt about it."

"Through all the houses?"

"Yes."

We were in a drawing room in Talbot Road, Westbourne Park, a distance of about four and one-half miles from the General Post Office.

"And how far do you think a dispatch could thus be sent?"

"Twenty miles."

"Why do you limit it to 20 miles?"

"I am speaking within practical limits, and thinking of the transmitter and receiver as thus far calculated. The distance depends simply upon the amount of the exciting energy and the dimensions of the two conductors from which the wave proceeds."

"What is the law of the intensity at a given distance?"

"The same as the law of light, inversely as the square of the distance."

This means that whatever the energy with which the waves are sent out, their power at, say 20 feet, when compared with their power at ten feet would be in the proportion of 10×10 to 20×20, or one-fourth, in this special instance.

"Do you think they are waves of invisible light?"

"No; in some respects their action is very different."

"Then you think these waves may possibly be used for electric lighthouses when fog prevents the passage of light?"

"I think they will ultimately be so used. A constant source of electrical waves, instead of a constant source of light waves, and a receiver on the vessel would indicate the presence of the lighthouse and also its direction."

"But would not the fog interfere with the passage of the waves?"

"Not at all."

"Nor metal?"

"Nothing affects them. My experience of these waves leads me to believe that they will go through an ironclad."

"Concerning the size of the apparatus, how large is it?"

"The transmitter and receiver we have been using at Salisbury Plain and at the post office are each about"—he held up his hands to indicate the dimensions—"say 15 inches by ten by eight. Small ones, effective enough for ordinary purposes, can be made of half that size."

"What are you working on at present?"

"Mr. Preece and I are working at Penarth, in Wales, to establish regular communication through the air from the shore to a light-ship. This will be the first direction in which my apparatus is utilized—communication with the light-ships. The light-ships lie off this coast at any distance from half a mile to 20 miles or more."

"What length of waves have you used?"

"I have tried various lengths, from 30 meters down to ten inches."

"Why would not these waves be useful in preventing the collision of ships in a fog?"

"I think they will be made use of for that purpose. Ships can be fitted with the apparatus to indicate the presence of another ship so fitted, within any desired distance. As soon as two approach within that distance the alarms will ring on each ship, and the direction of each to the other will be indicated by an index."

"Do you limit the distance over which these waves can be sent?"

"I have no reason to do so. The peculiarity of electric waves, which was noted, I believe, by Hertz, is the distance they travel when excited by only a small amount of energy."

"Then why could you not send a dispatch from here to New York, for instance?"

"I do not say that it could not be done. Please remember, however, that it is a new field, and the discussion of possibilities which may fairly be called probabilities omits obstacles and difficulties which may develop in practical working. I do not wish to be recorded as saying that anything can actually be done beyond what I have already been able to do. With regard to future developments I am only saying what may ultimately happen; what, so far as I can now see, does not present any visible impossibilities."

"How large a station would be necessary, assuming the practicability, to send a message from here to New York?"

"A station the size of this room in square area. I don't say how high." The room was 20 feet square.

"What power?"

"Fifty or sixty horse-power would, I think, suffice."

"What would be the cost of the two stations completed?"

"Under £10 000, I think."

"Would the waves go through the ether in the air or through the earth?"

"I cannot say with certainty. I only believe they would go that distance and be recorded."

"You say that no lens or reflector is of value. Then the waves would go outward in all directions to all places at the same distance as New York?"

"Yes."

"Do you think that no means will ever be found to stop this progress in all directions and concentrate it in one direction?"

"On the contrary, I think that invention will give us that."

"Do you see any way of accomplishing this?"

"No, not as yet."

"In what other directions do you expect your invention to be first utilized?"

"The first may be for military purposes, in place of the present field telegraph system. There is no reason why the commander of an army should not be able to easily communicate telegraphically with his subordinate officers without wires over any distances up to twenty miles. If my countrymen had had my instruments at Massowah, the reinforcements could easily have been summoned in time."

"Would the apparatus be bulky?"

"Not at all. A small sender and receiver would suffice."

"Then why would it not be equally useful for the admiral of a fleet in communicating with his various ships?"

"It would," said Marconi, with some hesitation.

"Is there any difficulty about that?"

"Yes," said he, very frankly, but in a way which set the writer to wondering. "I do not know that it is a difficulty yet, but it appears to be."

The writer pondered the matter for a moment. Then he asked: "Do you remember Hertz's experiment of exploding gunpowder by electric waves?"

"Yes."

"Could you not do the same from this room with a box of gunpowder placed across the street in that house yonder?"

"Yes. If I could put two wires or two plates in the powder, I could set up an induced current which would cause a spark and explode it."

"Then if you threw electric waves upon an ironclad, and there happened to be two nails or wires or plates in the powder magazine which were in a position to set up induction, you could explode the magazine and destroy the ship?"

"Yes."

"And the electric lighthouses we are speaking of might possibly explode the magazines of ironclads as far as light from a lighthouse could be seen?"

"That is certainly a possibility. It would depend on the amount of the exciting energy."

"And the difficulty about using your instruments for fleet purposes—"

"The fear has been expressed that in using the instruments on an ironclad the waves might explode the magazine of the ship itself."

It is perhaps unnecessary to say that this statement was simply astounding. It is so much of a possibility that electric rays can explode the magazine of an ironclad, that the fact has already been recognized by the English Royal engineers. Of all the coast defenses ever dreamed of, the idea of exploding ironclads by electric waves from the shore over distances equal to modern cannon ranges is certainly the most terrible possibility yet conceived.

Such are the astonishing statements and views of Marconi. What their effect will be remains to be seen. In the United States alone, considering the many able experimenters and their admirable and original equipments, like Tesla's dynamos, the imagination abandons as a hopeless task the attempt to conceive what—in the use of electric waves—the immediate future holds in store. The air is full of promises, of miracles. The certainty is that strange things are coming, and coming soon.

Because, underlying the possibilities of the known electric waves and of new kinds of electric waves, which seem to be numerous and various—underlying these is still the mystery of the ether. Here is a field which offers to those college students of today who have already felt the fascination of scientific research, a life work of magical and magnificent possibilities, a virgin, unexplored diamond field of limitless wealth in knowledge. Science knows so little, and seems, in one sense, to have been at a standstill for so long. Lord Kelvin said sadly, in an address at Glasgow the other day, that though he had studied hard through 50 years of experimental investigation, he could not help feeling that he really knew no more as he spoke than he knew 50 years before.

Now, however it really seems that some Columbus will soon give us a new continent in science. The ether seems to promise fairly and clearly a great and new epoch in knowledge, a great and marked step forward, a new light on all the great problems which are mysteries at present, with perhaps a correction and revision of many accepted results. This is particularly true of the mystery of living matter and that something which looks so much like consciousness in certain nonliving matter, the property which causes and enables it to take the form of regular crystals. Crystallization is as great a problem as life itself, but from its less number of conditions will perhaps be easier and earlier attacked. The best conception of living matter which we have at present, completely inadequate though it be, is that of the most chemically complex and most unstable matter known. A living man as compared to a wooden man responds to all kinds of impulses. Light strikes the living eye, sound strikes the living ear, physical and chemical action are instantly and automatically started, chemical decomposition takes place, energy is dissipated, consciousness occurs, volition follows, action results, and so on, through the infinity of cause and infinity of results which characterize life. The wooden man is inert. There is no chemical or physical action excited by any impulse from without or within. Living matter is responsive, nonliving is not. The key to the mystery, if it ever comes, will come from the ether. One great authority of today, Professor Oliver Lodge, has already stated his belief that electricity is actually matter, and that if the ether and electricity are not one and the same, the truth will ultimately be found to be near that statement. If this be true, it will be a great and startling key to the now fathomless mystery of life.

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Probir K. Bondyopadhyay (Senior Member, IEEE), for a photograph and biography, see this issue, p. 5.

The Work of Jagadis Chandra Bose: 100 Years of Millimeter-Wave Research

Darrel T. Emerson

***Abstract*—Just 100 years ago, J. C. Bose described to the Royal Institution, London, U.K., his research carried out in Calcutta, India, of millimeter wavelengths. He used waveguides, horn antennas, dielectric lenses, various polarizers, and even semiconductors at frequencies as high as 60 GHz. Much of his original equipment is still in existence, currently at the Bose Institute, Calcutta, India. Some concepts from his original 1897 papers have been incorporated into a new 1.3-mm multibeam receiver now in use on the National Radio Astronomy Observatory (NRAO) 12-m telescope.**

***Index Terms*—History, microwave technology, millimeter-wave technology.**

I. 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 20th century, many of the concepts now familiar in microwaves had been developed [2], [3], including 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 Lodge [5]. In 1897, Righi published a treatise on microwave optics [6].

Hertz had used a wavelength of 66 cm. Other post-Hertzian pre-1900 experimenters used wavelengths well into the short centimeter-wave region, with Bose in Calcutta [7], [8] and Lebedew in Moscow [9] independently performing experiments at wavelengths as short as 5 and 6 mm.

II. The Research of Bose

J. C. Bose [10]-[12] was born in India in 1858. He began his education in India, until he went to the U.K. in 1880 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 Prof. Rayleigh, who clearly had a profound influence on his later work. In 1884, Bose was awarded a B.A. degree from Cambridge, along with a B.Sc. degree from London University. Bose then returned to India, initially taking up a post as officiating professor of physics at Presidency College, Calcutta. Following the example of Lord Rayleigh, Bose made extensive use of scientific demonstrations in class, where he is reported as being extraordinarily popular and effective as a teacher. Many of his students at Presidency College were destined to become famous in their own right—e.g., S. N. Bose, later to become well known for the Bose–Einstein statistics.

Fig. 1. Bose at the Royal Institution, London, U.K., January 1897 (Photograph from [13]).

The book by Sir Oliver Lodge, *Heinrich Hertz and His Successors*, impressed Bose. In 1894, he converted a small enclosure adjoining a bathroom in 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 connected to a highly sensitive galvanometer. He plotted in detail the voltage–current characteristics of his junctions, noting their nonlinear 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 semiconducting crystal as a detector of radio

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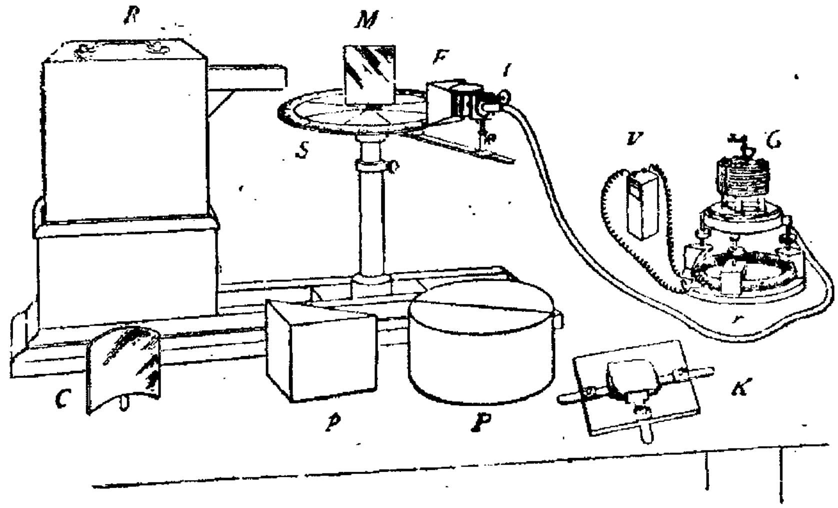


R, radiator; S, spectrometer-circle; M, plane mirror; C, cylindrical mirror; *p*, totally reflecting prism; P, semi-cylinders; K, crystal-holder; F, collecting funnel attached to the spiral spring receiver; *t*, tangent screw, by which the receiver is rotated; V, voltaic cell; *r*, circular rheostat;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

Fig. 2. Bose's apparatus demonstrated to the Royal Institution in 1897 [8]. Note the waveguide radiator on the transmitter (left), and that the "collecting funnel" (F) is, in fact, a pyramidal electromagnetic horn antenna, first used by Bose (Photograph from [8]).

waves. Sir Neville Mott, Nobel Laureate in 1977 for his own contributions to solid-state electronics, remarked [12] 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."

In 1895, Bose gave his first public demonstration of electromagnetic waves, using them to remotely ring a bell and to explode some gunpowder. In 1896, the *Daily Chronicle* of the U.K. 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 signaling with radio waves. The first successful wireless-signaling experiment by Marconi on Salisbury Plain, U.K., was not until May 1897.

The 1895 public demonstration by Bose in Calcutta predates all these experiments. Invited by Lord Rayleigh, Bose reported on his microwave (millimeter-wave) experiments to the Royal Institution and other societies in the U.K. [8] in January 1897. The wavelengths he used ranged from 2.5 cm to 5 mm. In his presentation to the Royal Institution, Bose speculated [8, p. 88] on the existence of electromagnetic radiation from the sun, suggesting that either the solar or the terrestrial atmosphere might be responsible for the lack of success so far in detecting such radiation. Solar emission was not detected until 1942, and the 1.2-cm atmospheric-water vapor-absorption line was discovered during experimental radar work in 1944. Fig. 1 shows Bose at the Royal Institution, London, U.K., in January 1897. Fig. 2 shows a matching diagram, with a brief description of the apparatus.

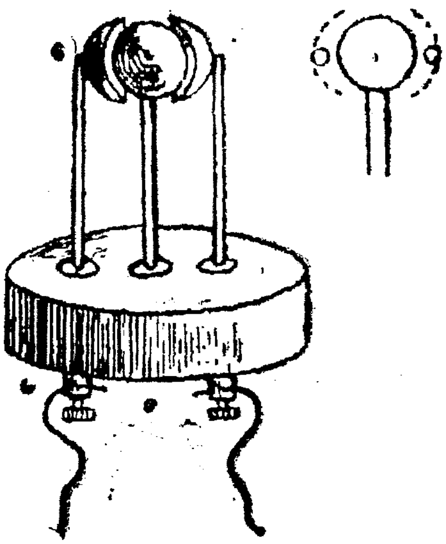
By about the end of the 19th century, the interests of Bose turned away from electromagnetic waves to response phenomena in plants; this included studies of the effects of electromagnetic radiation on plants, which is a topical field today. He retired from Presidency College in 1915, but was appointed Professor Emeritus. Two years later, the Bose Institute, Calcutta, India, was founded. Bose 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.

III. Bose's Apparatus

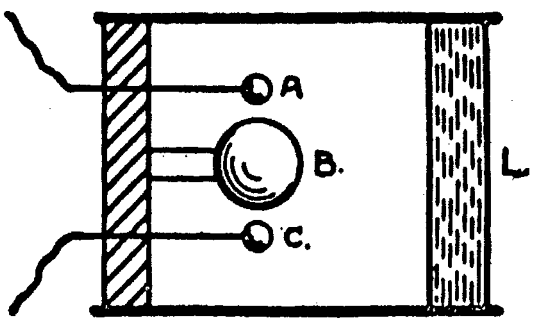
Bose's experiments were carried out at Presidency College, although for demonstrations he developed a compact portable version of the equipment, including transmitter, receiver, and various microwave components. Some of his original equipment still exists, currently at the Bose Institute. In 1985, the author was permitted by the Bose Institute to examine and photograph some of this original apparatus.

Fig. 3(a) shows Bose's diagram of one of his radiators used for generating 5-mm radiation.

Oscillation is produced by sparking between two hollow hemispheres and the interposed sphere. There is a bead of platinum on the inside surface of each hemisphere. For some experiments, a lens of glass or sulfur was used to collimate the radiation—the first waveguide–lens antenna. The lens was designed according to the refractive index measured by Bose at the wavelength in use. Fig. 3(b) shows Bose's drawing of such a radiator; the sparks occur between the two outer spheres to the inner sphere, at the focal point of the lens at the right.



(a)



(b)

Fig. 3. Bose's diagrams of his radiators. (a) The radiator used to generated 5-mm radiation (Photograph from [8]). (b) The arrangement with a lens at the exit of the waveguide [2]. In some designs the mounting stems for the outer spheres could be inclined to adjust the dimension of the spark gaps (Photograph from [2]).

Bose was able to measure the wavelength of his radiation with a reflecting diffraction grating made of metal strips [7].

Fig. 4 is a photograph of one of Bose's radiating antennas. The spark oscillations are generated inside the overmoded circular waveguide. A polarizing grid is built into the antenna, clearly visible at the radiating end of the waveguide.

Fig. 5 shows two of Bose's point contact detectors. In use, the detector would be placed inside an overmoded waveguide receiving antenna, very much like the transmitting antenna shown in Fig. 4, and with a matching polarizing grid.

Bose measured the *I–V* characteristics of his junctions; an example characteristic curve of a "single-point iron receiver" is shown in Fig. 6. The junction consisted of a sharp point of iron pressing against an iron surface, with pressure capable of fine adjustment. The different curves in Fig. 6 correspond to different contact pressures. Bose noted that the junction does not obey Ohm's law, and that there is a knee in the curve at approximately 0.45 V; the junction becomes most effective at detection of short wavelength radiation when the corresponding bias voltage is applied. He made further measurements on a variety of junctions made of different materials, classifying the different materials into positive or negative classes of substance. In one experiment, he noted that increasing the applied voltage to the junction actually decreased the resulting current, implying a negative dynamic resistance [14].

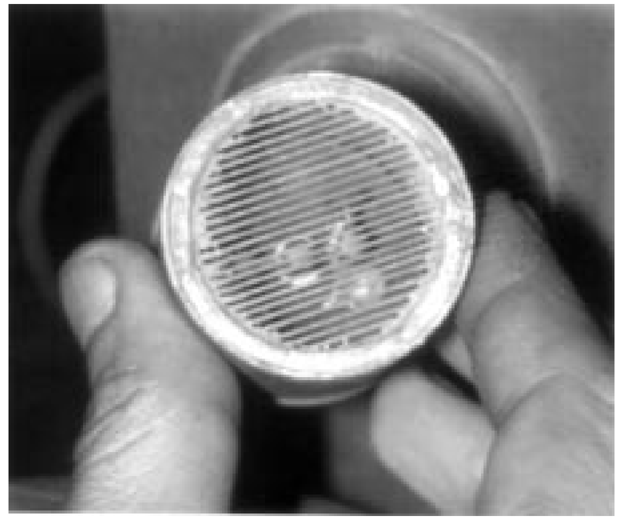


Fig. 4. One of Bose's transmitter antennas. Note the polarizing grid. The spark gap is just visible behind the grid.

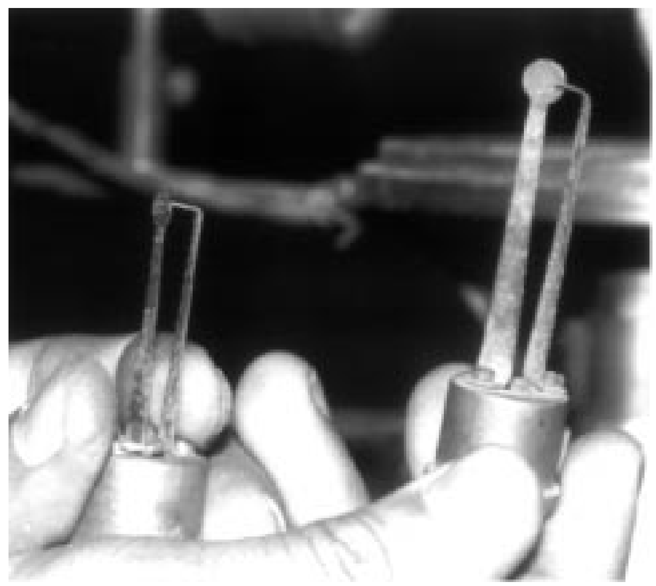


Fig. 5. Two of Bose's point contact detectors, removed from the receiving antenna.

Another of Bose's short-wavelength detectors is the spiral-spring receiver. A sketch of a receiver used for 5-mm radiation is shown in Fig. 7. The spring pressure could be very finely adjusted in order to attain optimum sensitivity. The sensitive surface of the 5-mm receiver was 1 cm $\times$ 2 cm. The device has been recently described [3] as a "space-irradiated multi-contact semiconductor (using the natural oxide of the springs)." A surviving, somewhat larger, spiral-spring receiver is shown in Fig. 8. The springs are held in place by a sheet of glass, seen to be partly broken in this example.

Fig. 9 is Bose's diagram of his polarization apparatus. The transmitter is the box on the left, and a spiral spring receiver

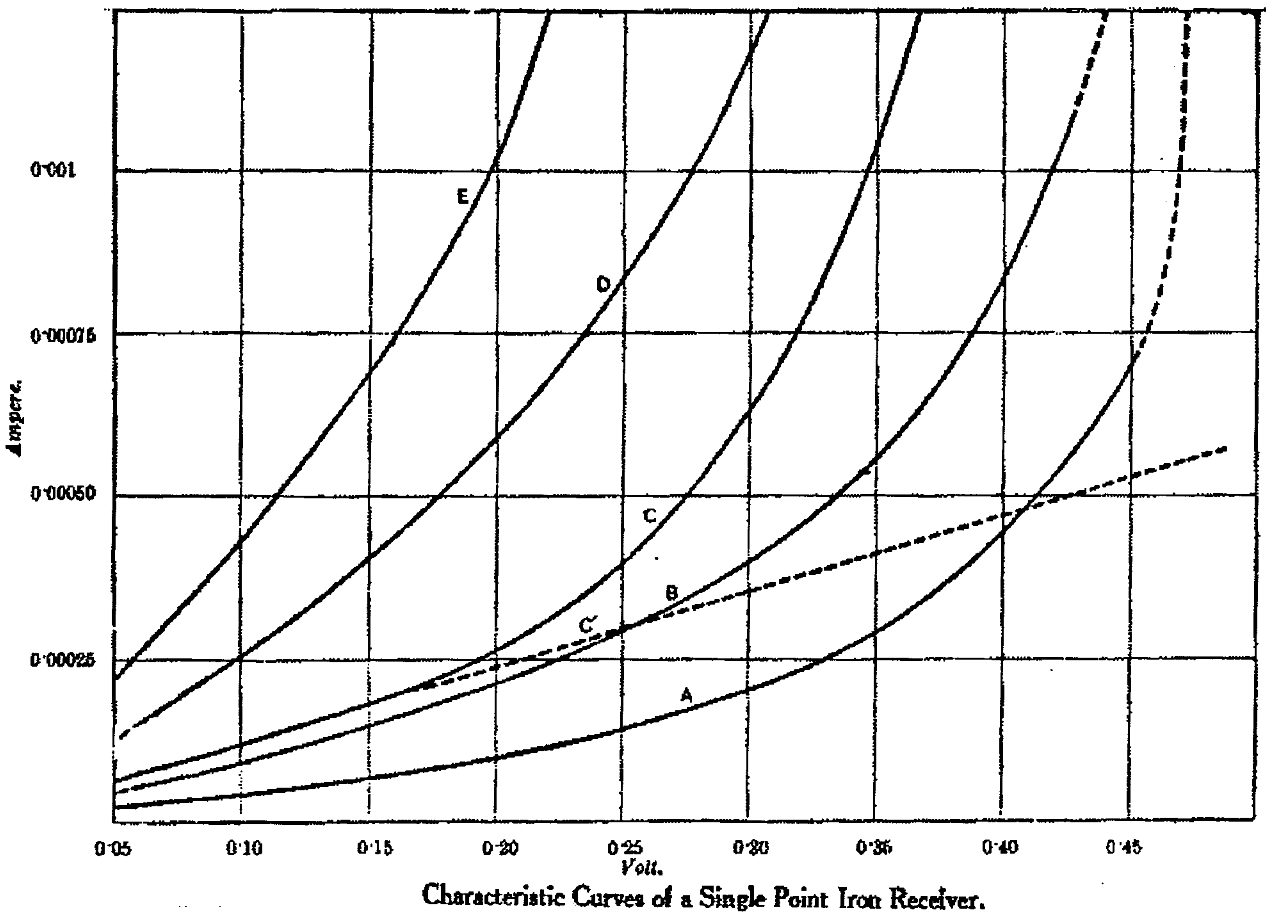


Fig. 6. The *I–V* characteristics measured by Bose for a single-point iron receiver. Note the similarity to modern semiconductor junctions, with a knee voltage of approximately 0.4 V. A, B, C, D, and E are different curves for different initial currents. C' is the curve for a constant rersistance (Photograph from [8]).

(R) is visible on the right. One of the polarizers used by Bose was a cutoff metal plate grating, consisting of a book (Bradshaw's *Railway Timetable*, Fig. 10) with sheets of tinfoil interleaved in the pages. Bose was able to demonstrate that even an ordinary book, without the tinfoil, is able to produce polarization of the transmitted beam. The pages act as parallel dielectric sheets separated by a small air gap.

Bose experimented with samples of jute in polarizing experiments. In one experiment, he made a twisted bundle of jute and showed that it could be used to rotate the plane of polarization. The modern equivalent component may be a twisted dielectric waveguide. He further used this to construct a macroscopic molecular model as an analogy to the rotation of polarization produced by liquids like sugar solutions. Fig. 11 shows Bose's diagram of the jute-twisted–fiber polarization rotator, and Fig. 12 is a photograph of a surviving twisted-jute polarizer at the Bose Institute.

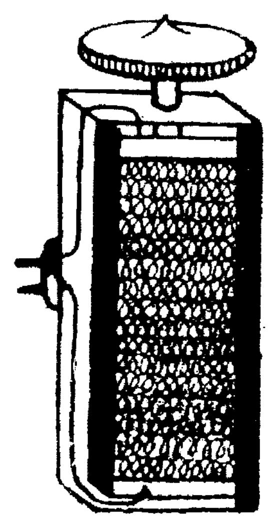


Fig. 7. Bose's diagram of his spiral-spring receiver used for 5-mm radiation (Photograph from [8]).

IV. The Double-Prism Attenuator

Bose's investigations included measurement of the refractive index of a variety of substances. He made dielectric lenses and prisms; examples of which are shown in Figs. 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 two prisms touch, radiation propagates unhindered through both prisms. By introducing a small air gap, the combination becomes a variable attenuator to incident radiation, illustrated in Bose's original diagram and shown in Fig. 13. Bose investigated this

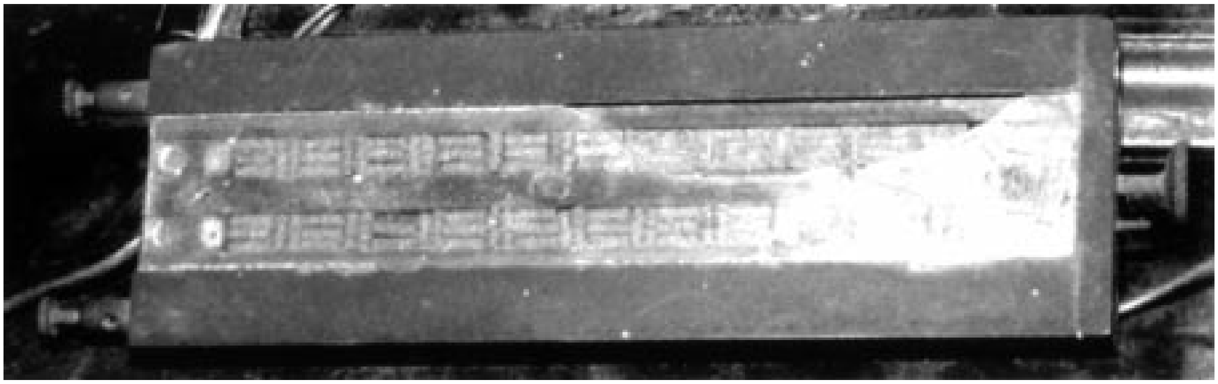
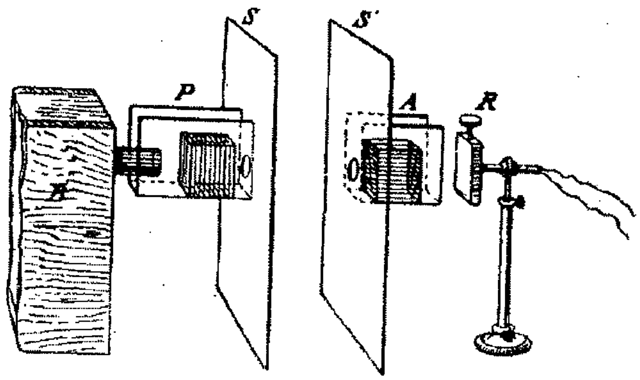


Fig. 8. One of Bose's free-space radiation receivers, recently described [3] as a "space-irradiated multi-contact semiconductor (using the natural oxide of the springs)." The springs are kept in place in their tray by a sheet of glass, seen to be partly broken in this photograph.



Polarisation apparatus. B, the radiating box; P, the polariser; A, the analyser; S, S', the screens; R, the receiver.

Fig. 9. Bose's diagram of his polarization apparatus. Note the spiral-spring receiver to the right (Photograph from [8]).

prism attenuator experimentally and his results were published in the *Proceedings of the Royal Society* in November 1897 [8]. Schaefer and Gross [15] made a theoretical study of the prism combination in 1910. The device has since been described in standard texts.

At the NRAO, a new multiple-feed receiver operating at a wavelength of 1.3 mm has recently been built and installed on the 12-m telescope at Kitt Peak [17]. The system is an eight-feed receiver, where the local oscillator is optically injected into the superconducting tunnel junction (SIS) mixers. With an SIS-mixer receiver, the power level of the injected local oscillator is critical. Each of the eight mixers requires independent local oscillator power adjustment. This is achieved by adjustable prism attenuators. Fig. 15 shows four of these eight prism attenuators installed on one side of the eight-feed system. This can be compared with Fig. 14, which is a photograph taken at the Bose Institute in 1985, showing an original prism system built by Bose.

V. Conclusion

Research into the generation and detection of millimeter waves and the properties of substances at these wavelengths was being undertaken in some detail 100 years ago in Calcutta, India, by Bose. 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

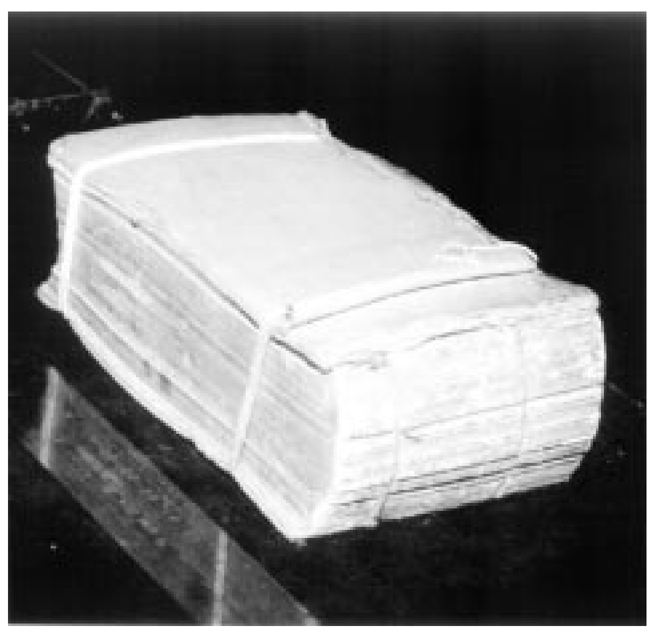


Fig. 10. One of Bose's polarizers was a cutoff metal-plate grating, consisting of a book (Bradshaw's *Railway Timetable*) with sheets of tinfoil interleaved within the pages.

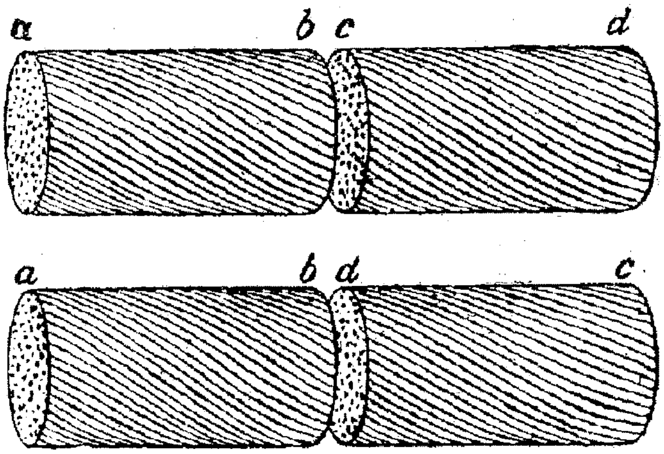


Fig. 11. Bose's diagram of twisted-jute polarization elements used to macroscopically simulate the polarization effect of certain sugar solutions (Photograph from [8]).

Fig. 12. One of the twisted-jute polarizers used by Bose.

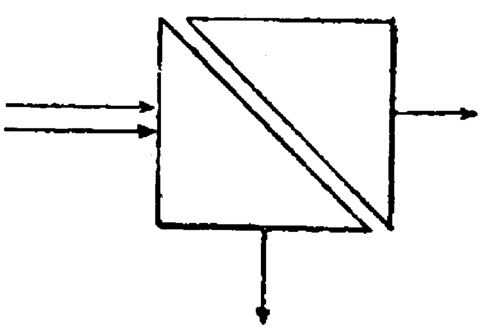


Fig. 13. Bose's 1897 diagram of the double-prism attenuator (Photograph from [8]).

of the 19th century. At about the end of the 19th 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

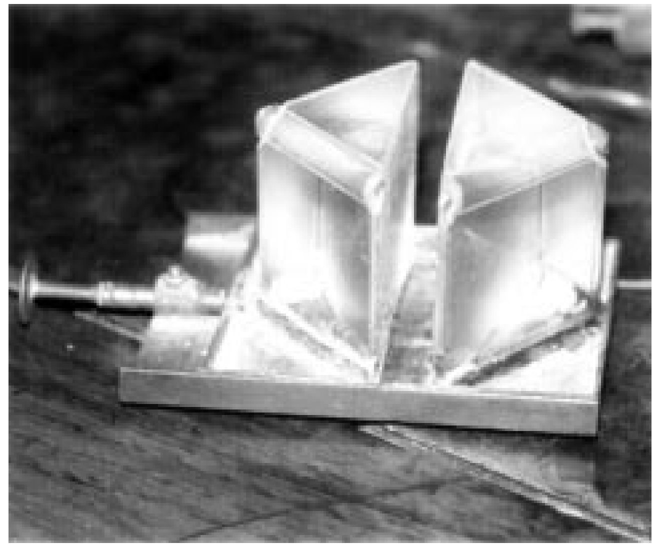


Fig. 14. One of Bose's original double-prism attenuators with adjustable air gap.

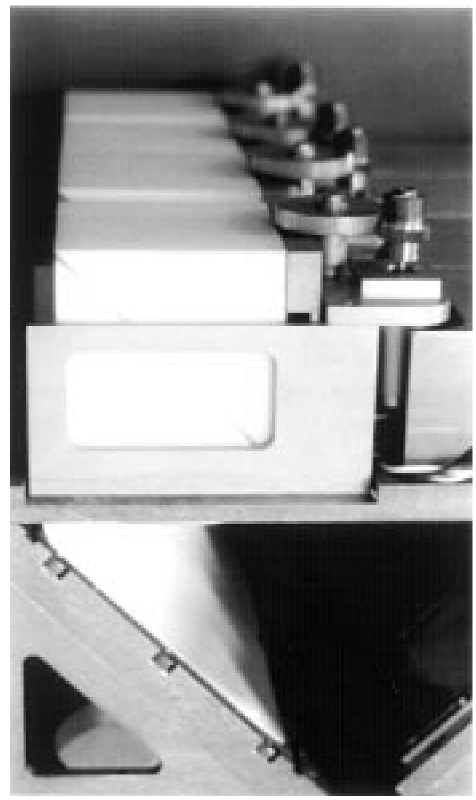


Fig. 15. Four of the eight double-prism attenuators used to control local-oscillator injection into the NRAO 1.3-mm eight-beam receiver in use on the 12-m telescope at Kitt Peak.

eventually, with the help of the then unknown ionosphere, were able to support signaling at very much greater distances.

Although it appears that Bose's demonstration of remote wireless signaling has priority over Marconi, that he was the first to use a semiconductor junction to detect radio waves and invent 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. Bose was at least this much ahead of his time.

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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

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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.

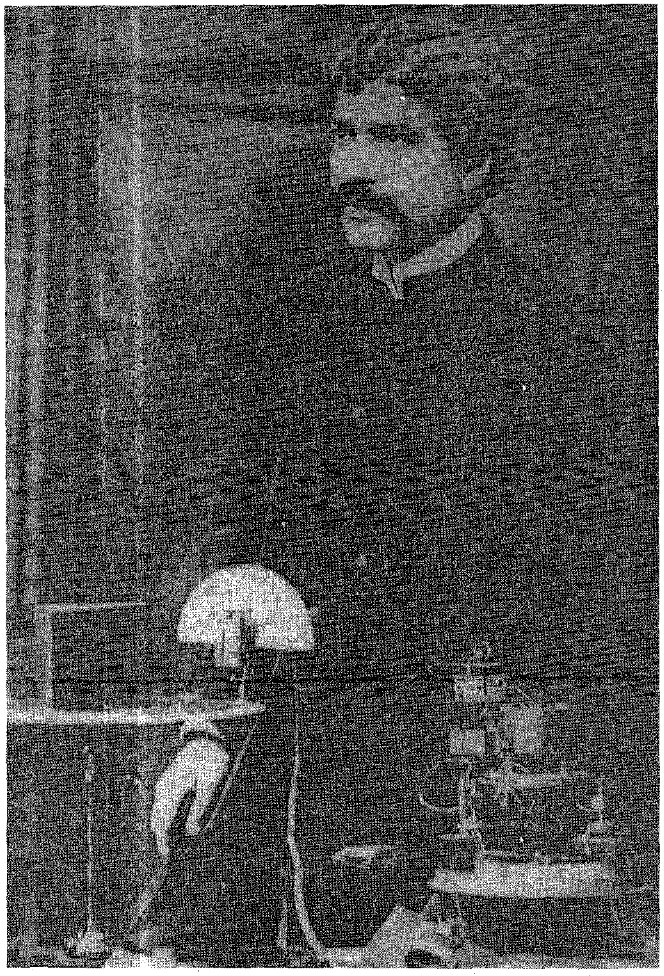

Figure 1. Professor J. C. Bose at the Friday Evening Discourse on Electric Waves before the Royal Institution (1896) [1].

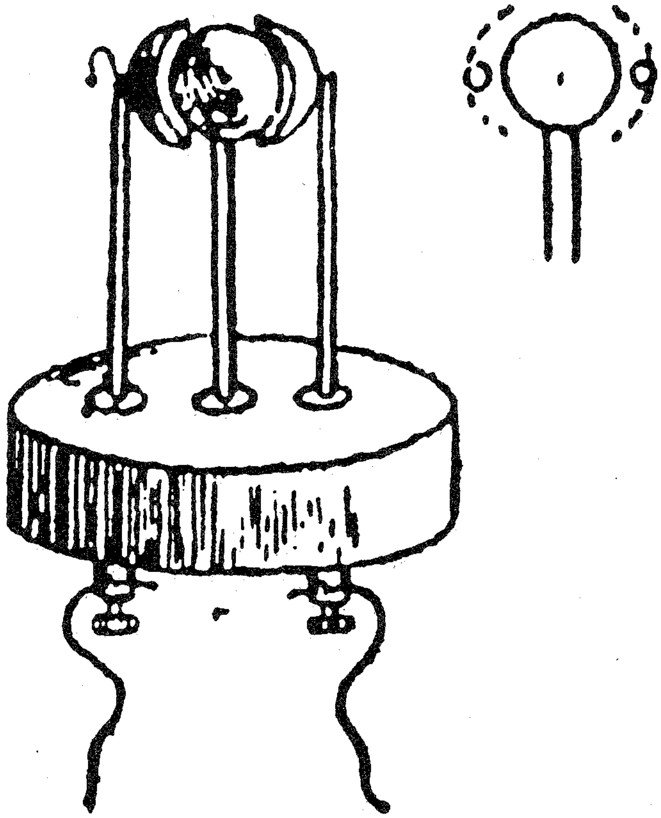

Figure 2. Spark gap arrangements for generating wavelengths of 2.5 cm to 5 mm. [4].

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.

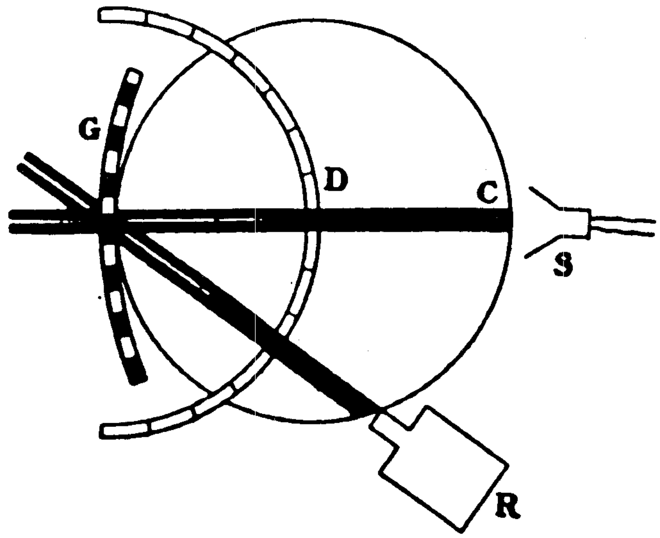

Figure 4. A sketch of the experimental setup to determine wavelength [14].

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.

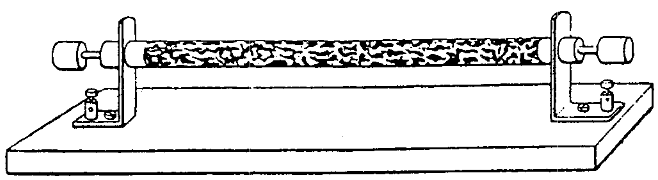

Figure 5. The conventional receiver of Hertz waves.

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

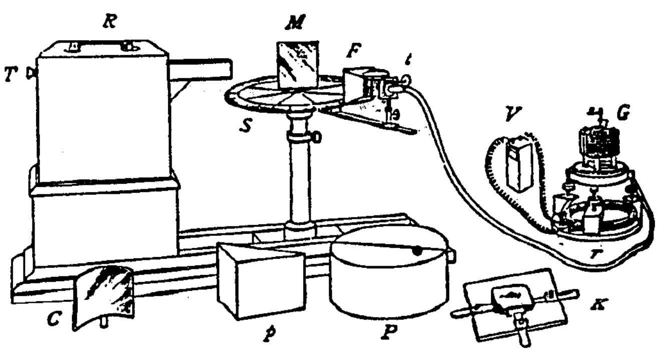

Figure 3. An electromagnetic-horn receiving antenna on a microwave spectrometer, used for quasi-optical demonstrations by Bose (1897). The transmitting antenna is a square-waveguide radiator, of wavelength 5 mm - 2.5 cm [4].

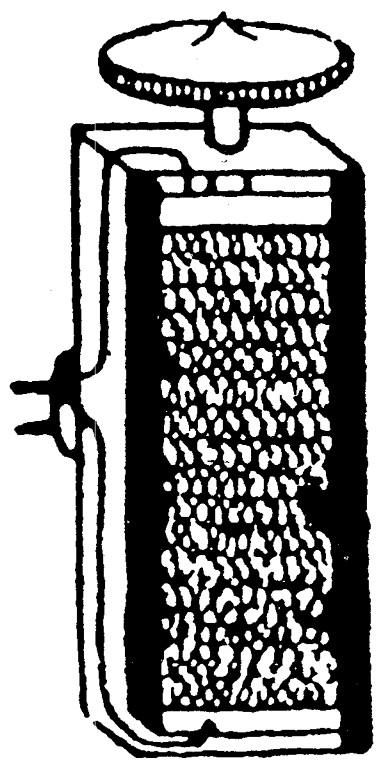

Figure 6. Bose's' microwave "semi-conducting" detector: the spiral-spring receiver [4].

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-

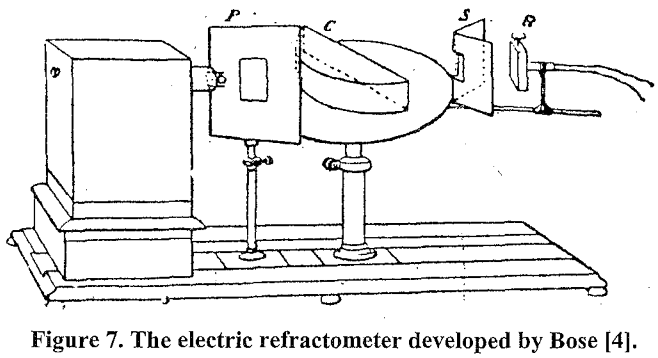

Figure 7. The electric refractometer developed by Bose [4].

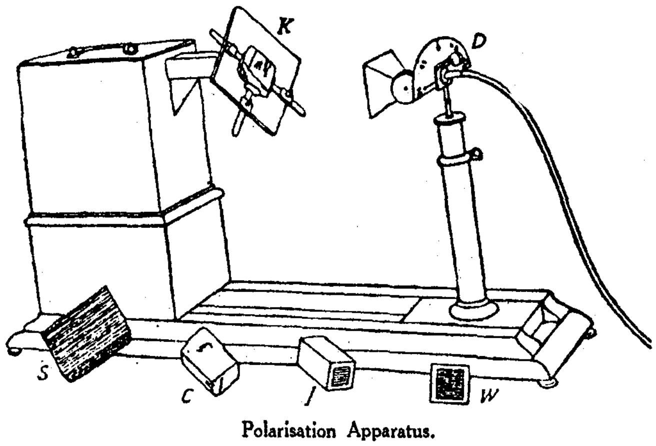

Figure 8. The polarization apparatus developed by Bose [4].

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-

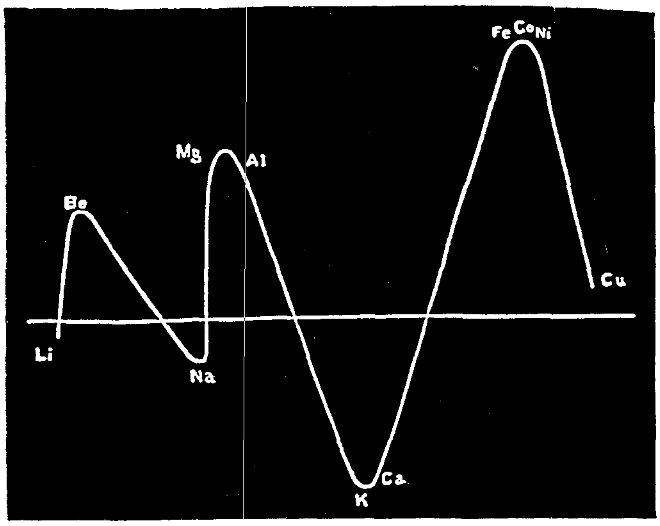

Figure 9. The periodicity of electric touch. The abscissa reports the atomic weight; the ordinate gives the electric-touch, positive or negative [1].

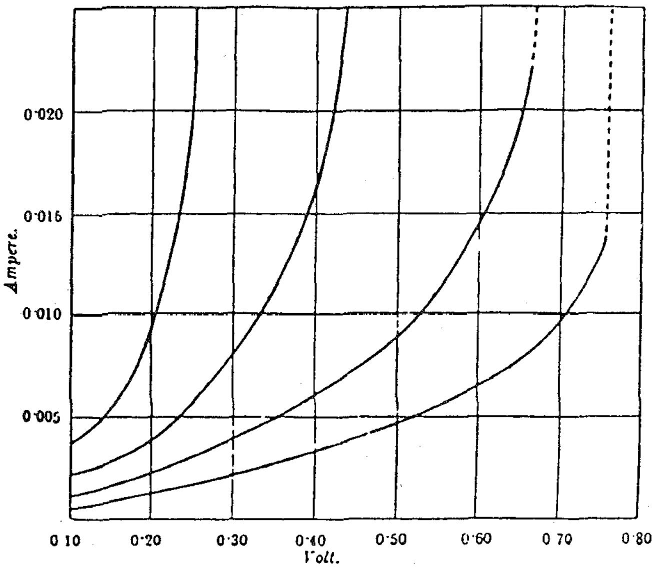

Figure 10. The *V-I* characteristics of a point-contact device [4].

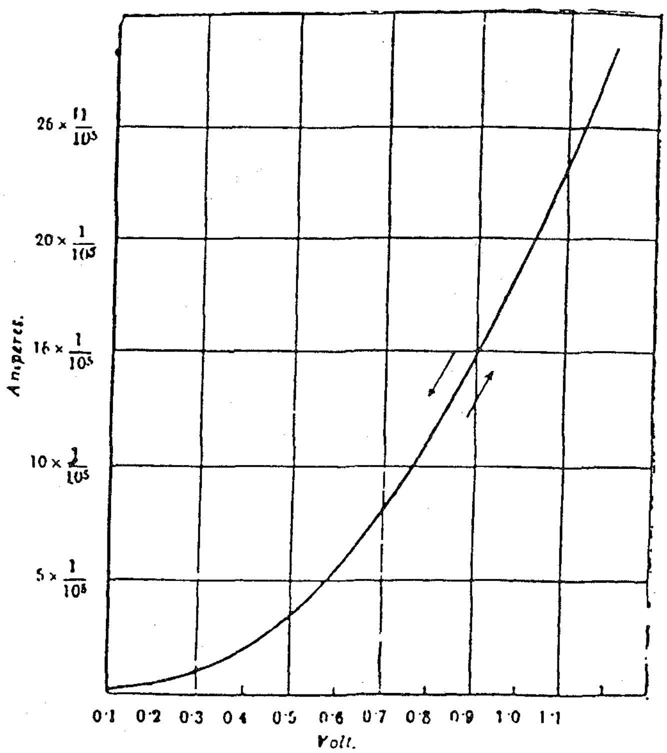

Figure 11. The characteristic curve of a self-recovering receiver of positive type [4].

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.

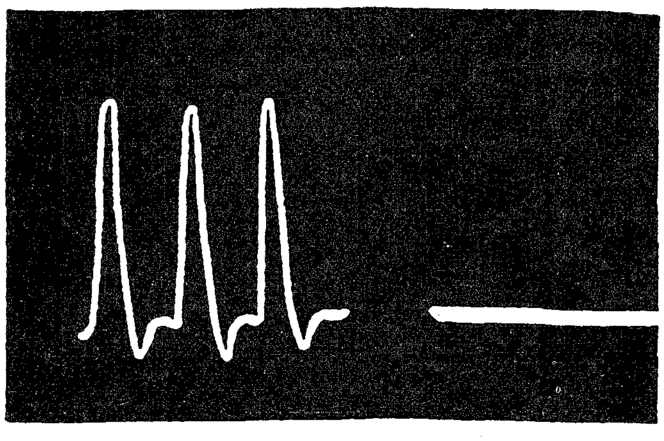

Figure 12a. The action of poison in abolishing the response of muscle.

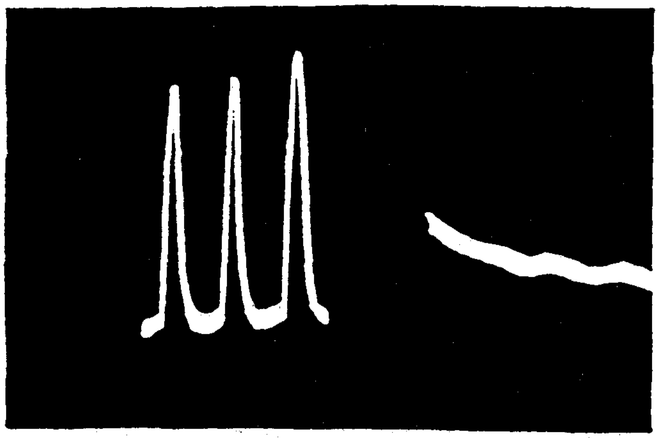

Figure 12b. The action of poison in abolishing the response of a plant.

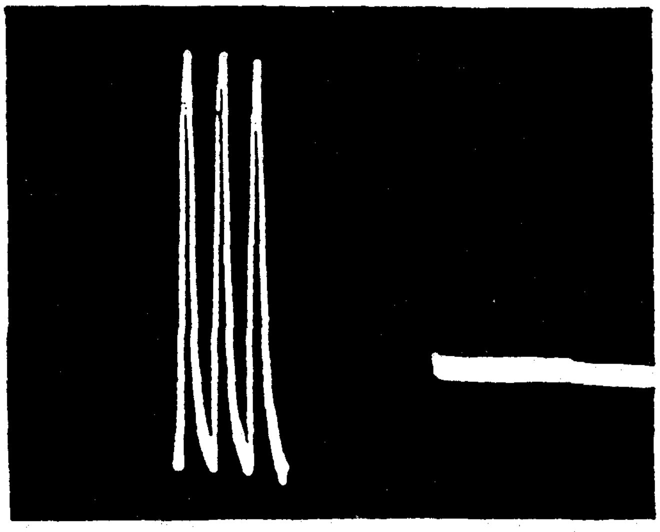

Figure 12c. The action of poison in abolishing tne response of metal.

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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Introducing Feature Article Authors

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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.

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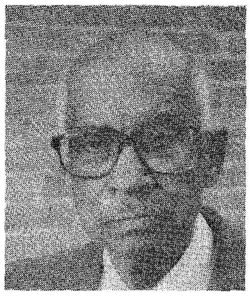

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"Modern Antenna Measurements and Diagnostics Including Phaseless Techniques," Y. Rahmat-Samii and R. G. Yaccarino, USA

"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

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