AN INVESTIGATION OF MARCONI'S FIRST TRANSATLANTIC EXPERIMENT IN NEWFOUNDLAND TO FIND THE CORRECT FREQUENCY OF TRANSMISSION

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An Investigation of Marconi's First Transatlantic Experiment in Newfoundland to find the Correct Frequency of Transmission

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Abstract

The birth of long distance radio communications made the world such a small place. Marconi's transatlantic experiment was the first pioneering attempt in this area. His experiment was conducted on the 12th of December 1901. Ever since the question of the correct frequency of transmission has been an area of speculation. The problem that is being solved here is in this regard only. To calculate an acceptable frequency of transmission the experiment is studied from the concerned aspects. First the antenna patterns are calculated for both the transmitting and the receiving antenna, at three different frequencies, 166 kHz, 9.375 MHz and 12.5 MHz. Then the ionospheric propagation characteristics are calculated at these same frequencies and the various characteristics are analyzed. To complete the study, the transmitter is modeled and simulated to find the output waveform propagating to the antenna. A study of the receiver has also been conducted. Based on the analysis of the investigation done, a range of frequency has been suggested.

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Notations and List of Abbreviations

λ	: Wavelength
f	: Frequency
m	: metres
μ	: micro
"	: inches
p	: pico
k	: kilo
hp	: horsepower
v	: volts
H	: henry
F	: farad
Hz	: hertz
rf	: radio frequency

HF	: High Frequency
ft	: feet
M	: Mega
A. M.	: Amplitude Modulation
hrs	: hours
KM	: kilometers
GMT	: Greenwich Mean Time
UT	: Universal Time
dB	: decibels
dBW	: decibels above a watt
sec	: seconds
N	: North
W	: West
NEC	: Numerical Electomagnetics Code
$G\max$	: maximum gain
dc	: direct current
ac	: alternating current
ANSI	: American National Standards Institute
MUF	: maximum usable frequency
VHITE	: virtual height
SNR	: signal to noise ratio

F Days	: the probability that the operating frequency will exceed the predicted MUF
DBU	: Median field strength expected at the receiver location in decibels above one microvolt per meter.
S DBW	: Median signal power expected at the receive input terminals in decibels above a watt
N DBW	: Median noise power expected at the receiver in decibels above a watt
REL	: Reliability
MPROBE	: The probability of an additional mode within the multipath : tolerance
FREQ	: frequency
RPWGR	: Required power of transmitter and antenna gain to achieve the required reliability in decibels
RCVR	: Receiver
XMTR	: Transmitter
SSN	: sun spot number

Chapter 1

Introduction

1.1 Introduction

The employment of electromagnetic waves for the purpose of communication is no modern invention; on the contrary, its origins are lost in time. The history of a scientific progress is closely analogous to the history of an individual. In science, it is the birth of an invention which is remembered, not its conception or the patient development leads to a practical device.

The discovery of the practical means of wireless communications is a typical instance of this. Everyone associates the name of Marconi with it, whereas the names of those concerned with the gestation period are much less known outside the scientific circle, although without them there could not have been an advancement to todays level. Ampere's contributions towards the principles of electromagnetic induction;

Faraday's lines of forces; a Dynamical theory of the Electromagnetic Field in which the electromagnetic wave theory was mathematically expounded, by James Clark Maxwell; Hertz discovery of the outspreading of electric waves, which was given the expression 'aether waves', formed the background for the epoch making Transatlantic Experiment[1].

Marconi is known as the father of radio communications. Following up with the Hertzian apparatus and venturing with his own innovations Marconi began his pursuit in this field. It was his effort that led to the possibility of long distance wireless communication. On the 12th of December 1901 the first radio signals were received at Signal Hill, St. John's, Newfoundland, Canada from Poldhu, Cornwall, England. covering over 3000 km across the Atlantic. It was this experiment that was to later crown Marconi with the Nobel Prize in 1909.

1.2 The Experiment

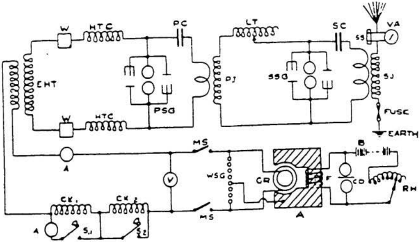
Before looking into the details of this experiment it is vital to know when and how this experiment took place. Marconi was preparing for his experiment for more than a year, and had a team of Engineers involved for this purpose. Discussing the preparation will be beyond the scope of this thesis, so only the experiment itself is discussed. The information to be listed below will be extracted from a number of references that include the works of Thackrey[10], Belrose[12], Bondyopadhyay[7], Simons[40], Ratcliffe[9], Phillips[3] and numerous other great works done in this area.

1.2.1 Transmitting Station

Marconi's transmitting station was set up in Poldhu, Cornwall in England. This was built at a height of nearly 150 m, on the coast of the Atlantic. Marconi and his team had worked months together to complete this set up.

The construction of the station was almost complete by the early part of 1901. The power plant was designed by Fleming. In place of the conventional battery power supply, a 32 hp Hornsby-Ackroyd oil engine drove a 25 kW Mather and Plat alternator, delivering a 2000 V, 50Hz supply. This was stepped upto 20,000 V and fed to a closed oscillatory circuit in which a capacitor discharged across a spark gap via the primary of an radio frequency transformer. The secondary of the transformer was connected to a second spark gap and capacitor and the primary of a second radio frequency transformer. The secondary of this transformer was in series with the antenna (Figure 1.1). Keying was effected by short circuiting chokes in the output of the alternator[1].

A number of huge transmitting antennas were built but later destroyed by the severe weather conditions prevailing in Poldhu. So during the actual experiment Marconi had to rely on a temporary one. The antenna that was used for the transatlantic experiment was a huge vertical monopole. The antenna was 48m high and 60m wide. It consisted of 50 copper wires all joined to form an inverted cone. Though the size of the antenna was not as big as it was intended it was still thought to be good enough for the experiment.



A. Alternator Frame; CR. Alternator Collector Rings; B. Battery; Rh. Rheostat; CD. Carbon Disc Protector across Field Windings; F. Alternator Field Windings; WSG. Wurtz Spark Gap Protector across Armature; MS. Main Switch; V. Voltmeter; A. Ammeter; CK1, CK2. Signalling Choking Coils; S1, S2. Signalling Switches; EHT. Transformer 2000–20,000 volt ratio; HTC. High Tension Inductance; WW. Wurtz Arrestors; PC. Primary Condenser; PSG. Primary Spark Gap fitted with Condenser Protectors; PJ. Primary Jigger; LT. Adjustable Tuning Inductance; SC. Secondary Condenser; SSG. Secondary Spark Gap with Protectors; SJ. Secondary Jigger; VA. Aerial Ammeter with SS Ammeter Shunt.

Figure 1.1: Marconi's Transmitter used during the 1901 experiment[1]

1.2.2 Receiving Station

The equipment available for Marconi for receiving wireless signals was understandably very poor, for the following reasons:

- *Initially the receiver was untuned, or if tuned, the selectivity was poor.*
- *There was no means to amplify the signal.*
- *A sensitive detector was still not invented.*

For his first Transatlantic Experiment in 1901 Marconi had two types of receivers, and three types of coherers. One was the tuned receiver which he referred to as a "syntonic receiver", i.e, receiver tuned to the frequency of the transmitter. The second receiver was an untuned one. The three types of coherers that he used were: one containing loose carbon filings; another designed by Marconi containing a mixture of carbon dust and cobalt dust; and thirdly the Italian Navy coherer containing a globule of mercury between a carbon plug and a movable iron plug. The device that was actually used is a matter of controversy as contradictory statements have been made by various people involved with this experiment.

Considering the winds in the month of December in Newfoundland, erecting an antenna on the peak of the Signal Hill was no easy task. After several attempts Marconi was able to form an antenna. He flew a kite with a vertical aerial wire of 400ft. This wire antenna was connected to the receiving circuit.

1.2.3 The Event

After reaching Newfoundland in the early part of December 1901, Marconi cabled his station in Cornwall to begin sending the prearranged signals. On December 11th the kite broke away and nothing was received. On 12th of December, however he had better luck. His arrangement was for Cornwall to send at specific intervals between 3 to 6 pm Cornwall time (noon to 3pm, St. John's time), the Morse letter "S" which consists of three dots. On 12th of December Marconi and his assistant Kemp, received these signals under such conditions that assured them that the received signals were genuine. They received the signals through a specially sensitive telephone attached to their instruments. As said by Marconi", The combinations were perfect and strong; the test was conclusive though not practically effective". The signals were received at 12:30 pm, 1:10 pm and 2:20 pm on 12th of December and 1:38 pm on the 13th of December. Marconi kept receiving the signals for a few more days to follow. But subsequently due to the baffling wind flying the kite became impossible[2].

Thus the inception of long distance wireless communication took place. With the passage of time, wireless communication keeps on improving. But still even today Marconi's experiment has remained a mystery in many ways.

1.3 Subsequent Studies of Marconi's Experiment

Marconi's experiment has been an area of discussion ever since this experiment was successfully completed. Marconi left a wide range of questions unanswered, which keeps scientists researching even today. First of all, there is a debate on the type of equipment that was used. A detailed record of the type of equipment used and their parameters have not been left behind by the experimenting team of 1901. Most of this equipment was not preserved and lost in the course of time. Along with this, the readings of the signals being transmitted and received were not recorded. This can be attributed to the lack of measuring instruments available at the time of the experiment in 1901.

As we approach the millennium, the studies being done to solve the mysteries of Marconi's experiment have attracted attention. Work has been done to find out the reasons behind the success of this experiment. Considering the number of papers that have been published in this direction, one comes to believe that not many convincing results have been obtained in this regard.

What Marconi and his two assistants had received at Signal Hill on the stormy day of the 12th of December 1901 was known only to them. Although nobody doubted Marconi's honesty, it was suggested that he might well have been deceived by his own ears and by the high level of atmospheric noise into thinking that he heard the signal. Later on, in February 1902 he conducted further trials aboard the *SS Philadelphia*, and was able to confirm the reception of the Poldhu signals at distances over 2000 miles[3].

But this was not the end, and the dust was yet to settle; more controversies came up. One of the major controvercies was the frequency of transmission of the signal during the transatlantic experiment. This was an issue that Marconi had no idea how to tackle. Immediately after the experiment, Marconi in his interview with R. S. Baker, 1902, [4] states: " The wave which was thus generated had a length of about a fifth of a mile, and the rate of vibration was about 800,000 to the second". On the other hand on the 13th of June 1902 in his address to the Royal Institute he doesn't talk about frequency at all[5]. But during a lecture at the Royal Institute on the 13th of March 1908[1], Marconi quoted the wavelength as 1200 ft. Marconi remained silent on the wavelength issue even during his Nobel lecture in 1909[6]. Then in a recorded message in the early thirties he says[7], " The wavelength was approximately 1800 meters and the power was 15 kilowatts". Scientific Advisor to Marconi, Fleming had said in a March 1903[8] lecture that the waves sent out from Poldhu had a wavelength of a thousand feet or more, say, one fifth to one quarter of a mile. This was the extent of the confusion as to the frequency in Marconi's camp.

To have a good view of all the works done on Marconi's transatlantic experiment the study can be divided into three basic parts.

1. transmitting and the receiving circuit.
2. ionospheric propagation
3. antennas.

But in 1974, over 70 years after Marconi's experiment, it seemed that the dust settled because ionospheric comunication system developed for running shortwave radio, overseas radio broadcast and other simple examples show that Marconi's experiment or his theory was correct. It was done by J. A. Ratcliffe[9], on the occasion of the birth centennial of Marconi in 1974. Ratcliffe tried to do the whole experiment once again, in his own setting, in order to find the wavelength of the first transatlantic wireless signal. Ratcliffe had made some mistakes. He failed to notice that the contingency communication setup was not a four tuned circuit. In other words, the receiver circuit actually used was neither a double tuned circuit by itself nor was it tuned to the double tuned transmitter circuit. Stated otherwise, the actual system employed did not work according to Marconi's famous 7777 patent of 26th April 1900[6]. Consequently the 1974 transmitting antenna cannot be viewed as a fixed radiation resistance in series with a capacitor whose value is set by the external discharging capacitor and the antenna coupling transformer turns ratio.

Desmond Thackrey, 1992, [10] has done a detailed study on some of the aspects of this experiment laying main emphasis on the transmitter. The problem of not knowing the parameters of the transmitting circuit was solved to a great extent. Thackrey depended on the measurements made by Dr. George Grisdale in 1974[3]. He begins by explaining the evolution of the Poldhu transmitter. A thorough study of the oscillation transformer (the "jigger" as it was called by Marconi) was done to explain its function. Based on Grisdale's measurements on a facsimile at the science museum 8" open jigger and the comments made by Fleming, Thackrey has postulated numerical values for the circuit. This work is analytical and is based on a number of assumptions. Based on the values he got, he has put forward a range of frequencies that could have been produced. According to his calculations the operating frequency could have been in the range 397 kHz to 664 kHz.

Thackrey[10] has not postulated the values of the extra coils in the primary of the primary jigger and the long adjustable tuning inductance in the primary circuit of the secondary jigger (Figure 1.1). Along with this spark, transmitters have a feature of producing oscillations. Based on the manner in which a spark transmitter functions, it is obvious that it will produce oscillations. What frequency is produced due to these oscillations is not known. However, going through the whole literature, one should accept that by far this is the most explanatory paper that has been published till today on this topic.

The receiver has been studied by V.J. Phillips, 1993, [3]. He has addressed the great controversy, which threatened to tarnish Marconi's reputation, concerning the invention of the coherer. The paper re-examines the issue, and also includes the technical observations as to the coherer's precise mode of operation. Phillips has given a very vivid view of the receiver. His experimental data have revealed that Marconi's mercury coherer happened to be in the rectifying mode just at the time when the signals were being sent out. Though to use a coherer to get a rectifying mode is a very inefficient arrangement compared with a proper diode which has almost zero reverse conduction, nevertheless, with a sensitive earphone this could easily have been the mechanism which enabled them to hear the Morse dots from Poldhu.

On the other hand Grisdale (at the Marconi Laboratories in 1974)[3] attempted to use the Italian Navy coherer as a diode envelope detector for the reception of A.M. signals and to compare its action with that of a germanium point contact diode. His conclusion was that the coherer would indeed rectify, but very inefficiently. Just like Phillips, Grisdale has found that the coherer would jump in and out of the rectifying mode and be affected by mechanical vibration and electrical overload. It was also their conclusion that better results were obtained if the mercury was not too clean, and had been left around for some time. This perhaps points to a mercury oxide film as being the most important factor in the operation. As the works of Phillips and Grisdale match, it can be considered to be a conclusive result. Moreover, as this thesis is concerned with finding the frequency of the signal, the frequency aspect will be discussed later.

Table 1.1: Results shown by Bondyopadhyay

Poldhu transmitter location:	50° 5'N 5° 15'W
Signal Hill Receiving location:	47° 30'N 53°W
Normal EIRP from Poldhu:	30dBW (1 kW assumed)
Selected receiving bandwidth:	3000Hz
Assumed SNR required at Signal Hill:	10dB
Sun spot number on 12th December 1901:	0
F2 layer height:	275 KM
Time:	16 00 hrs GMT

Received Signal wavelength:	32 meters	24 meters
	(9.375MHz)	(12.5MHz)
Received Signal at Signal Hill(50ohms system):	19dB μV	33dB μV
Ionospheric Propagation (F2 layer):	double hop	single hop
Calculated takeoff angle:	13°	1°
Received SNR at the selected bandwidth:	21 dB	35 dB
Total communication link reliability:	81%	92%

Fessenden[12] had realized that continuous wave transmission was required for speech, and he thought he could transmit and receive Morse code better by the continuous wave method than with spark apparatus as Marconi was using.

In 1994, John Belrose of Communication Research Center, Canada [12], conducted a comparative study between Fessenden and Marconi. In his work he describes the transmitter, while discussing the differing technologies of Marconi and Fessenden. This is a discussion of the transmitter technology and says nothing about the output of the transmitter.

Belrose has said that the distinctive sound of spark is not easily forgotten, yet he assumes that a vast majority of scientists and operators had no knowledge of how the spark transmitter used between 1900 and 1925 sounded, when received on the simple crystal receivers of the day, or what the first crude attempts of Fessenden to transmit voice on a transmitter might have sounded like. So keeping this in mind Belrose[13] constructed a 5 MHz transmitter using a high performance automotive ignition coil for the inductor, and circuitry to simulate a Braun type transmitter (Figure 1.2), simulating a 5 MHz quarterwave monoploe antenna. The Braun's transmitter was different from Marconi's spark transmitter. It had a single stage spark gap instead of two and had a dc source. Also the supply was ac in this case and the oscillation transformers were not there in the Braun transmitter. The inductance of these transformer windings were affecting the frequency of the output wave.

J.C.B. MacKeand and M.A. Cross[14], have, in 1995, done an investigation of

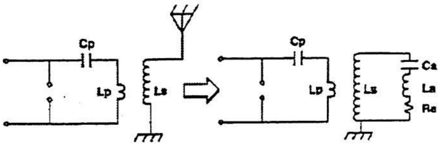


Figure 1.2: Braun's Spark Transmitter[13]

on many of the aspects of this experiment. They have considered the whole picture from the transmission to the receiving of the signals. In their transmitter study it has been assumed that as the spark gap and the primary capacitor are well defined and they have taken the aerial jigger dimensions as those suggested by Thackrey[10]. No schematic representation of the transmitter has been shown. A good effort has been made to feed the jigger from a sparking contact much as used in the buzzer wavemeters of more than 60 years old. In MacKeand and Cross's paper it is also mentioned that the output from such a device is not very stable, but it does offer advantages of small size and battery operation. The actual spark gap was connected to a high voltage ac source, while the spark gap being used by Mackeand and Cross is connected to a dc source. This use of a low voltage dc source will alter the charging and the discharging of the capacitors, and thus the output.

Vyvyan[15] states that, "The kite was rising and falling in the wind throughout the experiment 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, 12th December 1901, and one of his two assistants heard the faint S signals". There is a controversy on the receiver used by Marconi during the experiment as he had more than one with him at that time. So in this work we go by the statement made by Vyvyan. As has been widely acclaimed, we will also take the receiver to be an untuned one.

The short wave era in long distance radio communication began with the revolutionary discovery of the day light wave by Guglielmo Marconi in July- September 1924[16]. Tests carried out between Poldhu and the Elettra (Marconi's ship used for radio experiments), had revealed to Marconi that:

- *The day ranges proved to be reliable and not unconsiderable.*
- *The night ranges were much greater than anyone had anticipated and no doubt very considerably exceeded the maximum distance to which Marconi was able to proceed with the Elettra.*
- *The intervening land and large portions of continents do not present any serious obstacle to the propagation of these waves.*

The concept of daylight effect and the effect of skywave propagation was not known

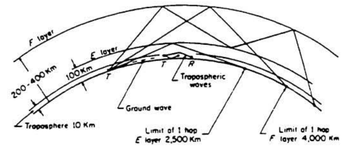


Figure 1.3: Some possible propagation paths [17]

to Marconi during the transatlantic experiment. Figure 1.3 shows the effect of the ionosphere on the skywave propagation. No prior attempt has been made to study this experiment from this ionospheric propagation point of view.

Antennas at Poldhu and St.John's were also the designs of Marconi and his colleagues. Marconi has said that the transmission took place at 166 kHz[7]. P.K. Bondyopadhyay[7], suggested in 1993 - 1994 that just by looking at the antenna one can say that it is a short wave antenna. So a signal of 166 kHz could not have been transmitted from this antenna. He has suggested two wavelengths in this regard that might have been responsible for the successful completion of this experiment. These wavelengths are 32m and 24m , and corresponding to 9.375MHz and 12.5 MHz.

Bondyopadhyay's results are shown in Table 1.3 [11]. It gives a total communication reliability of 81% and 92% for 32 and 24 meters waves respectively. He did not mention the software used for the calculations. It may be IONCAP. Also the signal to noise ratio has been calculated to be 21 dB and 35 dB respectively. These SNRs are capable of transferring a wave across the Atlantic ocean. These convincing results have been the inspiration for choosing these frequencies for study in this research work. What Bondyopadhyay has not shown is the effect of these conditions on the frequency that Marconi had mentioned, i.e. 166kHz.

In Mackeand and Cross's work the antennas have also been modeled. The transmitting antenna is supposed to have had 54 wires . But the number of wires used by Mackeand and Cross are just thirteen. It says that calculations have been made for capacitance to earth and an asymptote is rapidly approached with more than ten wires.

It appears that despite of being an important part of the whole communication system the antennas used by Marconi have not been studied widely. Very few publications can be cited in this regard. Belrose[18] has calculated the resonant frequency of the antenna and that of the transmitter and based on that he has predicted the frequency to be 500 kHz. Since the resonant frequencies of the oscillatory circuit (511 kHz) and the antenna circuit (463 kHz) are close, he postulates that the radiation would be spread about a single frequency, a frequency of about 500 kHz.

Belrose also said "Despite the crude equipment employed, and in our view the impossibility of hearing the signal, Marconi and his assistant George Kemp convinced themselves that they could hear on occasions three clicks more or less buried in the static, and clicks would be, not unlike atmospherics, if heard at all, because of the very low spark rate(estimated to be a few sparks/sec)"[18]

At another occasion Belrose[19] has modeled the transmitting antenna. He constructed 12 wire and 54 wire models using a scale factor of 1:75 for the dimensions according to the available information about the Poldhu December 1901 aerial. According to the experimental model measurements the 54 wire fan exhibits resonances at 935 kHz and 3.8 MHz; anti resonance at 2.4 MHz and 4.8 MHz; and appears to be approaching anti resonance. between 7 and 8 MHz. but no resonance are observed above 3.8 MHz.

It should be noted that when one is trying to predict the frequency of transmission, leaving the receiving antenna out will not yield accurate results. Also, most of the equipment being used were of erratic nature and that the atmospheric conditions have to be taken into account when trying to predict the frequency. It is not only at the resonance frequency at which radiation takes place. So a different approach is necessary.

1.4 Motivation

The transatlantic experiment was conducted nearly a century ago. This pioneering experiment led to the modern day wireless communication. The equipment used were of the first of their kind in the field of long distance radio communication. The mere fact that the features that led to the success of this experiment are still unexplained has been the greatest source of inspiration for this research work. The question of what frequency Marconi used is a major aspect that Marconi himself was not sure of, and there have been contradicting statements in this regard. As has been discussed, researchers have been working in this area to solve the problem in order to understand the experiment itself. Still no convincing answer has been reached. Another point is that this experiment has not been studied completely considering all the factors that could have affected or assisted the signal in the propagation path.

An important, though non-technical factor that influenced this work is the need for someone from Memorial University in St. John's to study the experiment since the whole episode had taken place in St. John's. The site of this experiment is in view, which in itself doubles the curiosity to learn more about this experiment. There is a museum that has been built on Signal Hill for Marconi, reminding people of his great contribution.

Both the transmitting and the receiving antennas are equally important in completing the whole communication system, so both the antennas need to be studied. This thesis, for the first time, takes into consideration both the antennas and tries to find the most suitable frequency that would have been transmitted.

The spark transmitter that Marconi used has been studied before. But it is only in this work that the computer modeling of the transmitter has been done. This gives the liberty to understand and work with the circuit with all different possibilities.

1.5 Analysis of Marconi's Experiment

This thesis is designed to analytically explore Marconi's transatlantic experiment in its complete and actual form. While investigating the transmitter we extend the work of Thackrey[10]. We use his postulated data for the functioning of the transmitter, and find out the exact output of the circuit by simulating the whole circuit to see what waves were propagating to the antenna, and hence get a step closer to finding a reasonable frequency.

MacKeand and Cross[14], designed a physical model of Marconi's antenna with 13 wires instead of 54. Our attempt here is to rather simulate the circuit to get the output waveform without altering the source i.e.using the actual ac source that was used during the experiment. Although MacKeand and Cross claim that there is not much of a difference by increasing the number of wires, it does make some difference. This fact is obvious by noting the difference between the radiation pattern of the antenna with 54 wires and the radiation pattern of the antenna with 13 wires as done by MacKeand and Cross. The point is to get as close as possible to the original experiment[1]. So here in this work the actual antenna in its original form is considered with all its wires in order to get results close to that of December 1901.

As stated elsewhere the concept of daylight effect and the effect of skywave propagation was not known to Marconi during the transatlantic experiment. However, no attempt has been made in the past to study this experiment from this ionospheric propagation point of view. This thesis will take a complete look into the ionospheric propagation characteristics of the signal on the 12th of December 1901. Data that are used for the calculation of these characteristics have been collected with the help of various studies conducted before. These data were used to find out the ionospheric conditions prevailing during the time of the experiment. The data used for the atmospheric conditions in this thesis are somewhat different than that used by Bondyopadhyay[11]. The results obtained from these calculations help strengthen the arguments on the frequency of transmission. Here the actual path taken by the signal will be shown in order to give a clear view of how the wave was traveling.

In this thesis three frequencies are studied, namely 166 kHz, 9.375 MHz and 12.5 MHz, under the conditions prevailing during the time of the actual experiment. The choice of these frequencies is based on the works of two researchers, Bondyopadhyay and Ratcliffe. Bondyopadhyay in his investigation has found that when Marconi was doing his experiments in the Mediterranean, he had reported the frquencies of 9.375 and 12.5 MHz as the frequencies of transmission[11]. Though Marconi was using the same transmitter and receiver as was used during the transatlantic experiment, he did have a frequency measuring device at that time[11]. Since the apparatus used was same, it is logical to consider the fact that these were the frequency responsible for the success of the transatlantic experiment also. The other frequency of 166kHz has been taken into consideration as this was the frequency that Marconi that Marconi himself had predicted[7]. Ratcliffe in his analysis has shown the power spectrum for the transtlantic experiment. In this power spectrum the power rises to reasonable heights only in the MHz range. The maximum gain, power input, virtual heights have been calculated at these three frequencies. Calculations made in this work consolidate the concept of short wave propagation. Along with this, the whole experiment has been studied in the conditions that would have prevailed had the experiment been done in summer. To get to these results first the radiation pattern of both the antennas have been calculated using the Numerical Electromagnetic Code(NEC)[20] which is based on the Moment Method. These radiation patterns are then used to calculate the ionospheric propagation characteristics. These characteristics have been calculated using "The Ionospheric Communication Enhanced Profile Analysis and Circuit Prediction Program"(ICEPAC)[21]. It has been shown in this work that the possibility of having a transmission at the frequency at which Marconi was supposed to have been working is a distant possibility and also that had this experiment been conducted in the summer there is no possibility of any transmission at 166 kHz.

Belrose has predicted the frequency of transmission based on the concept of resonance frequency. In this work the resonance frequency approach has not been considered. Instead the feature that defines the characteristics of an antenna, i.e., the radiation pattern has been taken into account. The radiation pattern is calculated at different frequencies to analyze the performance. Following this path new results have been obtained and are interpreted such that new information becomes available about this experiment.

1.6 Organization of Thesis

This thesis has been divided into five chapters. Chapter 1 is the introduction to the 1901 transatlantic experiment. In this chapter the work that has been done in this field by others has been discussed. Along with this the experiment that is in question has also been accounted for. Chapter 2 investigates the antennas that Marconi used. It gives the calculations for the antenna patterns and determines the frequency that these antennas are suitable for. Chapter 3 focuses on another important aspect of wireless communication, i.e., the ionospheric propagation characteristics. These characteristics have been calculated at three different frequencies and the maximum probable frequency has been predicted. In Chapter 4 the transmitter and the receiver have been modeled and studied. The results that were obtained with the antenna and the ionospheric propagation characteristics have been correlated with the results in this chapter. The conclusion of this work with some recommendations for future work are included in Chapter 5.

Chapter 2

Investigation of the Antenna System

2.1 Introduction

Marconi was a champion of multi-wire antennas. His ambitions fetched him the idea of sending signals across the Atlantic ocean to bridge the two continents of Europe and North America. Originally, the eastern terminal was at Poldhu, Cornwall, England and the western terminal was the sand dunes on the northern end of Cape Cod, MA at South Wellfleet.

At these locations the aerial (Figure 2.1) was constructed. It comprised of 20 masts, each 61 metres high, arranged in a circle, 61 metres in diameter. The ring of mast supported a conical aerial system of 400 wires each insulated at the top and

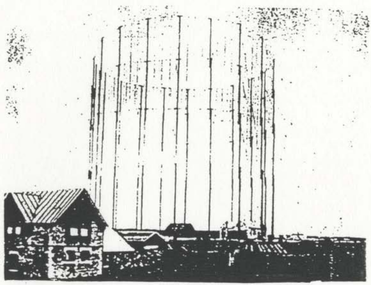


Figure 2.1: The antenna system initially constructed for the transtlantic tests[1]

connected at the bottom to form an inverted cone.

However, before testing could begin, a catastrophy struck. The Poldhu aerial collapsed and the same happened to the South Wellfleet aerial. At Poldhu, Marconi quickly constructed an aerial of 54 wires and a monopole receiving antenna was set up at Signal Hill, St. John's, Newfoundland, which was now the new receiving centre. This chapter takes a look into the characteristics of these two antennas to understand their contribution to the experiment on 12th of December 1901.

2.1.1 Calculating the radiation pattern

The radiation pattern of an antenna is a graphical representation of the radiation properties of an antenna[22]. It is understood that it represents the radiation pattern in the far field. The radiation pattern can be calculated if the current along the wire antenna are known. The currents along any wire antenna can be calculated by solving the integral equation where this current to be found is the unknown. The method used to solve the integral equation(IE) is the moment method(MM). Once the current density is found, the radiation integrals are used to find the fields radiated and the system parameters. The moment method is most convenient for wire type antennas and more efficient for structures that are electrically small. One of the first objectives of this method is to formulate the IE for the problem at hand. In general, there are two types of IEs. One is the *Electric Field Integral equation*(EFIE), which is based on the boundary condition of the total tangential electric field. The other is the *Magnetic Field Integral Equation*(MFIE), which is based on the boundary condition that expresses the total electric current density induced on the surface in terms of the incident magnetic field[23].

Another method, which has received a lot of attention in scattering, is the*Finite-Difference Time Domain* (FDTD). This method has also been applied to antenna radiation problems[24]-[27]. A method that is beginning to gain momentum in its application to antenna problems is the Finite Element Method[28]-[32]. But these are not of concern in this work.

2.1.2 Numerical Electromagnetic Code (NEC)

The Numerical Electromagnetic Code(NEC)[20] is a user-oriented program developed at the Lawrence Livermore Laboratory. It is a moment method code for analyzing the interaction of electromagnetic waves with arbitrary structures consisting of conducting wires and surfaces. It combines an accurate modeling for a wide range of applications. The code can model non-radiating networks and transmission lines, perfect and imperfect conductors, lumped element loading, and perfect and imperfect ground planes. It uses the electric field integral equation(EFIE) for thin wires and the magnetic field integral equation(MFIE) for surfaces. The excitation can be either an applied voltage source or an incident plane wave. The program computes induced current and charges, near and far zone electric and magnetic fields, radar cross section, impedances or admittances, and gain and directivity, power budget, and antenna-to-antenna coupling.

2.2 Transmitting Antenna

The antenna that was constructed in Poldhu is shown in Figure 2.2. This antenna consists of fifty stranded bare copper wires suspended from a triatic strained between two 48 m(160ft) masts 60 m (200ft) apart. These wires were then brought together in a fan shape to form a common connection to the transmitter.

The characteristics of the antenna is studied using the computer package Numerical Electromagnetics Code (NEC-2). To verify at what frequency this antenna

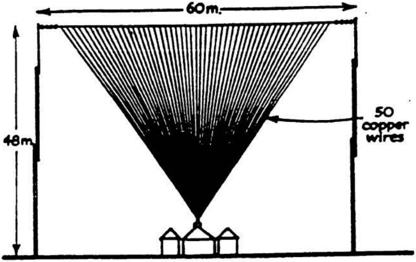


Figure 2.2: The Temporary transmitting antenna used at Poldhu for the transtlantic tests[1]

functions the best, tests are done at three different frequencies, i.e. 166 kHz, 9.375 MHz and 12.5 MHz. The reason for selecting the first frequency is obvious. The other two frequencies are selected by making an assumption. The short wave era in the long distance radio communication began with the revolutionary discovery of the 'daylight' wave by Marconi in July-September of 1924, while systematically experimenting with shorter wavelengths. Marconi, on voyages over the Mediterranean and towards the Syrian coast aboard his radio laboratory ship Elettra, received the 9.375 MHz and 12.5 MHz signals from Poldhu[11], day and night. Structures of both the transmitting antenna and the receiving antenna are such that they were capable of carrying short wave signals.

2.3 Radiation Patterns of the Transmitting Antenna

The radiation patterns of this antenna have been calculated, over ocean at three frequencies of 166 kHz, 9.375 MHz and 12.5 MHz[33] and shown in Figure 2.3, Figure 2.4 and Figure 2.5 The data fed to NEC for this purpose are shown below:

No. of Wires = 50

Radius of wire = 0.01m

Total no. of segments = 638

Table 2.1: Results from the Radiation Patterns of transmitting antenna

Frequency (MHz)	Max. Gain (dB)	Input Power (Watts)	Take-Off Angle (Degrees)
0.166	-14.7	8.31 E-07	0.7
9.375	7.62	4.24 E-04	11.8
12.5	9.05	1.81 E-03	11.8

Relative Dielectric Constant = 80

Conductivity = 4 mho/metre

As shown in Figure 2.2 the number of wires in the antenna has been taken to be 50. the radius of the wires is 0.01m. As required in the Moment Method each wire has to be divided into a number of segments. So here each wire is divided into 638 segments to satisfy the relationship shown in the following equation. The whole transmossion is taking over ocean so the relative delectric constant will be 80 and the conductivity 4 mho/metre

The length of each segment depends on the relation:

$$0.001 \leq (\tfrac{\Delta}{\lambda}) \leq 0.1 \qquad [1]$$

Where $\{\Delta\}$ is the length of one segment and $\{\lambda\}$ is the wavelength.

As shown in Table 2.1 the maximum gain G_{max} at 0.166 MHz is at a low of - 14.7 dB, whereas G_{max} at the higher frequencies is positive and is well placed at 7.62 dB

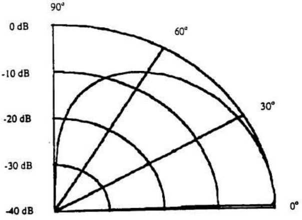


Figure 2.3: Normailzed E-Field pattern of transmitting antenna at 166 kHz over ocean

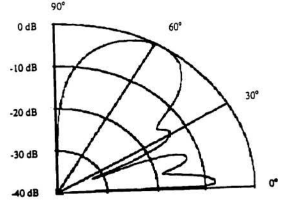


Figure 2.4: Normalized E-Field pattern of transmitting antenna at 9.375MHz over ocean

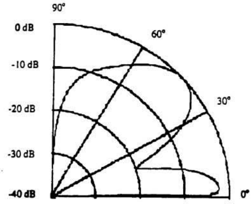


Figure 2.5: Normalized E-Field pattern of transmitting antenna at 12.5 MHz over ocean

and 9.05 dB at 9.375 and 12.5 MHz respectively. The take-off angle that has been mentioned in Table 2.1 will be discussed in Chapter 3.

The radiation patterns cited in Figures 2.3 to 2.5 reveal the characteristics of the transmitting antenna. Radiation pattern of this antenna at 166kHz has not been calculated before this. This new result reveals clearly that 166 kHz was not an effective frequency to work with. When compared to the works of other researchers it is seen that the radiation patterns are different from that found by MacKeand and Cross[14]. Evidently this might be because of the fact that MacKeand and Cross had used only 13 wires instead of 50. These results in Figures 2.3 to 2.5 point in the direction of higher frequency being responsible for the transmission during the transatlantic experiment. This finding is inline with the predictions made be Bondyopadhyay[11].

2.4 Receiving Antenna

On December 1901 Marconi set sail for St. John's with a small stock of kites and balloons to keep a single wire aloft in stormy weather. A site was chosen on the Signal Hill in St. John's, and the apparatus was set up in an abandoned military hospital. On 12th of December, 1901, under strong weather conditions, a kite was launched with 152.4 m (400 ft) long wire.

No. of Wires = 1

Radius of wire = 0.005m

Total no. of segments = 32

Relative Dielectric Constant = 80

Conductivity = 4 mho/meter

2.5 Radiation Pattern for the receiving antenna

Field patterns for the receiving antenna have been calculated and shown in Figures 2.7 to 2.9. The receiving antenna behaves in a similar manner as the transmitting antenna. The gains increase with increasing frequency, and so does the power as shown in Figure 2.7, Figure 2.8, Figure 2.9. This trend has been shown in Table 2.1

Another aspect that decides the reliable working of an antenna is the electrical height of an antenna. An antenna whose dimensions are smaller than one sixth of

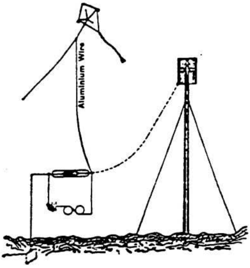


Figure 2.6: The Temporary receiving antenna used at Signal Hill for the Transtlantic tests[1]

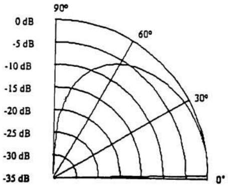


Figure 2.7: Normalized E-Field pattern of receiving Antenna at 166 kHz over ocean

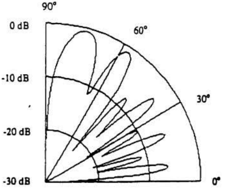


Figure 2.8: Normalized E-Field pattern of receiving Antenna at 9.375 MHz over ocean

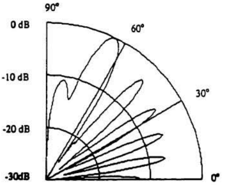


Figure 2.9: Normalized E-Field pattern of Receiving Antenna at 12.5 MHz over ocean

Table 2.2: Results from the Radiation Patterns of receiving antenna

Frequency (MHz)	Max. Gain (dB)	Input Power (Watts)	Take-Off Angle (Degrees)
0.166	-5.07dB	8.67 E-06	0.7
9.375	8.39dB	1.46 E-03	11.8
12.5	10.87dB	5.09 E-04	11.8

Table 2.3: Height of transmitting Antenna in terms of wavelength

Frequency (MHz)	Wavelength (Meters)	Height in Wavelength (λ)
0.166	1800	0.0266λ
9.375	32	1.5λ
12.5	24	2λ

Table 2.4: Height of receiving Antenna in terms of wavelength

Frequency (MHz)	Wavelength (Meters)	Height in Wavelength (λ)
0.166	1800	0.0683λ
9.375	32	3.84λ
12.5	24	5.12λ

wavelength is referred to as an electrically small antenna. One possible definition for electrically small antenna is that the antenna fit inside a "radiansphere" i.e. a sphere whose diameter is $\lambda/2\pi$, or (about one-sixth of a wavelength). Such antennas are inherently inefficient[22]. In both the transmitting and the receiving antennas Table 2.2 and 2.3 show that the electrical height is smaller than a wavelength at 166 kHz. So the antennas will be inefficient at this frequency. On the other hand, say at 12.5 MHz the transmitting antenna is 2λ long, (1.5λ for 9.375 MHz),which gives more efficient antenna and enables a reliable transmission. With respect to the receiving antenna the electrical length is 3.84λ and 5.12λ for 9.375 MHz and 13.5 MHz respectively. Evidently the performance of the antennas is going to be more reliable at these high frequencies.

2.6 Summary

The study of the antennas has revealed some interesting features. The calculation of the field pattern using the Moment Method has given the correct category this antenna falls in. Records of Marconi's historical experiment are not able to convey all the aspects behind the success of this event. The study shown in this chapter has revealed that the antennas were not at all suitable for long wave transmission and reception at f = 166 kHz. As the gain and the power at 166 kHz are so low and the electrical height is practically very small, indicate that the antennas will be very inefficient at that low frequency. This study clarifies that only if the transmission had been in the range of a few megahertz that a reliable transmission and reception was possible. In Chapter 3 the experiment will be studied from ionospheric propagation point of view.

Chapter 3

Investigation of the Ionospheric Propagation

3.1 Introduction

In this chapter Marconi's transatlantic experiment will be studied from the ionospheric propagation point of view. Till now no serious attempt has been made to examine the experiment from this angle. The layout of the ionosphere decides which way the waves will be traveling. The radiation patterns that were calculated in the last chapter will be used here to calculate the ionospheric propagation characteristics. The weather conditions prevailing during that time have been predicted using the data available[1]. Before commencing the study of the ionospheric conditions during Marconi's experiment, it will be easier to understand the concept if the ionosphere itself is explained first.

In this endeavor, Marconi's experiment[1] will not only be studied from the winter conditions (the actual time of the experiment) but also will be studied for summer conditions to determine the results of the experiment. After the transatlantic experiment, it is known that Marconi proceeded towards the Mediterranean to further his work on long distance wireless communication. He conducted those experiments from his ship during the summer time. At that time he reported high frequency signals as the reason for his success. So the question is: Were these the same high frequency signals responsible for the success of the first transatlantic experiment?

3.2 Sky-Wave Propagation

It is known that whether it is day or night, the ionosphere is always present. Only the density of the ions vary in the absence of the sun. The electron density distribution is the major controlling factor over the HF radio wave propagation. The regions of the ionosphere that are deemed to be important for the transmission path of a signal are the D , the E and the F *regions.* To understand the concept, further study of these regions [17] is made.

3.2.1 *D Region*

This region occupies the lowest altitude. It extends to the height of 50 to 90 km, where the electron density rapidly increases with altitude in the daytime. When the sun-spot is high, it is considered that the solar activity is high. The maximum ionization takes place in the D region near the subsolar point and is maximum when the solar activity is at its peak. The D region may not be explicit in some ionospheric models where its effects are accounted for with an empirically derived path loss calculation. Most models have this nondeviative absorption as a median value plus distribution. Because of the high electron density, the D region does not reflect useful transmissions in the frequency range above 1 MHz. However here the absorption is important at all frequencies and because its ionization is produced by ultraviolet solar radiation, it is primarily a daytime phenomenon. After sunset the ionization decreases rapidly and nondeviative absorption becomes negligible after two to three hours.

3.2.2 *E Region*

The E region ranges from the height of 90 to 130 km. The ionization region reaches its maximum at the height of 110 km, with sunshine. In addition, there may be anomalous ionization, referred to as sporadic E. This latter ionization layer is thin in altitude, may be either smooth or patchy, is seasonally and diurnally variable but not well correlated with solar activity, and has marked variations with latitude. For communication, the most important characteristic feature of this region is the temporal and geographic variation of its critical frequency (it is the frequency at which the signal from the ionosonde just penetrates that layer). It is very much comparable to the F2 layer.

3.2.3 *F Region*

This is the highest altitude region of interest for sky-wave propagation, and it is also the region of greatest electron density. In the daylight hours two components may be recognized, especially in summer. The F1 region lies between 130 and 200 km, and like the E region, is directly dependent upon solar radiation; it reaches the maximum intensity about 1 hour after local noon. The F2 region is variable in both time and geographical location. The altitude of F2 region peaks are considered to lie between 250 and 350 km in the middle latitudes. The F2 region ionization shows marked day-to-day variation, and in general is not the regular sun follower that the E and F1 regions are. Most models have a statistical description of F2 maximum electron density (or critical frequency) in the form of a median and upper and lower decile values.

3.3 Ionospheric Communications Enhanced Profile Analysis and Circuit Prediction Program (ICEPAC)

The Institute for Telecommunication Sciences, and its predecessors in the U.S. Department of Commerce, has been collecting ionospheric data and developing methods to use these data in the prediction of the expected performance of high frequency (HF) sky-wave system since the start of World War II. Based on these data the ICEPAC software was developed[21]. It is an improved version of IONCAP(IONospheric Communications Analysis and Prediction). ICEPAC is a computer package designed to predict high frequency sky-wave system performance and analyze the ionospheric parameters which affect the wave propagation. It is in modular form and coded in simple FORTRAN, following as much as possible the ANSI 77 standard. The ICEPAC program uses an integrated system of subroutines designed for its analysis and outputs. These predictions can be used in the planning and operation of high frequency communication system using sky-waves.

The program is divided into seven largely independent sections(subroutines):

1. Input subroutines
2. Path geometry subroutines
3. Antenna subroutines
4. Ionospheric parameters subroutines.
5. Maximum Usable Frequency (MUF) subroutine
6. System performance subroutines, and
7. Output subroutine

Before using this program to predict the ionospheric characteristics during the experiment it is necessary to verify the validity of ICEPAC. The verification has been done in Memorial University, in 1993[34]. ICEPAC's predictions were for Canadian regions. This was achieved by correlating ICEPAC's ionospheric data with the measured data from two different sites in Canada (Churchill, Manitoba and Ottawa, Ontario). The results arising out of these tests are shown in the plot Figure 3.1. In this figure it the frequency is shown on the X-axis in MHz and the Y-axis is marked with the virtual height of the ionosphere in kms. We see the trend here that as the frequency increases the virtual height goes on increasing. This means that the signals of higher frequency travels further than the signals of lower frequency before being reflected back to the source. Figure 3.1 shows both the actual and the ICEPAC predicted virtual heights. These measurements put forward were taken during daytime. The actual virtual height shown was measured using a digital ionosonde system[34]. It is very clear form this figure that the ICEPAC and the actual ionosphere are very close to each other.

3.4 Program Operation Review

ICEPAC performs four basic analysis tasks which are summarized below.

1. *Ionospheric Parameters*: The ionospher is predicted using parameters which describe four different ionospheric layers which are, the E, F1, F2 and Es (E-Sporadic) layers for each sample area, the location, the time of day. These can be used to find an electron density profile which can be integrated to construct an ionogram.

2. *Antenna Pattern*: If a pattern is precalculated, then the antenna gain is com-

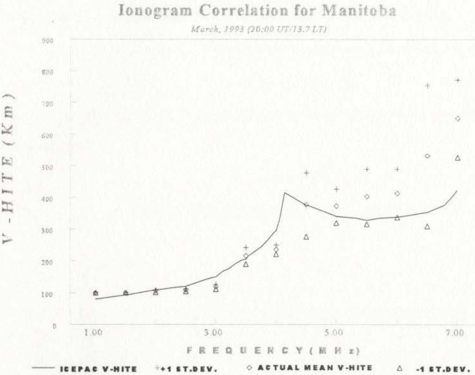


Figure 3.1: Ionograms based on Ionosondes and ICEPAC for Manitoba on March 1993 at 13.7 LT[34]

puted for frequency ranging from 2 - 30 MHz and elevation angles ranging from 0 - 90°. If the antenna pattern is not precalculated, then the gain values are determined for specific types of antennas at a particular frequency and elevation angle.

3. *MUF*: The maximum usable frequency at which sky-wave mode propagation exists can be predicted.

4. *System Performance*: A comprehensive prediction of radio system performance parameters (upto 22).

3.5 Ionospheric Propagation Characteristics Calculation

3.5.1 Input Data for conditions during December 1901

There is a METHOD command line in the input data file of ICEPAC. METHOD command defines the analysis task to be performed for a particular configuration. Method is the parameter which controls the type of program analysis and prediction performed. The employed version of code, has 30 task options available [21]. Many of these tasks differ only in the representation of the output and require the same computation. These tasks are distinguished by numbers. The one used for output display here is METHOD 16.

The input data file for ICEPAC consists of several command lines. The data used in this work for the required command lines is given below:

1. *Method* command line - Method 16

2. *Month* command line - Month = 12, Year = 1901

3. *Sun-spot* Number - 150

4. *Circuit* command line - latitude and longitude of Poldhu and Signal Hill

Transmitter at Poldhu - $50.50^o N$ $5.15^o W$

Receiver at Signal Hill - 47.3^o $53.0^o W$

5. *System* command - Power = 25kW,

man made noise = -164 dBW,for remote area

required reliability = .90

6. *Time* command line - 15 hrs to 18 hrs GMT

7. *Frequency* command line - 0.1, 0.2, 9.3, 9.4, 12.5, 12.6 MHz

8. *Antenna* command line - Read from file, the NEC - 2 pattern is used.

In this work three frequencies are considered: 0.166 MHz, 9.375 MHz and 12.5 MHz. ICEPAC has a limitation that the frequencies mentioned in the input data must be given in MHz and should be corrected to only one decimal place. So the frequencies 0.166 and 9.375 MHz have to be approximated. What has been done here is that 0.166 is taken as 0.1 and 0.2 MHz and 9.375 is taken as 9.3 and 9.4 MHz. As the signals were received by Marconi at 1230 hrs (St. John's time), all the characteristics are calculated close to and at 1600 hrs GMT. Though radiation patterns for standard antennas are included in the ICEPAC package, in calculating the ionospheric propagation characteristics the NEC2 antenna pattern of Figures 2.3, 2.4, 2.5, 2.7, 2.8, 2.9 are used.

The sun-spot number has a feature of repeating its value in a cycle of seven years. The data that has been used for this thesis work has shown that the year 1901 was a year of high solar activity and the sun-spot number was 150 [34]. The sun-spot number is taken as the average of the solar activities for the 12 months in that particular year. The noise factor has been taken as -164 dBW. This is the noise level made in a remote area. Considering Signal Hill as a remote place is logical as in 1901, no radio broadcasting was going on and the disturbances were galactic or atmospheric. The required reliability is 90% as all the frequencies are analyzed with an expectation of getting a good transmission.

3.5.2 Ionospheric Propagation Characteristics for Dec 1901

The output of ICEPAC is shown in Table 3.1. However as all the parameters shown in this table are not needed in reaching a conclusion another table is extracted form this extended table inorder to simplify the discussion. Table 3.2 illustrates the main ionospheric parameters on that month of 1901. The frequency column has the listing of all the frequencies that have been considered for this analysis. Some of the important parameters will be defined. The **MUF** is the maximum usable

Table 3.1: Regular Icepac Output

DECEMBER 1901, SSN = 150

Reception at Signal Hill, AZIMUTHS- 66.04

Distance 3454.1 km, N. MI 1865.2

ITSA 1 Antenna Package, MINIMUM ANGLE .0 DEGREES

XMTR - Poldhu $50.5°N$ *and* $5.15°W$

RCVR - Signal Hill $47.3°N$ *and* $53.0°W$

XMTR- 48m H, 60 m L

REQ. REL = 0.90, REQ SNR = 0.40

MULTIPATH DELAY TOLERANCE = 0.850 MS

MULTIPATH POWER TOLERANCE = 10.0 dB

3 MHz noise = -163.6 dBW

Universal Time - 1600 HRS

UT	MUF							
16.0	40.0	0.1	0.2	9.3	9.4	12.5	-	FREQ
	1F2	2E	2E	2E	2F2	2F2	-	MODE
	4.7	0.7	0.7	11.6	11.8	11.8	-	ANGLE
	12.1	11.6	11.6	11.7	12.2	12.2	-	DELAY
	397	70	70	118	248	248	-	VHITE
	0.5	1.0	1.0	0.57	1.0	1.0	-	F DAYS
	168	160	166	146	146	145	-	LOSS
	15	-43	-43	17	17	23	-	DBU
	-134	-129	-134	-109	-109	-108	-	S DBW
	-189	-109	-126	-168	-168	-167	-	N DBW
	55	-21	-10	59	59	58	-	SNR
	-29	34	21	-41	-47	-46	-	RPWGR
	1.0	0.03	0.15	1.0	1.0	1.0	-	REL
	0.0	0.0	0.0	1.0	1.0	1.0	-	MPROB

Table 3.2: Results obtained for December 1901

DEC 1901, Sun-spot Number = 150

Reception at Signal Hill, from Poldhu

Distance 3454.1 km

XMTR - Poldhu $50.5^{o}N$ *and* $5.15^{o}W$

RCVR - Signal Hill $47.3^{o}N$ *and* $53.0^{o}W$

3 MHz noise = -163.6 dBW

Universal Time - 1600 HRS

Frequency (MHz)	**Mode**	**VHITE (km)**	**Angle (Degrees)**	**Loss (dB)**	**SNR (dB)**
40 (MUF)	1F2	397	4.7	168	55
0.1	2E	70	0.7	160	-21
0.2	2E	70	0.7	166	-10
9.4	2F2	248	11.8	146	59
12.5	2F2	248	11.8	145	58

frequency. This is the highest frequency that can be used for reliable transmission for that particular existing circuit that is being investigated, based on the prevailing ionospheric conditions. The **Mode** represents the number of hops the signal makes before it reaches the receiver and the ionospheric layer that it reflects from in doing so. For example, if the mode is given as 2F2, this would mean that the signal will make two hops and that the reflection will take place between the earth's surface and the F2 layer of the ionosphere. The modes listed here are the most reliable and are based on the given atmospheric conditions. The **VHITE** is the Virtual Height of that particular layer of the ionosphere. Virtual height is defined as the speed of light times the time delay for the ionospheric echo [17]. This is different from the true height, that is, the actual distance to the reflection height. The **Angle** represents the take-off angle for the signal. This is the elevation angle for the signal from the transmitting side. The losses given are the system losses of the radio circuit, which is defined as the ratio of the signal power available at the receiving antenna terminals relative to that available at the transmitting antenna terminals, in decibels. This includes all the losses caused by radiation from the transmitting antenna circuits, not only the transmission loss caused by radiation from the transmitting antenna and re-radiation from the receiving antenna, but also any ground losses, dielectric losses, antenna loading coil losses and terminating resistor losses. The last column of the table contains **SNR** (Signal to Noise ratio). A minimum required signal to noise ratio is associated with the desired grade of service. This ratio is determined in terms of the class of emissions, modulation index, modulation rate and signaling code, and includes the effects of fading, error correcting schemes, noise reducers, optimum modulation and detection techniques, and diversity schemes. The required signal to noise ratio for a minimum acceptable grade of service must be specified by the user. In this case, the minimum SNR used is 40.

Following the results that are obtained for the December 1901 case, the MUF is 40 MHz. This represents the highest frequency for getting a reliable transmission. At 0.1 and 0.2 MHz the signal reflects from the E layer making two hops before reaching Signal Hill. The E layer has a property of absorbing the signal with lower frequencies. The 0.1 and 0.2 MHz signals fall in this category. Apart from this, the virtual height of the ionosphere is very low, 70 km. Also the SNR in case of the lower frequencies is -21 and -10 dB for 0.1 and 0.2 MHz respectively. Combined with this, another disadvantage with the lower frequencies is that the losses are high.

Now, coming to the higher frequencies, one will note that the favouring features are more evident. The signal at these frequencies hits the F2 layer and makes two hops. Even for modern day HF radio communications F2 region is considered to be the vital region for reliable transmission to take place. The losses are lower in this case when compared to the lower frequencies. The SNR improves drastically now and shoots up to 59 and 58 dB for 9.4 and 12.5 MHz, respectively.

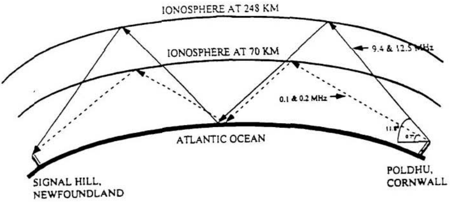


Figure 3.2: Ionospheric propagation path for December 1901

3.5.3 Analysis done for summer conditions

Marconi did the actual experiment during the winter month of December. Tracing the activities and the preparations that were going on for this great experiment, it is evident that it was initially planned to try this experiment much earlier in 1901, had the weather in both the continents been friendly. Let us for a moment consider that the weather was good around the year and that it did not hamper the schedule of the original transatlantic experiment. So taking this experiment a few months back we consider here the experiment was done in July, which is summer time in the northern hemisphere. It will be investigated here if 0.166 MHz gives any results that favour a reliable transmission or not. As mentioned Marconi had actually planned to do this experiment in summer, but due to unavoidable reasons had to do it in winter. The summer condition study is done inorder to find out what Marconi would have achieved transmitting at the frequency of 166 kHz.

3.5.3.1 Input Data used

The data used here are almost the same as those for the winter condition. Other than the date all the other data used are the ones that are averaged for 12 months. So only the date is altered to July 1901. What varies most with the change in the season in the ionospheric characteristics is the height of the ionosphere and the electron density. So a change in the date itself will bring about a change in the output.

3.5.3.2 Ionospheric Propagation Characteristics for July 1901

The actual results calculated using ICEPAC is shown in Table 3.3. As can seen in Table 3.4, the SNR deteriorates to a great extent for the summer conditions. The values go down to -212 and -196 dB for 0.1 and 0.2 MHz respectively. Whereas in the case of the higher frequencies the SNR is large enough for a reliable transmission to take place. Considering the fact that 1901 was a year of high solar activity, still the signals at 0.166 MHz were weak to cross the Atlantic ocean and cover a distance of 3400 km. Also the losses at the lower frequencies are so high that even if the signal reached the receiver, the signal would have been so weak that it would have been impossible to hear anything. Analyzing the experiment in the summer conditions prevailing during 1901, it is very much evident that there was no possibility of the signal being transmitted at 0.166 MHz [35].

Table 3.3: Regular Icepac Output

JULY 1901, SSN = 150

Reception at Signal Hill, AZIMUTHS- 66.04

Distance 3454.1 km, N. MI 1865.2

ITSA 1 Antenna Package, MINIMUM ANGLE .0 DEGREES

XMTR - Poldhu 50.5°*N and* 5.15°*W*

RCVR - Signal Hill 47.3°*N and* 53.0°*W*

XMTR- 48m H, 60 m L

REQ. REL = 0.90, REQ SNR = 0.40

MULTIPATH DELAY TOLERANCE = 0.850 MS

MULTIPATH POWER TOLERANCE = 10.0 dB

3 MHz noise = -163.6 dBW

Universal Time - 1600 HRS

UT	MUF								
16.0	22.8	0.1	0.2	9.3	9.4	12.5	12.6	-	FREQ
	1F2	2E	2E	3F2	3F2	2F2	2F2	-	MODE
	7.2	0.7	0.7	35.2	34.3	21.5	21.4	-	ANGLE
	12.4	11.6	11.6	15.1	15.0	13.2	13.2	-	DELAY
	499	70	70	450	447	440	445	-	VHITE
	0.5	1.0	1.0	1.0	1.0	1.0	1.0	-	F DAYS
	151	354	359	163	164	168	169	-	LOSS
	16	***	***	-13	-14	-5	-3	-	DBU
	-118	-344	-348	-135	-136	-140	-136	-	S DBW
	-184	-132	-152	-171	-175	-176	-173	-	N DBW
	66	***	***	35	39	36	35	-	SNR
	-39	253	238	-10	-9	-10	-13	-	RPWGR
	1.0	0.0	0.0	.96	.96	.97	.98	-	REL
	0.0	0.0	0.0	0.9	0.8	0.0	0.0	-	MPROB

Table 3.4: Results obtained for July 1901

JULY 1901, Sun-spot Number = 150

Reception at Signal Hill, from Poldhu

Distance 3454.1 km

XMTR - Poldhu $50.5^{o}N$ *and* $5.15^{o}W$

RCVR - Signal Hill $47.3^{o}N$ *and* $53.0^{o}W$

3 MHz noise = -163.6 dBW

Universal Time - 1600 HRS

Frequency (MHz)	**Mode**	**VHITE (km)**	**Angle (Degrees)**	**Loss (dB)**	**SNR (dB)**
22.8 (MUF)	1F2	499	7.2	151	66
0.1	2E	70	0.7	354	-212
0.2	2E	70	0.7	359	-196
9.4	3F2	447	34.3	164	39
12.5	2F2	445	21.5	168	36

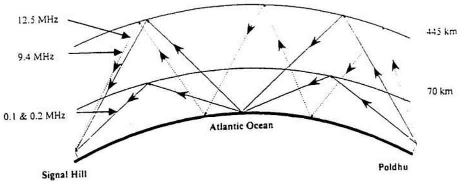


Figure 3.3: Ionospheric propagation path for July 1901

3.6 Gains at the take-off angle

The radiation patterns, that were calculated in Chapter 2 give us the maximum gain for the antennas at that particular frequency. But if the takeoff angle is known then the exact gain at that angle for each frequency can be determined. In this section the gains at different frequencies at the exact take-off angle are analyzed, to verify how strong or weak the signals were.

The take-off angles have been marked in the corresponding field patterns in Chapter 2. Based on these plots the gains are listed in Tables 3.6 and 3.6 for both antennas. Firstly analyzing the transmitting antenna results, the gain that is obtained at 166 kHz is very small (-25 dB) for a reliable transmission. On the other hand at 32m (9.375 MHz) and 24m (12.5 MHz), the gain is comparatively better at -2 and 1 dB respectively; and a transmission over the Atlantic ocean can be expected. A similar trend is seen for both the transmitting and the receiving ends. For the receiving antenna the gain at 166 kHz is -35 dB and at 9.375 and 12.5 MHz the gains are -8 and 4 dB respectively. Here for the receiving end also the gain values are very low for 166 kHz and it can be inferred from this factor alone that transmission covering over 3000 km is not possible.

Table 3.5: Gains at Take-Off angle for the receiving antenna

Frequency (MHz)	**Take-Off Angle** (Degrees)	**Gain** (dB)
0.166	0.7	-25
9.375	11.8	-2
12.5	11.8	1

Table 3.6: Gains at the Take-Off Angle for the transmitting antenna

Frequency (MHz)	**Take-Off Angle** (Degrees)	**Gain** (dB)
0.166	0.7	-35
9.375	11.8	-8
12.5	11.8	4

3.7 Summary

The ionospheric propagation studies done here have further consolidated the fact that the frequency of transmission was much higher than 0.166 MHz. As one can see, the SNR in the case of the lower frequency is very low and the gain at the relevant take-off angle has the same negligible value. So no reliable transmission is possible at the lower frequency. Also one should note the fact that Marconi's choice to do the experiment in the month of December was a decision that went in his favour. Had he attempted to do the transatlantic experiment in July then the results would have been far more different, and the chances of success would have been very low. Also one is very well aware that all modern day HF radio communications, use the F layer for reflection or propagation. But in the case of 0.166 MHz, the virtual height of the ionosphere is just 70 km, which falls very much into the lower region of the E layer. This makes it even more difficult to believe that the transmission would have taken place at this frequency. The summer analysis completely eliminates 0.166 MHz as the possible frequency for transmission during the transatlantic experiment

Chapter 4

Investigation of the Transmitter and the Receiver

4.1 Introduction

The transmitter[10] and the receiver[3] used during the transatlantic experiment were a design that was used only during the period. They are no longer used and have very minute similarities with the modern day radio communications. This makes it even more difficult to study this equipment. Marconi used a spark transmitter in Poldhu. The Poldhu transmitter was a curious two stage circuit, in which a first stage spark at some attainable lower voltage provided the energy for the second stage spark gap to spark at a higher voltage. While this voltage multiplication was innovative in the field of wireless at the time, it carried with it many problems and the inefficiencies of two spark stages. For his transatlantic experiment in 1901 Marconi had two types of receivers and three types of coherers. One receiver was tuned and the other was untuned. The three coherers were: one containing the loose carbon filling, another containing carbon dust and cobalt dust and the third one was the Italian Navy Coherer.

4.2 Basic Spark Transmitter

Development of the spark transmitter was a very profound area of research in those days. The working of these transmitters can be explained using a basic circuit as shown in Figure 4.1. In its simplest form, a spark transmitter consists of a capacitor (condenser) and an inductor (induction coil) in series. The capacitor C1 is charged to a high voltage by an induction coil L1. When the potential across it is sufficiently high to break down the insulation of the air in the gap, a spark is then passed as an arc is formed in the spark gap.. Since this spark has a comparatively low resistance, the loop formed by the spark discharge, is equivalent to an L-C-R circuit. The condenser then discharged through the conducting spark, and the discharge took the form of a damped oscillation, at a frequency determined by the resonant frequency of the spark transmitter. The working of this circuit will make more sense if we analyze the output waveform considering a spark rate of 12 sparks/sec, as shown in Figure 4.2. The figure illustrates the basic output waveform of a spark transmitter. As this circuit in Figure 4.1 makes 12 sparks/sec, at the beginning of each spark a peak is reached

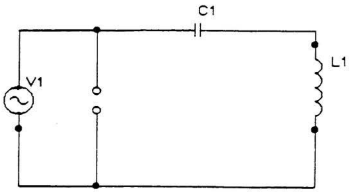


Figure 4.1: Basic Spark Transmitter

which damps out before the start of the next spark. So 12 peaks can be seen in 1 sec (Figure 4.2).

4.3 Marconi's Transmitter

As nearly 100 years have passed by, it has been realized that very little effort has been made in order to preserve all the equipment that Marconi used. The necessity of the original equipment is perhaps most badly felt while investigating the transmitter as a number of assumptions have to be made because of this. One of the surviving documents that was written close to the heat of the action in 1901 at Poldhu, is Fleming's own experimental notebook[36] which contains many pages of his jotting related to the commissioning of the transmitter. Much of the data that he recorded relate to the details of improvements and adjustments which increased the spark

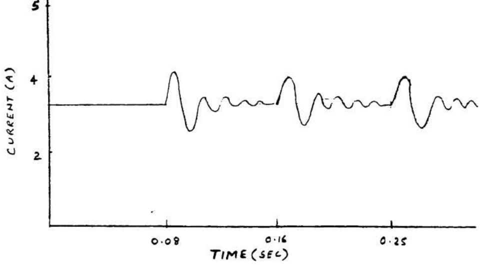


Figure 4.2: Basic Spark Transmitter Output waveform

energy and power delivered on those occasions when he was able to participate. A sketch of the transmitter made by Fleming during the 1901 experiment is shown in Figure 4.3.

Transmitter technology was at its evolutionary stages during the transatlantic experiment. Marconi's success also contributed in this evolution. One of the biggest problems he faced was to quench the spark in the spark gap. To get over with this, it was decided that no messages will be sent and only dots will be transmitted from Poldhu. The complete detailed circuit diagram of the Poldhu transmitter is shown in Figure 1.1. But as it is difficult to explain the operation of this circuit in this form, a simplified circuit, explaining all the features, is shown in Figure 4.4. As shown, the transmitter has two stages of spark gaps. This accounts for some difference in the functioning from the basic spark transmitter. The Poldhu transmitter had

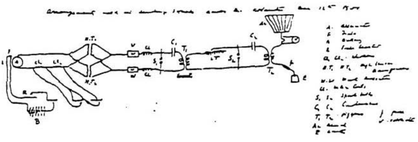


Figure 4.3: The Circuit Diagram of the December 1901 Poldhu Transmitter sketched by Fleming[11]

two oscillation transformers called the primary jigger and the secondary jigger. A sketch of the primary jigger is shown in Figure 4.5[10]. This is a sketch in cut-away form, not shown accurately to scale. The sketch shows some constructional features of the massive First Oscillation Transformer based on a wooden-drum former on which was wound a solenoid primary of 4 paralleled 7 strand 16 SWG wires (rubber insulated power cable) over a 40" length, with a parafined (waxed) rope as a helical spacer. Three layers of 1/16" ebonite sheet were used as an insulator between core and primary, and between primary and secondary. The secondary winding must have increased the diameter by another 8.5" to 23.5", and was composed of 16 disc shaped 7/16 SWG power cable coils each of 20 turns, together with spacers/separators. One should not ignore the possibility that the secondary might have been expected to be

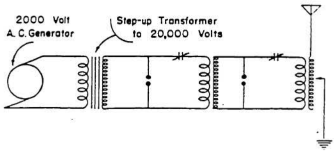


Figure 4.4: Simplified Circuit Diagram of Poldhu Transmitter

self-resonant, but in this particular circuit any secondary self-capacitance would have been swamped by the $1/30\mu F$ of the second condenser.

These transformers were added to the circuit in order to generate an alternating source of extra high voltage from the power frequency alternator plus transformer supply. The secondary jigger was also called the aerial jigger as it was connected to the antenna. The size of the containing box for the first Poldhu aerial jigger was 48" x 40" x 18". This shape is similar to the jiggers fitted by Marconi's engineers in ship installations at the turn of the century. These marine jiggers still survive in the British Science Museum and is an excellent sample of the aerial jigger[37] as they are very similar to each other in their functions. One is fortunate in knowing that the ship's jiggers resonated vertical aerials to what Marconi called "Tune A", somewhere around today's 80 metre ham band. This knowledge can be coupled with the description of half a dozen experimental jiggers in the famous 7777 patent[38] to provide a visual picture of the state of fixed jigger development at that time.

The turns ratio that was used for these transformers was a result of a number of experiments that were done before the transatlantic experiment. Fleming has suggested that the coupling factor of these transmitting jiggers was between 0.3 and 0.7. The low tension winding was initially connected through a large key. The closing and the opening of the key altered the impedance of the alternator transformer circuit and thus slow signalling was possible. But later this was replaced by a choking coil, and then by short circuiting this coil it was possible to signal without breaking the large current in the circuit and thus at a considerably higher speed. Thus one will see that the source voltage was first stepped up to 20,000 volts and fed to a closed oscillatory circuit in which a capacitor discharged across the spark gap via the primary of an radio frequency transformer. The secondary of the transformer was connected to the second spark gap and capacitor and the primary of a second radio frequency transformer. The secondary of this transformer was in series with the antenna. The capacitors referred to were made up of twenty glass plates, each sixteen inches square, coated on one side with one square foot of tin foil. These plates were immersed in stoneware boxes filled with linseed oil, and each box had a capacitance of $0.05\mu F$.

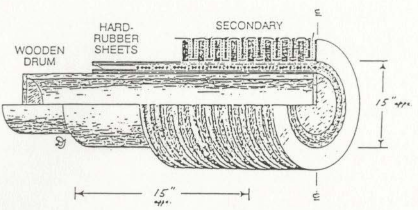


Figure 4.5: Fleming's Primary Jigger[10]

4.4 Investigating the Transmitter

Most of the parameters of the Poldhu transmitter are missing[10]. In this work, a computer model of this transmitter is first developed and then this circuit model is simulated to get the output waveform of the circuit. The software package used for this purpose is PSpice, Version 8 of Microsim Corporation[39]. This is a circuit analysis package. The parameters that have been used in this work for the transmitter circuit are mainly taken from the reports of Thackrey[10].

The Poldhu transmitter had no aerial tuning inductance, but it probably had substantial figures for secondary leakage inductance and for the stray inductance in the primary circuit. Fleming did however tune the Poldhu discharge circuit to the aerial, by varying the discharge capacitance.

There is a big discrepancy on the spark rate at the spark gaps. Based on the literature that has been analyzed in this work, the spark rate that is considered to have occurred during the transatlantic experiment was 100 sparks/sec with each spark producing 250 Joules of energy[10]. The transformer specifications for both the primary and the secondary jiggers (given by Thackrey) are based on certain assumptions, but they are most widely accepted to be closer to the original than any other work[19], as these are the parameters that have been used by most of the reaserchers. The coupling factor is k = 0.53, and the turns ratio is 1:7. The inductance of the primary coil is $2.6\mu H$ and that of the secondary is $47\mu H$, including stray reactances. Apart from this the capacitor connected to the primary of the first transformer is $1.43\mu F$ and the discharge capacitor connected to the aerial was tuned at $0.037\mu F$. The spark gap was specified by Marconi to have a discharge of $0.02\mu F$. The whole circuit was connected to a 25 kV, 25kW and 50 Hz alternator that recharged the condenser every half cycle, generating 100 sparks/sec.

Implementing these parameters the transmitting circuit is simulated to get the waves that are actually propagating to the antenna. The antenna connection is shown on the extreme right hand side in Figure 4.4. One should note that the aerial capacitance has some bearing on the wavelength of the signal that is generated by the transmitter. It would be possible to measure this capacitance on a scaled down model, but reasonable values have now been derived by calculations. The traditional method described by Howe[10], Grover[36] and Nottage[10] involves an unproven assumption about charge redistribution on the aerial wire, but otherwise is vulnerable only to arithmetic slips. Computer modeling permits greater refinement in programming well chosen algorithms. It is comforting to note that the results obtained for the Poldhu aerial by these two methods are not widely different. By digital computation it is 1200 pF and by Howe's method it is 1553 pF. As there is no original record available, so it is agreed that the capacitance was 1553 pF. Also one can see that 1553 pF is close to the measurement of 1600 pF noted by Fleming for 25 wires, 200 feet in height in July 1901, probably an erected segment of the original doomed aerial.

4.5 Simulation of the Transmitter Circuit

The transmitter is simulated using the circuit analysis and design package Pspice. Pspice has been used for both the computer modeling and simulation of this circuit. This package has a limitation with regards to this circuit as there is no model of the spark gap available. It has been understood from the functioning of the simple spark transmitter that the spark gap functions as a switch. So here in the transmitter circuit the gaps are replaced by switches. These switches are timed so that they produce the equivalent of 100 sparks/sec. The circuit model is shown in Figure 4.6.

4.5.1 Transmitter model

Figure 4.6 shows the transmitter model that has been developed to find the output of Marconi's transmitter. The circuit shown in this figure has been designed using Pspice. Instead of an alternator an ac source has been given to the circuit. The current from the source charges the capacitor to its peak, and then the switch is turned on. The capacitor discharges through this closed switch. After being completely discharged the capacitor charges again, taking current from the source. This cycle is repeated as long as the supply is on. Simple switches are used. These switches can only be turned on or off. There is a limitation in Psipce that prevents one switch from performing both on and off action. So to overcome this situation, two switches are connected in series, one for on and the other for off. Both the switches will be connected only when a spark is simulated. A number of such connections are shown in the model, for each spark gap. Since Marconi's transmitter had two spark gaps, two such arrangement os switches are shown in the figure.

4.5.2 Parameters used for the Transmitter model

1. Transformer

(a) Coupling Factor k = 0.53

(b) Turns ration = 1:7

(c) Inductance of primary coil = 2.6μH

(d) Inductance of secondary coil = 4.7μH

2. Capacitor connected to first transformer = 1.43μF

3. Capacitor connected to the second transformer = 0.037μF

4. Capacitor connected to each switch = 0.02μF

5. Capacitance of the aerial = 1553 pF

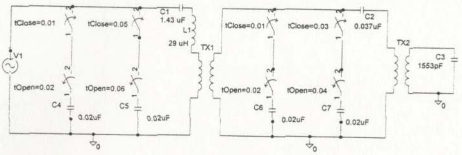


Figure 4.6: Transmitter Computer Model

6. Source = 25 kV, 25 kW and 50 Hz alternator

7. Switches timed to turn on every 10 ms

8. The switch gives a resistance of 2 ohms.

4.5.3 Results obtained from the model

When simulated this circuit shows the typical characteristics of a spark transmitter. A spark transmitter emits a series of damped waves, the period of which is the spark rate. As seen in Figure 4.7, the Poldhu spark transmitter is showing a series of damped waves that is repeated 100 times in one second. The damped waves that have been recorded are shown more explicitly in Figure 4.8. The frequency of the output waveform that was recorded from the output of the simulation is 1 MHz. It is observed from Figure 4.7 that the waves that are periodically repeated are not the exact same pattern. This is attributed to the fact that the switching elements have a time delay in opening and closing. As the spark rate is very high the time delay of the switches overlaps with that of the switching time and causes a disturbance in the periods of the waveform.

The output waveform of 1 MHz proves that the transmitter operates at a high frequency. The output can be altered if any of the parameters are changed. But since the parameters used here are the ones that have been published [10] and accepted by other researchers, there is no reason for these to be changed. The transmitting and receiving antenna analysis done in chapter 2 has shown to support frequencies in the megahertz range. This falls inline with the results of the transmitter model. The output of 1 MHz further eliminates the possibility of the 166 kHz signal, that Marconi had predicted. The results of the model is also supported be the findings in chapter 3, where it is seen that the ionosphere was more feasible for higher frequencies.

4.5.4 Validation of the model

Result obtained form the simulation shows that the signals were being produced in the MHz range. Belrose modeled a spark transmitter, but not the one that Marconi was using. He designed a 5 MHz spark transmitter[13]. The results obtained by Belrose, shows a similar pattern of waveforms as is seen in Figures 4.7 and 4.8. It shows a peak at the first cycle and then the waves are damped out before the next peak. This pattern is repeated at every spark. Thackrey[10] has done a detailed study of the

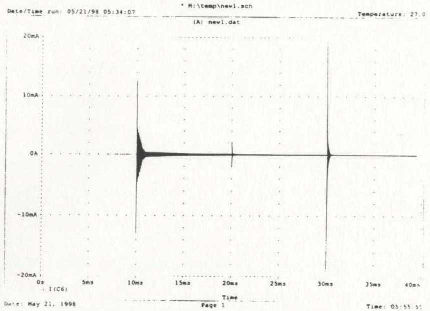


Figure 4.7: Current Waveform showing periodic waves[41]

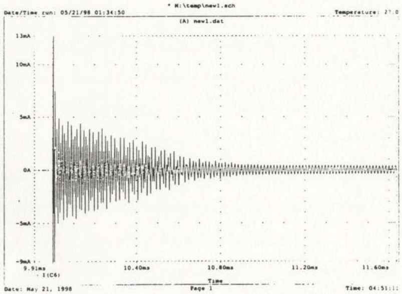


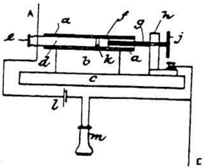
Figure 4.8: Current Waveform showing Damped Oscillations[41]

transmitter and has found the higher side of the frequency to be 664 kHz. This is close to the results shown here. It should also be noted that Thackrey in his work has predicted the possibility of wave of 1 MHz being produced by the transmitter, which is exactly the same as the results obtained here. Since this model confirms with the results of both Belroe and Thackrey, it validates the model that has been put forward.

4.6 Study of the Receiver

The receiver technology that was used by Marconi has been an area of controversy for a long time. But with the passage of time some general agreements have been reached based on the various studies done in this regard. The type of coherer used by Marconi during the 1901 transatlantic experiment is very commonly known as the *Italian Navy Coherer*. The coherer was the first device to detect radio frequency signals in wireless telegraphy. Its operation is based upon the large resistance offered to the passage of electric current by loose metal filings, which decreases under the influence of radio frequency alternating current. The *Italian Navy Coherer* consisted of one or more small globules of mercury contained in the gap or gaps between iron or carbon plugs in a glass tube as shown in Figure 4.9.

In its most usual form, the coherer consisted of a mass of metal filings in a small air gap between two metal plugs fitted tightly into a glass tube. One plug was connected to the receiving antenna and the other to the earth. On reception of a pulse of RF, the



d = carbon plug
f = adjustable iron plug
k = drop of mercury
A = antenna
E = earth

Figure 4.9: The Italian Navy Coherer as patented by Marconi in September 1901[40]

filings cohered to the low resistance state. This change of resistance was monitored by a circuit consisting of a cell, a resistor and a relay coil, all in series with the device, and the circuit was adjusted so that when the resistance dropped, the relay would trip. Figure 4.10 shows this arrangement. Further secondary circuit could be operated by the relay contacts, causing an electric bell to sound, or a Morse inker to operate and provide a permanent record of the signal. Due to the drop in the resistance the current will also change and this change could be heard through a telephone ear piece.

The Italian Navy Coherer did not behave like a coherer during the reception. But the reception of "S" was due to the action of a simple diode rectifier during the experiment. Studies conducted by Phillips[3] has shown that the coherer could operate in two modes. In the first mode it acted simply as a linear ohmic conductor producing no asymmetrical effects at all. Then due to variations in the conditions it

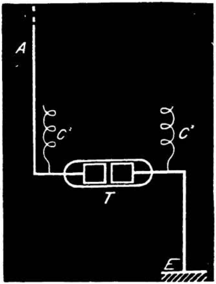


Figure 4.10: Layout of Early Receivers[40]

would jump into a second mode of operation where partial rectification would occur.

It seems from the behavior of the coherer that the rectifying action is due to an oxide film either on the surface of the mercury or on the iron (or both). This forms the junction with rectifying properties. Solid state rectifying junctions exhibit capacitance across their depletion regions. The effect of such capacitance would be to introduce a small phase difference between the current and the voltage waveforms. Furthermore the extent of the phase shift would vary with the frequency[3].

4.7 Summary

This chapter has further consolidated the fact that the transatlantic experiment was a short wave affair. The computer modeling and simulation of the transmitter circuit has proved this. The output of this simulation is considered to be correct because that pattern of the waveform obtained is very similar to that of a spark transmitter[13]. But one must always keep in mind that these calculations are based on the data that have been discovered, or estimated, by other researchers over a period of time. Had the original records been available it would have been easier to pin point the frequency of transmission, rather than simply predicting a range of shortwave frequencies, that would have made this experiment a success. By far all the studies have shown that receiver circuit was in a rectifying mode at the time of the experiment. So one must consider that Marconi was very lucky in this regard that the coherer came to this mode at the time when he was supposed to receive the signals. Despite the harsh weather things did work out his way.

The idea of transmitting through the Atlantic was Marconi's. But the communication system developed for this was an attempt made by a group of people who worked with him. Power engineering at 150 kV was not then the commonplace activity it later became. But this experiment did certainly provide valuable engineering experience for those involved, and who later went on to build bigger and better transmitters.

Chapter 5

Conclusion

5.1 Conclusion

Marconi's first transatlantic experiment has been studied. The fact that the experiment was done under conditions that were conducive for long distance propagation is an important factor in this experiment. The objective behind this thesis is to reach a reasonable range of frequencies at which the transatlantic waves would have propagated during the first transatlantic experiment. In this work the experiment has been studied from the antenna, ionospheric propagation, transmitter and the receiver points of view, so that all the main aspects of wireless communications are correlated and a conclusive result is obtained. Through this study it has been proved that if sky-wave propagation was responsible for carrying the wave across the Atlantic ocean then the possibility of the signal being transmitted at 166 kHz is not there, because the signal is very week at this frequency.

The antenna has been investigated at three different frequencies, 166 kHz, 9.375 MHz and 12.5 MHz. Here, the radiation pattern was calculated for both the antennas and from that several other data were derived. It very conclusively shows that the long waves of 166 kHz will not travel the distance of 3400 kM. But the higher frequency waves were more feasible in these conditions. While discussing the antennas it will be unjustified if the weather conditions are not analyzed. One will note that the receiving antenna that Marconi was using was a wire lifted to its height by a kite. The winds are very strong in winter in St. John's and the same is obvious from the fact that the kites were blown away a number of times before the signals were received. Obviously when Marconi used this kite antenna it must have been moving in all directions because of this wind. But while calculating the radiation pattern of this antenna this was not incorporated. If this is done the radiation pattern will vary, and will give a somewhat deviated result from what has been calculated now.

The ionospheric conditions should not be missed. Ionospheric propagation characteristics has been studied for December 1901 and July 1901. Investigations in both these cases have again proved that the signal could not have been received at the frequency suggested by Marconi, i.e., 166 kHz. The studies conducted here have suggested the possibility of short waves being responsible for the reception of the signal at Signal Hill. In the investigation of the ionospheric propagation, there is a drawback that is worth noting. The ion distribution in the ionosphere is dependent on the solar activities. The data that has been used here are the best that we could get. It has been averaged for the 12 months in a year and in general the results have shown that the SSN (Sun Spot Number) repeats every seven years. So the SSN was taken to be 150 based on this idea. But this is the closest one can get to the solar conditions in 1901. But the exact condition on that day is not known to anyone. So, here again, investigations have to be done based on some logical assumptions.

The transmitter circuit has been studied by modeling and simulation. Based on the parameters that have been postulated by other researchers the transmitter gives an output of 1 MHz. Here too the concept that the waves would have traveled at 166 kHz is disproved. The transmitter study is by far the most critical in this whole study. The problem is mainly with the circuit parameters. Nevertheless the calculations done in this work have established the waves propagated from the transmitter. The study of the receiver circuit has shown that the equipment used was only a crude form of a rectifier.

The investigation of Marconi's first transatlantic experiment has revealed that the signals that were transmitted on the 12th of December 1901 were short waves and were most probably in the range of 1 MHz to 10 MHz. It was certainly not 166 kHz as was claimed by Marconi. This work establishes this fact beyond any doubt.

5.2 Comparing the findings of this work with others

When compared with the works of Bondyopahdyay[11] it is seen that in both the cases the ionospheric conditions have been found to be conducive for the transmission of 9.375 and 12.5 MHz waves. There are differences in the ionospheric parameters calculated. But significant similarity has been found with respect too the SNR. Nevertheless Bondyopadhyay's calculations point in the direction of higher frequencies. The prediction made by Thackrey[10] based on the works of Entwistle's that the upper frequency could have been 1 MHz is matched with the results obtained in this work. Belrose[18] in one of his works has experimentally modeled a 54 wire fan monopole. The experimental model exhibits resonances at 935 kHz and 3.8 MHz. The value of 3.8 MHz falls in the range predicted in this work. Since the receiving antenna radiation pattern has not been calculated before, the results here cannot be compared. MacKeand and Cross[14] have cited that at lower frequencies, multiple paths were open for propagation and as the frequency increased towards the MUF, the probability of a single hop F layer path increased. This trend is seen in Tables 3.2 and 3.4.

5.3 Recommendations

No research work can be complete in itself. Here too there is scope for further studies. Like all electromagnetic radiation, radio is also affected by the medium it propagates through. The type of propagation that can be supported depends on the frequency. There are different modes of propagation that are known. These modes are:

- Free-space waves
- Ionospheric waves
- Tropospheric waves
- Ground wave

In this work the experiment has been investigated based on the ionospheric propagation point of view. Two of the other modes, free space and tropospheric waves, are not possible in this case. But there is a possibility of ground wave propagation. Ground wave is only of practical interest with low frequencies. If more consideration is to be given to Marconi's suggested frequency then this study with ground wave propagation will yield more results.

Apart from this, some more work needs to be done with respect to the transmitter. The parameters should be postulated more closely with as few approximations and assumptions as possible. This will give even closer results to the waves that were being propagated from the transmitter. These results can be even more convincing. Perhaps the best thing to do will be to redo the whole experiment once again as we approach the turn of the 20th century. It will be nearly 100 years since Marconi completed his experiment successfully. It is high time we answer all the question surrounding this pioneering experiment. But that will be a difficult task as, these days, we have a number of radio stations transmitting their signals around the clock.

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