A Radioscientist's Reaction to Marconi's first transatlantic Wireless Experiment – Revisited*

John S. Belrose
Radio Science Branch
Communications Research Centre Canada
Ottawa ON K2H 8S2

Introduction

On 12 December 1901 signals from a high power spark transmitter located at Poldhu, Cornwall, were reported to have been heard by Marconi and his assistant George Kemp at a receiving site on Signal Hill, near St. John's, Newfoundland. For this reception experiment Marconi used a kite supported wire aerial, an untuned receiver, a detector of uncertain performance and a telephone receiver. The signals if heard would have traveled a distance of 3500 kilometres. Even at the time of the experiment there were those who said, indeed there are some who still say, that he misled himself and the world into believing that atmospheric noise crackling was in fact the Morse code letter 'S'.

A little later, in February 1902, when Marconi was returning to the North America on the SS Philadelphia, using a tuned ship-borne antenna, he received signals using his filings coherer from the same sender up to distances of 1120 km by day and 2500 km by night. Even these distances are rather remarkable considering the receiving apparatus he used.

This paper revisits that first transatlantic experiment.

The Poldhu Station

Marconi's ambition at the turn-of-the-century to demonstrate long-distance wireless communication, and develop a profitable long-distance wireless telegraph service, led to his pragmatic proposal in 1900 to send a wireless signal across the Atlantic. He conceived a plan to erect two super-stations, one on each side of the Atlantic, for two-way wireless communications, to bridge the two continents together in direct opposition to the cable company (Anglo-American Telegraph Company). For the eastern terminal, he leased land overlooking Poldhu Cove in southwestern Cornwall, England. For the western terminal the sand dunes on the northern end of Cape Cod, MA at South Wellfleet, was chosen.

The aerial systems comprised 20 masts, each 61 metres high, arranged in a circle 61 m in diameter, see **Fig. 1**. The ring of masts supported a conical aerial system of 400 wires, each insulated at the top and connected at the bottom, thus forming an inverted cone. **Vyvyan [1]**, the Marconi engineer who worked on the 1901 experiment, when

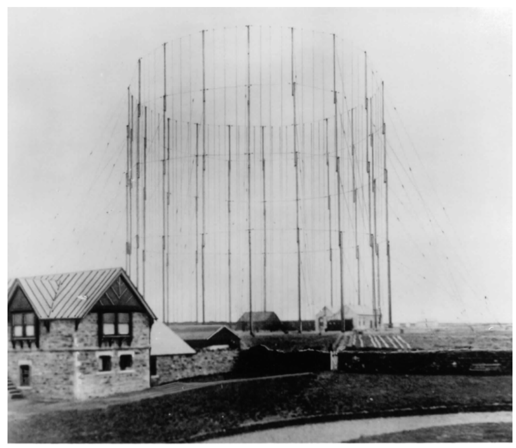

Fig. 1 Photograph of the original conical antenna system installed at Poldhu, Cornwall (after **BAE Systems Marconi Research Centre, Chelmsford, Essex**).

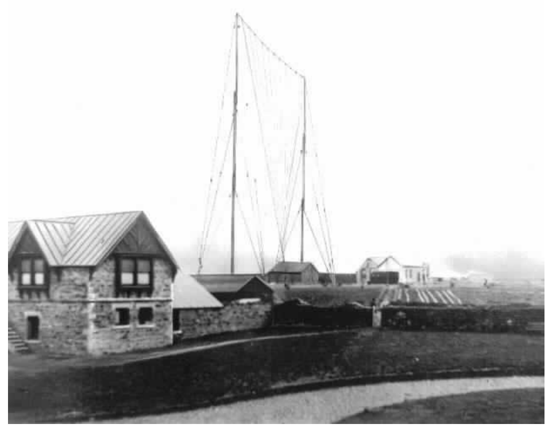

Fig. 2 Photograph of Marconi's fan monopole, December 1901 (after **BAE Systems Marconi Research Centre, Chelmsford, Essex**).

shown the plan, did not think the design to be sound. Each mast was stayed to the next one, and only to ground in a radial direction, to and away from the center of the mast system. He was overruled, construction went ahead, and both aerial systems were completed in early 1901.

* Revised version of the paper published in the Conference Digest, 2001 IEEE Antennas & Propagation Society International Symposium, Boston, MA, July 8-13, 2001, **Vol. 1**, pp. 22-25.

However, before testing began catastrophe struck. The Poldhu aerial collapsed in a storm on 17 September; and the South Wellfleet aerial suffered the same fate on 26 November, 1901.

At Poldhu Marconi quickly erected two masts and put up an aerial of 54 wires, spaced 1 meter apart, and suspended from a triadic stay stretched between these masts at a height of 45.7 m. The aerial wires were arranged fan shaped, insulated at the top, as was his conical wire aerial, and connected together at the lower end, see **Fig. 2**. This photograph has been published and republished, and clearly one can see only 12-wires with blobs at the end of the wires (which might be insulators?) -- but the view generally held is that the aerial system as described above by Vyvyan is right, that is there were 54 wires. The photograph has been touched up to show wires, and for emphasis insulators are shown at the end of each wire. It is believed that all wires were connected to the triatic, certainly 54 insulators would be very expensive.

In fact a recent study of archive documents reveals that no true photograph exists of the Poldhu fan aerial. The photograph in **Fig.2** is clearly a modified reprint **Fig. 1**, showing two masts exactly as originally sited and rigged, with the others painted out **[2].**

The antenna was driven by a curious two stage spark transmitter (**Fig. 3**). There were many problems in getting it to work at the high power levels desired **[3]**. Our principal concern here is the frequency generated by the Poldhu station. The oscillation frequency is determined by the natural resonant response of the antenna system, tuned to a lower resonant frequency by the inductance of the aerial jigger (Marconi's words).

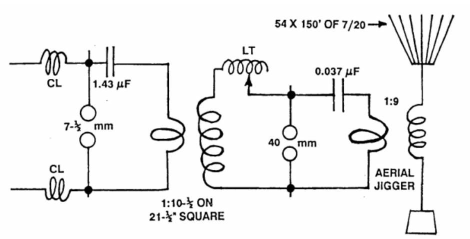

Fig. 3 Schematic showing component values for discharge circuit of the Poldhu transmitter in December 1901. Note the additional components C_L (extra coils), and L_T (a long adjustable tuning inductance of 40 turns using 40 feet of wire). From Fleming's Notebook (after **Thackeray [3]**).

The inductance values for the oscillation/aerial jigger transformer, have long been debated, since the original transformer is lost, there are no drawings, and reports about it differ. Fleming's notes record that the primary was 2-turns paralleled, and the secondary had 9-turns; but **Entwistle [4]** said there were 7-turns. Possible limits for the size of the windings range from 45 to 60 cm on a square former. **Thackeray [3]** has postulated on possible values for this transformer, based on measurements by George Grisdale in 1985. Grisdale on a facimile of the Science Museum's 20.3 cm open jigger, measured primary and secondary inductances of 1.05 and 18.8 microhenries (μH) for a turns ratio of 1:7. Scaling directly to a 50.8 cm square frame, multiplies all reactances by the ratio 50.8/20.3, which yields inductance values of 2.6 and 47 μH.

This author experimentally modelled (scale factor 75) a 54 wire fan monopole, wires connected to the triatic, and measured the resistance and reactance for this model on a large elevated ground plane. The experimental model exhibits resonances (frequencies scaled to full scale), see **Fig. 4**, at 935 kHz, and 3.8 MHz; anti-resonance at 2.4 MHz and 4.8 MHz; and approaching an anti-resonance between 7 and 8 MHz; but no resonances above 3.8 MHz.

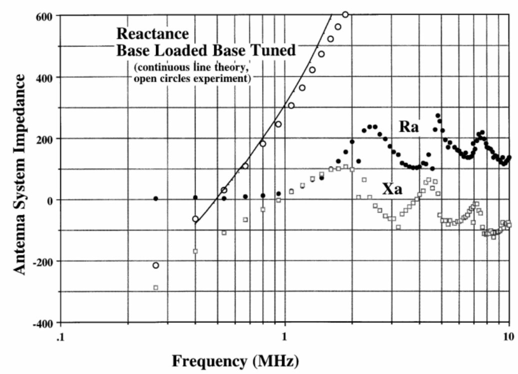

Fig. 4 Impedance vs. frequency for Marconi's temporary fan monopole December 1901 (experiment and simulation)

The author has also numerically modelled, using NEC-4D, a 23-wire fan, included a realistic sag for the triatic wire. Both numerical and experimental modelling give essentially the same resonant frequency (base load inductance 47 μH included) for the antenna system (see **Fig. 4**), but the high frequency self impedance response for the experimental model is not reproduced by the numerical simulation, see **Belrose [5]**.

While the high frequency resonances and anti-resonances of this multi-wire fan aerial are of academic interest, the antenna system impedance for frequencies above the lowest resonant frequency is dominated by the inductive reactance of the aerial jigger. The aerial jigger is in effect a base-loading-base-tuning coil, which (for an inductance value of 47 μH) brings the resonant frequency of the antenna to about 500 kHz.

Note: the antenna circuit itself was not separately tuned, but resonance was established. Fleming tuned the oscillator circuit by varying the value of the discharge condenser, a parallel series connection of 24 condensers, to maximize the RF aerial current. Vyvyan has given the value of the discharge condenser for resonance as 0.037 mfd. Using the postulated value for the inductance of the primary of the jigger (2.6 μH), the resonant frequency of the oscillatory circuit is 511 kHz.

Since the resonant frequencies of the oscillatory circuit and the antenna circuit (according to the author's model studies) are closely the same, the author postulates that the radiation would be spread about a single frequency of about 500 kHz.

Marconi himself has been evasive concerning the frequency of his Poldhu transmitter. Fleming in a lecture that he gave in 1903 said that the wavelength was 304.8 m or more (984 kHz). Marconi remained silent on this wavelength, but in 1908 in a lecture to the Royal Institution he quotes the wavelength as 365.8 m, 820 kHz. But in a recorded lecture in the early thirties he says the wavelength was approximately 1800 metres (166 kHz) and the power about 15 kW, see **Bondyopadhyay [6]**.

Reception on Signal Hill

For his transatlantic experiment, Marconi decided to set up receiving equipment in Newfoundland. In December 1901 he 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 Signal Hill, and apparatus was set up in an abandoned military hospital. A cable was sent to Poldhu, requesting that the Morse letter 'S' be transmitted continuously from 3:00 to 7:00 PM local time.

On 12th December, 1901, under strong wind conditions, a kite was launched with a 155 m long wire. The wind carried it away. A second kite was launched with a 152.4 m wire attached. The kite bobbed and weaved in the sky, making it difficult for Marconi to adjust his new syntonic (tuned) receiver, which employed the Italian Navy coherer. 'Difficult' one can certainly agree with, but how he would determine the frequency of tuning for his receiver is a mystery. Whatever, because of this difficulty, Marconi decided to use his older untuned receiver. History has assumed that he substituted his metal filings coherer previously used with this receiver for the newly acquired Italian Navy coherer, but Marconi never really said he did, see **Phillips [7]**. Marconi referred only to his use of three types of coherers, as if there were something to hide: '---one containing loose carbon filings, another designed by myself containing a mixture of carbon dust and cobalt filings, and thirdly the Italian Navy coherer containing a globule of mercury between two plugs'.

Clearly there are uncertainties concerning the type and reliability of the detector used with the land-based receiver. The Italian Navy Coherer consisted of a small blob of mercury between two end plugs. Wetted contacts behave ohmically, like a resistance. Non-wetted contacts seem to behave like a metal/oxide rectifier, some of the time.

Vyvyan gives rather quite a different account in his book **[1]**:

"It was impossible to use any form of syntonic (tuned) apparatus and Marconi was obliged to use the next best means at his disposal. He therefore used a highly sensitive self-restoring coherer of Italian Navy design, simply connected with a telephone and the aerial, and with this simple apparatus on Thursday 12 December, 1901, he and one of his two assistants (reportedly) heard the faint 'S' signals".

Vyvyan is quite definite in his statement that it was the Italian Navy coherer which was used. Vyvyan's account casts quite a different light, too, on technical matters, as it is clear that if the letter 'S' was heard, it was due not to coherer action, but to the unwitting and unrecognized use of a simple diode rectifier. Thus we conclude that if Marconi did hear a signal, his mercury coherer by chance **[7]** happened to be in the rectifying mode just at the time when signals were heard. The unreliability of the device is made clear by present day experiments **[2,7],** and by Marconi himself. In his June 1902 lecture delivered to the Royal Institution he stated: 'These no-tapped coherers (Marconi referred to the device as a type of coherer) have not been found to be sufficiently reliable for regular commercial work. They have a way of cohering permanently when subject to the action of strong electric waves or atmospheric electrical disturbances and have an unpleasant tendency toward suspending action in the middle of a message'.

Despite the crude equipment employed Marconi and his assistant George Kemp convinced themselves that they could hear on occasion three clicks more or less buried in the static. And clicks they would be, not unlike atmospherics, because of the very low spark rate of his two-stage spark transmitter (estimated to be only a few sparks/sec). Marconi wrote in his laboratory notebook: Sigs at 12:30, 1:10 and 2:20 (local time). This notebook is in the Marconi Company archives and is the only proof today that the signal was received.

It is ironic that the low-PRF transmitter was in fact compromised by Marconi himself, when in Newfoundland he put a telephone receiver to his ear to listen for three dots from Poldhu. Fleming must certainly have known about Tesla's widely published 4-circuit arrangement (2-circuits in the transmitter, a single stage spark transmitter, and 2- in the receiver **[8,9]**). A higher spark rate which could have been easily achieved with Tesla's transmitter, would have given the received signal, assuming that the mercury detector was working like a rectifier, a buzz-buzz sound, or a more musical sound, depending on the spark rate, rather than just clicks, indistinguishable from electrostatic discharges or atmospherics.

The Enigma

Today we know that signals (depending on frequency used) can indeed travel across the Atlantic, and far beyond. But in 1901, anyone who believed that they could, and did, believed so as an act of faith based on the integrity of one man -- Marconi.

If 500 kHz was the frequency of the sender, the tests took place at the worst time of day, because the entire path would have been daylight, and the daytime skywave would be heavily attenuated, even though it was a winter day, in a sunspot minimum period, and there were no magnetic storms at the time, or before the experiment. From a knowledge only of propagation conditions, reception on Signal Hill is consistent with the observed limiting ranges of reception on the ship only if the untuned land-based receiver was 47-55 dB more sensitive than the tuned receiver on the ship, see **Table 1**. The author considers this unlikely. Table 1 establishes the sensitivity of the tuned receiver on the ship.

Historians have speculated that the transmitter might also have radiated a high-frequency signal as well, since an HF signal would have been more suitable for transatlantic communications, c.f. **Ratcliffe [10]**. But based on the author's better understanding and more detailed modelling studies of the antenna system used, one must conclude that the Poldhu spark-transmitter system radiated efficiently on only the fundamental oscillation frequency of the tuned antenna system, about 500 kHz.

In summary

It is difficult therefore to believe that signals could have been heard on Signal Hill, since:
(1) the receiving equipment consisted of a long-wire antenna, coupled to an untuned receiver which had no means of amplification whatsoever;
(2) the type of detector used was less sensitive and its performance unpredictable (compared with Fessenden's barretter detector, devised in c1902, or the galena crystal detector which evolved a few years later); and,
(3) the untuned land-based receiver would have had to be 47-55 dB more sensitive then was his tuned ship receiver.

Whether Marconi heard the faint dots or not is really unimportant at this time in history. His claim "sparked" a controversy among contemporary scientists and engineers about the experiment that continues today, and kick started the race, by Marconi himself and by Fessenden (see for example reference **[9]**) to achieve reliable transatlantic wireless communications.

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Table 1

Distance kilometers	Field Strength dB µ V/m* (for 1 kW radiated)		
	Ground Wave	Skywave	Total Field
<u>Limiting Ship Ranges</u>			
1120 km Day	24	16	23 ± 3.6
2500 km Night	- 23	15.3 ± 4	15.3 ± 4
<u>Signal Hill, Newfoundland</u>			
3500 km Day	--	- 32	- 32

***Computations are based on CCIR (now ITU Radiocommunications) Report 265-7, Reports of CCIR 1990, Annex to Volume VI, Propagation in Ionized Media, Geneva, 1990, pp. 212-229.**

<u>Note</u>: The ± symbols must not be considered to be an indication of accuracy, but results from the addition and subtraction of field strength vectors. The first and second hop skywaves at the distance of 2500 km at night are of comparable amplitude.