

Jagadish Chandra Bose: The Real Inventor of Marconi's Wireless Receiver

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1. Introduction

The aim of the present article is to acquaint the younger generation that the real inventor of wireless was not Guglielmo Marconi (Italy), but Jagadish Chandra Bose (India). The classic paper of Dr. P. K. Bondopadhyay [1] published by the IEEE has now established this fact.

The article is organised as follows. In the second section, the motivation of this article is discussed. In Section 3, the technical details of the experiment conducted by Marconi in the year 1901, where he claimed to receive trans-atlantic waves on a radio for the first time are given. Next, Section 4 discusses the controversy surrounding the experiment and provides substantial evidence that the receiving device was invented by J. C. Bose. Thereafter, in Section 5, the technical aspects of the receiving device and its working is discussed. Finally, Section 6 concludes the given report.



Fig. 1: Jagadish Chandra Bose

2. Motivation

This article takes you into the past into the history of radio invention. In this section, I will like to discuss the motivation for choosing this topic.

1. The choice of this topic is apparently linked with the irritation of a student of electronics and communication engineering (studying in India) that the fact that Marconi's wireless was actually invented by Sir J C Bose is not well-known among engineering students, academicians and professionals.

The classic text on antenna theory, which is widely referred across the globe is "Antennas", by J D Kraus [2]. The author dedicates the book is to Hertz and Marconi and has a scarce mention of Bose. While discussing the historical perspective of radio invention, the book reads:

“Rarely has an invention captured the public imagination like Marconi’s wireless did at the turn of the century. We now call it radio, but then it was wireless: Marconi’s wireless. ... Marconi changed that all. Marconi became the wizard of wireless”

One cannot understand why the book doesn’t mention anything about the receiving device used by Marconi, which has been in controversy for a long time [3]. Infact, it was this device which was invented by J C Bose.¹[1]

Again the book, “Antenna Theory Analysis and Design”, by C. A. Balanis [4] doesn’t mention Bose at all, while the book, “Antenna & Wave Propagation” by K.D. Prasad [5] doesn’t discuss the history of Radio communication.

Also the science textbooks used at high schools in India uphold Marconi as the inventor of radio. Therefore, it is suitable to believe that the audience doesn’t know about the contribution of Bose to the field of radio communication.

2. Though, there is a lot of literature present on the experiment done by Marconi, its technical details, the controversy, etc. [1,3,6-10] it becomes difficult for a person who has not studied the history of radio communication to understand the technical details of the experiment in context of what we study/practice today. In the present article, I have tried to systematically explain the actual experiment conducted by Marconi and thereby explaining the relevance of all equipment used. This would clearly give an idea as to what exactly was Marconi’s contribution and what Bose did.
3. History always opens channels for new thinking. It would be interesting and exciting to note how communication was done for the first time without any amplitude modulation techniques, no understanding of bending of electromagnetic waves, existence of any of the active (non-linear) devices (e.g., diode, vacuum tubes, etc.). It gives a definite peep into how science progressed and came to the current stage and how it would progress further.

3. Marconi’s experiment

a. **Information transmission when modulation was not known:** Consider a time, when the principles of amplitude or frequency modulation were not known. The experiments conducted by Hertz dealt with generating and receiving electromagnetic waves of wavelength 30 centimeters to 8 meters. Hertz had no idea that this transmission of electromagnetic waves can be used to transmit information.

In 1889, Heinrich Hertz in reply to an inquiry from one H. Huber, stated [8] that continent size dishes will be necessary to send audio frequency range wireless waves for voice communications. We can understand this in today’s perspective, since for the low

¹ I referred to the 1988 edition of the book, “Antennas”, by JD Kraus. By that time, it had not been accepted that Bose had invented the receiving device. However, the still makes a hero out of Marconi and doesn’t talk about the controversy surrounding the experiment [3]. Unfortunately, I didn’t have a latter edition of the book.

audio frequency very large antennas would be required. Apparently, Hertz had no conception of modulation.

It was Marconi, a 20 yr-old who thought he could use Hertzian waves to send signals. It was actually. Marconi conceived the idea of using morse code for transmitting information through the EM waves [8]. The idea was simple, but excellent. It is to send a small EM wave for a dot, a longer EM wave for the dash and no EM wave for a space. This way using a simple apparatus for generating EM waves, one could transmit information. This could be understood as amplitude modulation of a digital signal.

b. Marconi's experimental setup for transmission of signal: Marconi used what are called Spark transmitters today. The circuit of Fig. 2 explains the principle of working of these circuits. The loop containing C_p and L_p comprises of the basic spark transmitter. The capacitor is charged to a very high voltage, till the gap shorts through a spark, which causes an oscillatory (damped) current whose frequency is determined by the resonating frequency of the circuit. This loop was coupled to the antenna through the inductor L_s , which induced current in it. [24]

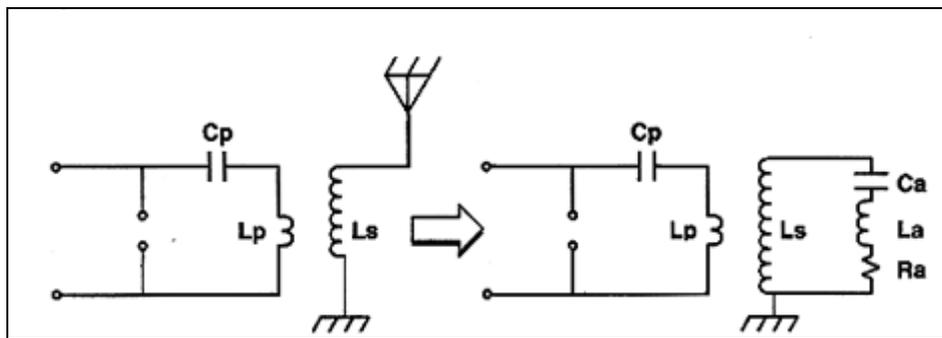


Fig. 2: Basic Spark Transmitter (Reproduced [24])

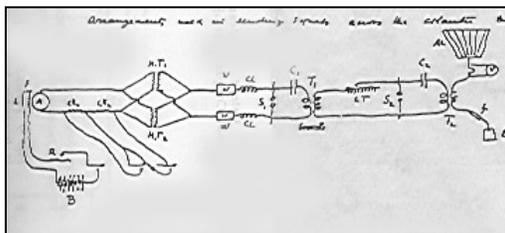


Fig. 3a: Poldhu Transmitter, 1901 (Reproduced [8])

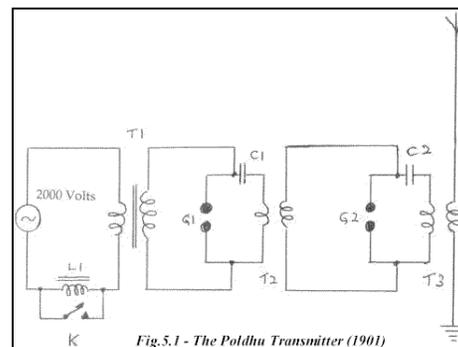


Fig.5.1 - The Poldhu Transmitter (1901)

Fig. 3b: Equiv. Poldhu Transmitter, (Reprod. [25])

The (assumedly) actual transmitter used by Marconi is shown in Fig. 3. The two-stage spark circuit (somehow caused) a multiplication of voltage, such that the second capacitor (C_2) discharged at a much higher voltage. Several periods of the supply generator were required to charge the first capacitor, while the second loop had a spark rate of just two to three sparks per second [26]. Finally the current was sent to the antenna

through the coupling. It is interesting to note that the power of the generating plant was around 25 KW and capacitor sizes went to several times human height! [8]

The antenna used by Marconi is believed to be a cone antenna as shown in Fig. 4 (70 metres in height [2]). It was essentially based on the concept of Hertzian Monopole, but was extended by Fleming to this form. It is also believed that Marconi was using an end-loaded antenna (by connecting a horizontal wire) at the top of the monopole, which improved the performance of the antenna. An interesting study of what probably Marconi was using is given in [10].

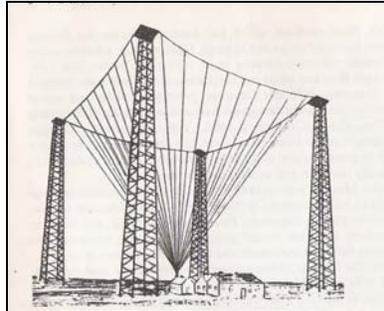


Fig. 4: Marconi's Poldhu's transmitter (Reproduced [2])

c. Details of experiment: All scientists at the time of Marconi thought that he would never be able to transmit information across the trans-atlantic, since EM waves behave like light and they couldn't bend due to earth's curvature. However, Marconi had a queer faith that he would be able to transmit information across few hundred miles using EM waves.

To test his hypothesis, Marconi had established a huge transmitting antenna at Poldhu in Cornwall, UK and aimed at receiving the signal at Newfoundland, St. Johns, which was a distance of around 2000 miles. [3]

On December 12, 1901, Marconi set to receive the letter 'S' (three dots) at Newfoundland as they were transmitted from Poldhu. He had the antenna (150m long wire [26]) put on a kite, from which a wire came to a pole and finally to the receiver. The receiver consisted of some kind of a 'coherer' and a telephone receiver to hear the signal using an earphone. Marconi claimed to hear the three dots of the signal 'S'. This is the famous transatlantic experiment of Marconi, where signal was transmitted wirelessly for the first time.

Interestingly, the exact wavelength of the EM wave used by Marconi is unknown and is considered around 366 metres (820 KHz). An article by H. M. Bradford [9] argues the claim of Marconi whether he received the first transatlantic wave.

d. The receiving equipment: As mentioned before, Marconi used a coherer to detect the EM waves. Consider that we have EM waves coming at the RF frequency, which the antenna would sense and supply a current at the same frequency. It was required to detect this current on a galvanometer or paper tape recorder. The only way which seems

plausible to detect such a current is to convert it into (or trigger) a direct current that could be measured or used to drive a secondary action. This is analogous to what we do to detect AM signals using a diode detector. However, no diodes were available at that time and ‘coherer’ was the device, which replaced the diode detector. The technical details of the coherer are given in Section 5.

The coherer used by Marconi to receive the first trans-Atlantic signal was invented by Sir J. C. Bose [1]. Marconi got it patented in his name since he didn’t want to share the credit of his accomplishment with any other scientist [11]. The next section brings to light the whole scandal.

4. The Real Inventor of the Mercury Coherer: J C Bose

a. Chronology of events:

1878-1880: David Edward Hughes uses some kind of a coherer. (Didn’t use mercury)

1891: E. B. Branly (Paris) uses a coherer for reception of radio waves.(Didn’t use mercury)

April 27, 1899: J. C. Bose reads his paper, “On a Self Recovering Coherer and study of cohering action of different materials” [12] at the Royal Society, UK. He clearly talks about his invention of coherers using conductors separated by mercury.

1899: Tommasina, in one of his paper states “In my researches into contact coherers, after having obtained some very sensitive ones by means of a drop of mercury placed between cylindrical brass electrodes. . .” No mention of mercury is there in the whole paper except the line mentioned above. Use of a telephone is also not discussed. [1]

1900 : Tommasina states in one of his paper, “a drop of mercury decoheres automatically if it is compressed so as to just form a layer filling the space between the electrodes.” at the Geneva Society’s Proceedings.

Sept’ 1900 - Feb 1901 : P. Castelli (Italy) invents coherer similar to that of J. C. Bose. (disputed)²

Jan 1901 – Late 1901 : L. Solari (Italy) invented coherer similar to J. C. Bose. (disputed)³

Sept 1901: Marconi patents a Steel-Mercury-Carbon Coherer on his name.

December 1901: Marconi receives transatlantic waves using an autocoherer. Marconi claims that it was gifted to him by L. Solari, his childhood friend and called it ‘Italian Navy Coherer’.

² Printed in Italian publication L’Elettricista by Prof. Banti, editor, 1902.

³ Printed in Italian publication L’Elettricista by Prof. Banti, editor, 1902.

1902: Prof. Banti, editor, L'Elettricista [13] (Italian publication) sparks a controversy as to the inventor of the coherer used by Marconi. He finally, but rather doubtfully accepts the works of Castelli and Solari as documented above. **There is absolutely no mention of J. C. Bose.**

April 1902: S. P. Thompson sparks a controversy as to the inventor of the coherer by writing letters to Saturday Review [Ref. 13-26 of 3] (England). He involves Lodge, Castelli and Solari into the controversy as the inventor of the coherer. Marconi is silenced. **There is absolutely no mention of J. C. Bose.**

June 1902: Marconi delivers lecture at Royal Institution of Great Britain on his transatlantic wireless signal reception. He talks about the Italian Navy Coherer, but doesn't give a definitive source of the coherer he used. **There is absolutely no mention of J. C. Bose**

July 1902: Solari categorically denies that Castelli had invented the Coherer [14]. He says 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..."

December 1902: Controversy regarding the coherer sparks up again due to an article in the Electrical Review over the patent application filed by Marconi. The patent on the name of Marconi is modified and the Steel-Mercury-Coherer is considered a gift from the Italian Navy. **There is absolutely no mention of J. C. Bose.**

June 1903: An article by Guarani [15] claims T. Tommasina as the inventor of the coherer used by Marconi. L. Solari leaves claim of inventing the coherer, but denies that Tommasina had invented it. Tommasina supports his claim. **There is absolutely no mention of J. C. Bose.**

1997: Ms. Mita Mukherjee publishes in The Telegraph, Calcutta, "Bose invented Marconi's Wireless". [16]

Jan 1998: Dr. P. K. Bondyopadhyay publishes the paper stating that Bose invented the coherer used by Marconi. The paper is published by IEEE Proceeding thus accepting the fact. IEEE published several other articles on J.C. Bose in the same year. [1,7,12,17,18]

Marconi keeps on making contradictory statements on the origin of the coherer till the end of his life. This can be studied in Section VIII of the paper by P K Bondyopadhyay [1].

Solari makes statements contradictory to that of Marconi, however completely refutes that Tommasina, Castelli or Marconi had invented it. He doesn't mention Hughes at all. He only mentions J. C. Bose slightly when he says, "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..."

Three important inferences:

1. In the above timeline, there is no mention of any one using an iron-mercury-iron coherer before the presentation of a paper on it by J.C. Bose in his lecture at the Royal Society in 1899. Tommasina in his work before 1989 never talks about using a telephone with the coherer and doesn't use iron or carbon. Bose clearly mentions in his paper the use of mercury between conductors as a coherer and the use of telephone together with it.
2. In all the controversies that ensued regarding the coherer used by Marconi, the name of Bose was never mentioned. In [1], it is believed that none of the scientists could connect the work of Bose with Marconi's experiment. However the reason for the same could be that the English scientists could never acknowledge the fact that a grey-skinned man from a third world country could make an invention which revolutionized the field of communication.

In the same context, it is noteworthy that in [1,8], even after exposing the scandal of the mercury coherer, the author holds Marconi in high esteem. What could be the reason for the same?

3. Where was J.C. Bose all this time, when the controversy regarding the mercury coherer had erupted? Surely, he must have been following it, but didn't comment about it.

b. J C Bose's letter to Rabindranath Tagore [19]

(In context of his 1901 lecture at the Royal Society, 17th May 1901, reproduced):

A short time before my lecture, a multi-millionaire proprietor of a very famous telegraph company telegraphed me with an urgent request to meet me. I replied that I had no time. In response he said that he is coming to meet me in person and within a short time he himself arrived with patent forms in hand. He made an earnest request to me not to divulge all valuable research results in today's lecture : "There is money in it -- let me take out patent for you. You donot know what money you are throwing away" etc. Of course, " I will only take half share in the profit -- I will finance it" etc.

This multi-millionaire has come to me like a beggar for making some more profits. Friend, you would have seen the greed and hankering after money in this country, - money, money - what a terrible all pervasive greed ! If I once get sucked into this terrible trap, there wont' be any escape ! See, the research that I have been dedicated to doing, is above commercial profits. I am getting older - I am not getting enough time to do what I had set out to do -- I refused him.

Here, the proprietor is believed to be Major Stephen Flood Page, the Managing Director of the Marconi's Wireless and Telegraph Company. [8]

- c. **Marconi acknowledged J C Bose:** In the book by Dunlap [6, ch. VIII, p. 95], which Marconi himself personally edited, devoted full one and a half page in a tribute to Sir

Jagadish Chandra Bose for providing crucial support to Marconi at the critical juncture when Marconi needed it most.

- d. **Similarity of Bose and Marconi Coherer:** The only (trivial) difference between the coherer invented by Bose and that used by Marconi was that the U-tube containing mercury in Bose's arrangement had been replaced by a straight tube.

5. The Coherer: A technical Overview

Coherer was the device used to detect the RF signal picked up by the antenna. Essentially the antenna was followed by a tuning circuit to pick up only the desired frequency (the tuning circuit was not used in experiments at the beginning), which fed the RF signal to a device called coherer. The coherer was followed by the autocoherer. The aim of the coherer/autocoherer was to convert the ac (RF signal) somehow to a dc signal (pr a low frequency signal), which can then drive a Morse printer or an earphone.

Though both auto-coherer and coherer were used for RF signal detection, there principle of operation is quite different.

1. **Coherer:** The name coherer was coined by Prof. Oliver Lodge [3]. Coherer is essentially a device whose resistance drops sharply on application a direct or alternating voltage over a given threshold. Coherers were built by enclosing metal filings (generally silver and nickel) in a tube and dipping electrodes in it.⁴ When the RF or direct signal was applied across the coherer (more than a given threshold), the filings cohered and the resistance sharply fell down [3,10] (from the order of tens of thousands to tens of Ohms).

Together with the RF circuit, the coherer had a battery in series. When the RF signal lowered the resistance of the coherer, the battery passed a small dc current which switched on a relay connected in series. The secondary circuit, which was driven by the relay connected to a Morse printer, which was used to record the signal. [20]⁵

The problem with the coherer was that once cohered, it could only be 'decohered' by tapping the tube mechanically. Therefore, for continuous reception of the signal, the coherer needs to be tapped after each detection of the RF signal. For this purpose, the secondary circuit driven by the relay also triggered a mechanical arrangement which hammered the coherer tube to decoher the particles.

A diagrammatic representation of the system is given in Fig. 5.

⁴ Interestingly, J. C. Bose invented a more accurate coherer, called the Spiral Spring Receiver. [18]

⁵ Some of the references, don't clearly show the biasing battery for the coherer. It is unclear that the dc energy came from the RF signal or the biasing battery.

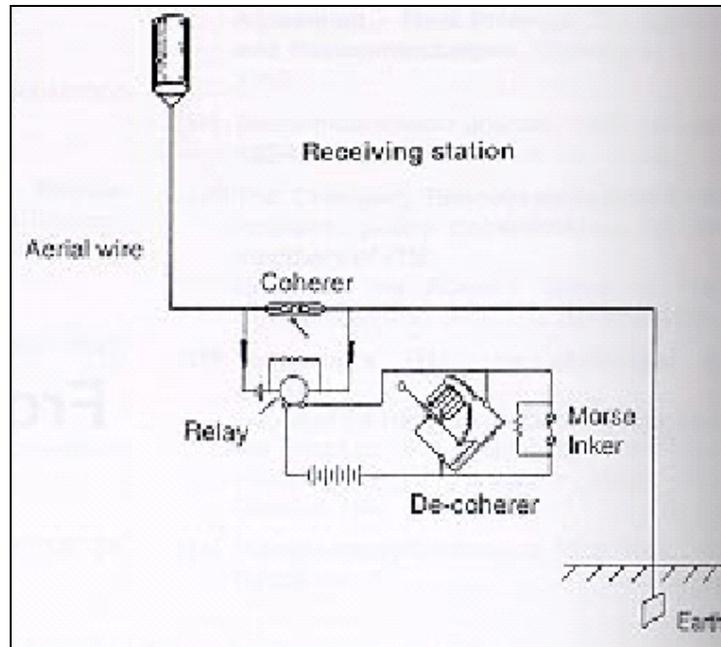


Fig. 5: A coherer system to receive signal (Reproduced [20])

The possible explanation of the cohering action was that in the uncohered (restored state), the metal particles were covered by oxide layers. These layers were broken when the voltage was applied, giving a conduction path for the current. However, there are other explanations for this operation too. [18]

This coherer was not very accurate and the mechanical tapping system made it unreliable. A coherer which would automatically decohere would be much more advantageous and that led to the invention of the autocoherer.

It is interesting to note the analogy of the coherer with a diode in series with a grounded capacitor (Shown in Fig. 6). Once the capacitor charges to the peak of the RF signal it would remain in that stage. The decohering action would be analogous to discharging the capacitor. In principle, the only difference which may be noticed is that the coherer needed an additional dc source, while a diode needs none (it uses the energy of the AC/RF signal).

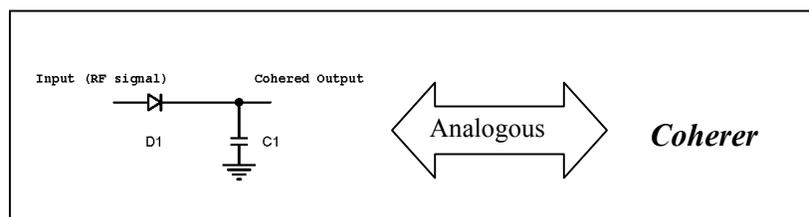


Fig. 6: A circuit analogous to the coherer.

2. **Autocoherer:** As mentioned above, autocoherer was a device which would decohere (restore automatically). It would be most interesting to read its description as given by the inventor, Sir J. C. Bose. (Excerpt from his paper in Royal Society [12])

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.

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.

In the experiments of J. C. Bose used an arrangement where he made contact between a metal and mercury. The arrangement could be understood by looking at Fig. 7. The pressure was varied by using the plunger in one of the limbs, while the contact with the metal formed in the other limb. Bose found out that the applied EMF and the pressure greatly influenced the cohering properties of the arrangement. Also the device lost its auto-cohering properties after receiving the signal for some time. The apparatus used by Bose is shown in Fig. 7.

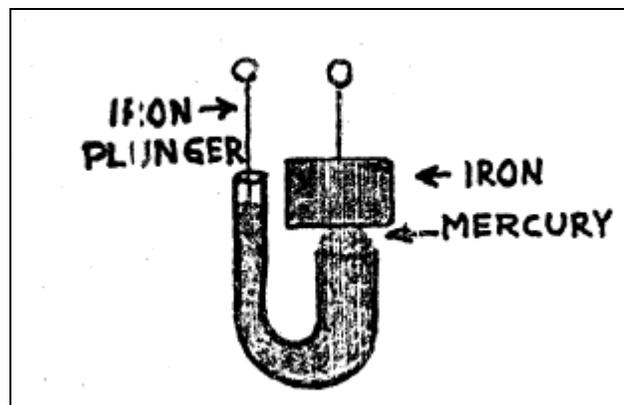


Fig. 7: Coherer designed by J.C. Bose (Reproduced [21])

In the above, excerpt, the last paragraph talks about the invention of an autocoherer. The original paper clearly mentions that potassium had the auto-cohering property, but whether iron also showed similar properties is unclear.⁶

The coherer patented by Marconi [11] is depicted in Fig. 8. The main point in the patent was the drop of mercury enclosed between two metals. This was very similar to the work of Bose. The coherer disputed to be invented by Castelli is shown in Fig. 9.

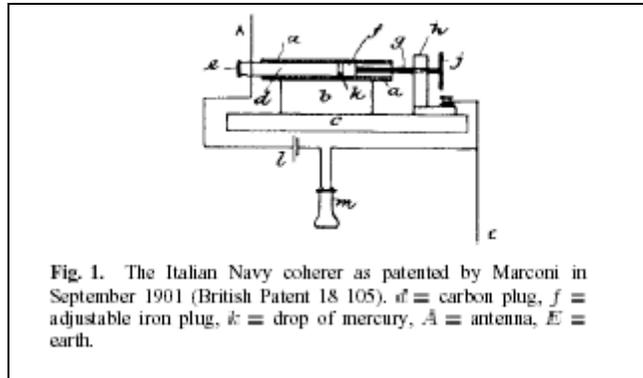


Fig. 8: Coherer patented by Marconi (Reproduced [3])

Interesting, the circuit for receiving RF signal using the autocoherer was different from that used for the coherer. Bose simply inserted the telephone receiver in series of the autocoherer [12]. Assumedly, the rectified dc was heard as a sound on the receiver.

⁶ The use of telephone in autocoherer is clearly an invention by Bose. However, whether Bose's autocoherer used iron is unclear.

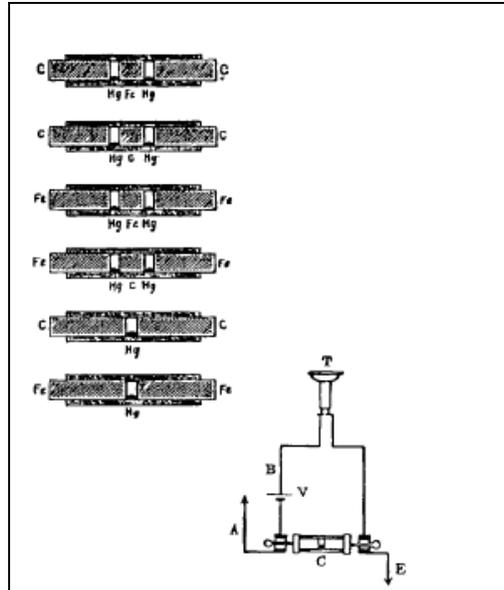


Fig. 9: Coherer invented (disputed) by Castelli (Reproduced [3])

Please note, that the action of the autocoherer is analogous to that of the diode. **Actually, solid-state diode was invented some 40 years after the experiments done by Bose!** In principle the difference between diode and the autocoherer is the requirement of a biasing circuit for the autocoherer, where diode requires none. It is unclear, how the autocoherer used the energy of the dc source on application of RF signal.

To clearly understand the functioning of the autocoherer, the Fe-Hg-C coherer was studied in [3], where its action as a rectifier is verified. In [3], a simple circuit as shown in Fig. 10 is constructed and the output waveform maybe seen in Fig. 10. The authors concluded that the autocoherer had rectifying properties which were extremely poor. (10uA for a 480uA p-p signal)

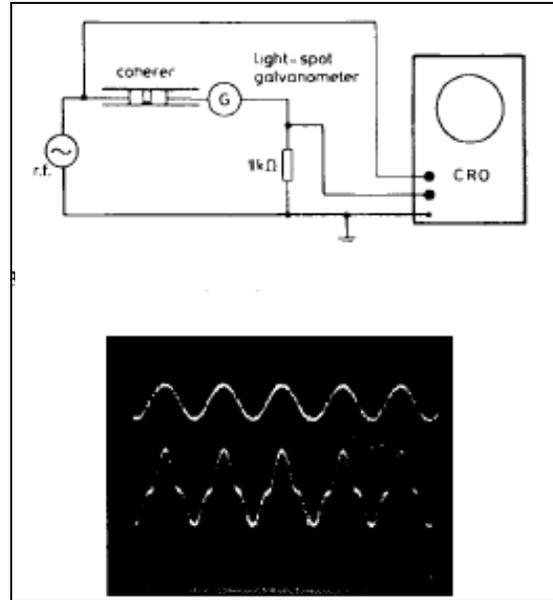


Fig. 10: Test Equipment and I/O Waveform (Reproduced [3])

In another experiment, the autocoherer was re-built by K L Groenhaug [22]. The characteristic curve (V-I curve) for the autocoherer (solid line) as found is shown in Fig. 11. It is amazing to see that the curve is very similar to that of a diode (dotted line).

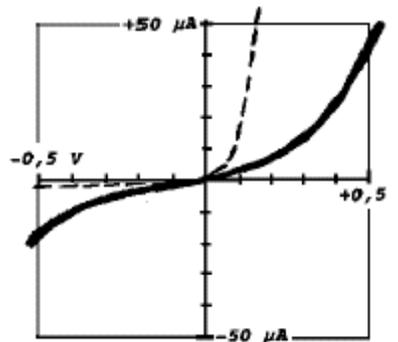


Fig. 11: V-I curve for a replica of Bose Detector (Reproduced [22])

The coherer and autocoherer gave way to the magnetic detector (invented by Marconi), to the vacuum tube diode → triode, pentode → Super heterodyne receivers. Today research goes in making receiver using dsp processors. [20]

6. Concluding Remarks

The article has brought into light, the principles and devices used at the time of first wireless communication. There has been an attempt to explain the experiments keeping in mind engineers as the audience. This clearly demonstrates the pioneering contribution of J. C. Bose in wireless communication.

The scandal surrounding the invention of the coherer used by Marconi has been discussed briefly, but effectively. Some concluding points are:

- In 1998, IEEE accepted J. C. Bose as the inventor of the mercury drop coherer used by Marconi.
- Bose holds the first patent for the solid-state diode detector based on galena crystal. [23]
- Bose was also a pioneer in his work on microwave devices. His contribution remains distinguished in the field and was acknowledged by the likes of Lord Kelvin, Lord Rayleigh, etc. [17,18]
- In 1895 Bose gave his first public demonstration of electromagnetic waves, using them to ring a bell remotely (more than a mile) and to explode some gunpowder. [17]

Further Reading

Due to the vast amount of literature on the contribution of Bose and the scandal surrounding the controversy, I am unable to cover all of it here. Kindly refer to references [1,3] for studying the controversy regarding the coherer. I recommend references [17] for studying the pioneering work of Sir J. C. Bose.

Acknowledgement

I will like to thank Drs Henry Bradford and K. L. Groenhaug for reviewing this article and for having interesting discussions with me on this issue. Furthermore, I will like to thank Drs D. K. Upadhyay (NSIT, Delhi), John Belrose, Alan Boswell and Nyle Steiner for answering my questions through mail. A special thanks to Dr. P K Bondyopadhyay.

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