AWA Review

The Marconi Beacon Experiment of 2006-07*

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ABSTRACT

The success of the 2006-'07 Marconi Beacon Experiment shows the skill and tenacity of amateur historians and amateur radio operators on both sides of the Atlantic. The International Telecommunications Union defines amateur radio: "A radiocommunication service for the purpose of self-training, intercommunication and *technical investigations* carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest." [1] This technical investigation not only shed welcome and favorable light on Marconi's claims of transatlantic signals in 1901, it also resulted in revisions to one of today's most sophisticated radio propagation models to account for its success. Moreover, the critical role of engineer John Ambrose Fleming and his high power pulse transmitter (Figure 1) in Marconi's success now comes to the fore.

INTRODUCTION

The Marconi Beacon Experiment, U.K. call sign GB3SSS, created and documented an extended technical experiment in the service of radio history: How did Marconi get across the Atlantic in December of 1901? Did he do what he claimed, that is, did he hear the letter "S", the three dots, near Cabot Tower on the hill overlooking St. John's, Newfoundland? Could these jury-rigged primitive wireless outfits do it in the daylight, between 14:00 and 18:00 London time? Did he hear it on the 800 KHz frequency he thought it was transmitted on? Could his 1901 transmitting and receiving apparatus do it at all?

Some distinguished authorities, such as John S. Belrose, VE2CV, are long on record that Marconi's 1901 claim was at best self-deception. [2] Marconi historians concede: "... the transmis-

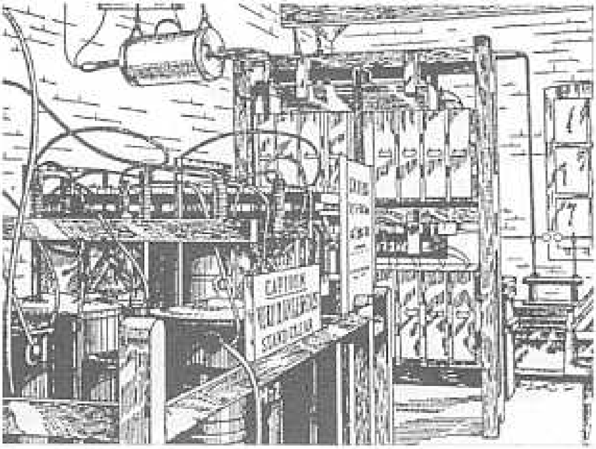

Fig. 1. A drawing of the Poldhu 1901 spark transmitter, after a contemporary photograph [see footnote 29 below]; note the spark gap by the window which is retouched in the photograph. The inductors are in the foreground (e.g., HT2), and the condensers towards the back, with horizontal handles on their drawers.

*This article is dedicated to the memory of our colleague Lane Upton, IEEE.

sion times and frequencies were, as later learned, the worst possible in view of propagation conditions on the North Atlantic path." [3] Others were entirely persuaded, but perhaps in part by the sheer audacity of the attempt given the state of the radio art in 1901, and take comfort from Marconi's successful February, 1902 transatlantic shipboard (*SS Philadelphia*) tests. Some have analyzed the circumstances of 1901 to have permitted only high frequency harmonic or spurious or parasitic radiation to cross the ocean. [4] But with respect to Marconi's claimed frequency of 800 KHz (more or less, about 360 meters wavelength) modern propagation simulations by complex computer programs implemented by experts hitherto have simply declared: *no way*. But Marconi did not believe in experts; if he had, he'd have been selling silk in Bologna.

Several committed historians of technology came together thousands of miles apart to think through and then implement this Beacon Experiment and related investigations. In the U.K., one of us, KM, helped persuade the Poldhu Amateur Radio Club (PARC – Figure 2) to put up a beacon in the 160 meter amateur band, which is the band closest to the frequency employed by Marconi from Poldhu in 1901. The special purpose beacon transmitter (Figure 3) was designed and built by Andy Talbot, G4JNT, for the Poldhu club. E.L.D. "Davey" Davey-Thomas, G3AGA, converted an existing remote tuned doublet to a 'T' configuration. He then worked long and hard to tune it against an extensive radial system. This was needed because effective grounding posed extraordinary challenges – which also have a bearing on

Fig. 2. The Poldhu Amateur Radio Club purpose-built "radio shack" and museum on the National Trust Marconi Historical Site, from which the Beacon GB3SSS and amateur radio station GB2GM operate. (Photo Bart Lee).

Fig. 3. Andy Talbot's 1960 KHz Beacon transmitter, operational. (Photo Steve Nichols, G0KYA).

Marconi's success in 1901. (Figure 4). These radials then necessitated the purchase of an electric fence system to keep the cows at bay, lest cow shocks corrupt the signal. Davey-Thomas deserves considerable credit for the effectiveness of the Poldhu contribution.

In Newfoundland, one of us, JC, with the support of the Marconi Radio Club of Newfoundland, set up near St. John's (Figures 5,6) a sophisticated monitoring system to record and analyze reception 24 hours a day for months. The transmitter in Poldhu transmitted every 15 minutes, a standard amateur radio beacon mode. The GB3RAL beacon software (by Peter Martinez, G3PLX) sampled 5 seconds of this transmission. The program sampled the noise for one minute before the transmission. Sampling was done at 8 KHz but effectively sampled at 50 Hz. The software enabled a 256 point Fast Fourier Transform (FFT) to achieve an effective bandwidth of 0.39 Hz. This in turn was normalized to a one Hz bandwidth.

Also on his side of the pond, in support of JC's work, Jeff Briggs, K1ZM/VY2ZM [6] on Prince Edward Island (PEI) also monitored the beacon. He listened for, measured and recorded GB3SSS for extended periods (while racking up a first place in the *CQ* magazine 160 meter contest).

Carl Luetzelschwab, K9LA, the propagation columnist for *WorldRadio* magazine, guided much of the

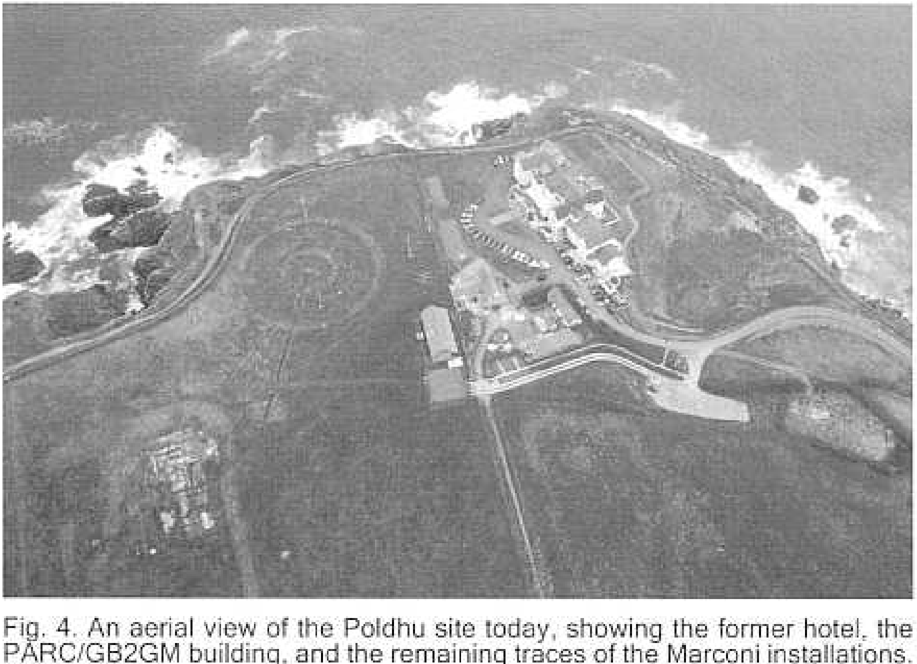

Fig. 4. An aerial view of the Poldhu site today, showing the former hotel, the PARC/GB2GM building, and the remaining traces of the Marconi installations. (Photo PARC).

Fig. 5. A celebratory milepost at Cabot Tower, Signal Hill, St. John's, Newfoundland, pointing to distant Poldhu. (Photo Bart Lee).

ongoing analysis of propagation conditions. He has commented in his column: "[I]t's encouraging to see individuals applying sound engineering methods to understand the Marconi claim. My hat is off to all those people for their efforts." [5] He used the Beacon Experiment results, and the focused research it stimulated, to modify a leading computer propagation prediction program. [5, 7] Lane Upton seized the opportunity to replicate and measure a mercury detector modeled after Marconi's (Figure 7), shedding light on the challenge of the transatlantic tests of 1901 and 1902. He has concluded that as a rectifying detector, on the conventional assessment of Marconi's power output, Marconi's mercury detector could not have been sensitive enough to hear Poldhu, which suggests higher power at work in 1901 than has been assumed. His work appears in this volume of the *AWA Review*. The ARRL's magazine *QST*, *WorldRadio*, RSGB's *RadCom* magazine and others [8] have reported on the success of the Beacon Experiment.

THE GEOPHYSICS OF 1901

This experiment came about as a result of some research done by one of us, BL, almost ten years ago. [9] He asked if sunspot data could support the suggestion that some higher order harmonics or spurious emissions of Marconi's 1901 transmitter could have crossed the ocean by way of ionospheric reflection, which is known commonly as "skip." (Spark transmitters of that era did not generate true harmonics, being more like slot filters (series inductance and capacitance) in their circuits, but could generate significant emissions higher than their "fundamental" frequency). The sunspot data, however, pointed in the opposite direction: the sunspot number for December 1901 (and for February,

Table 1. Sunspot numbers (SSN) and standard deviations (SD) by year and month, from National Aeronautics and Space Administration (NASA):

YEAR	MONTH	SSN	SD	YEAR	MONTH	SSN	SD
1901	7	0.7	2.1	1901	11	3.8	4.3
1901	8	1.0	2.7	1901	12	0.0	1.0
1901	9	0.6	2.2	1902	1	5.5	8.1

Fig. 6. Cabot Tower on top of Signal Hill, above St. John's, taken from the approximate location of the long-gone fever hospital in which Marconi set up his receiving apparatus in 1901. (Photo Bart Lee).

1902) was *zero*; if nothing else, a remarkable coincidence (Table 1).

This implies a very low daylight maximum useable frequency (and hence few if any skipping high frequencies), but also a very low absorption frequency. The practical absorption frequency depends on power input, modulation, antennas, and receiver sensitivity. In December, 1901, the absorption frequency could well support skip propagation on Marconi's declared frequency, 800 KHz, and up to some low multiple of it. Modern transatlantic reception in Newfoundland and Northern Canada of European and North African broadcast stations, under similar conditions, is well documented. [9]

Further research and analysis suggested that propagation conditions would be excellent at higher latitudes at the winter solstice, primarily by reason of less absorption, which is inversely proportional to latitude. [9] This is so because those latitudes get the least solar radiation in that season, and hence the filtering D-layer of the ionosphere is the weakest. With a weak D-layer, reflection by the higher E-layer and perhaps the highest F1-F2 layers comes into play. As one expert, Thomas F. Giella, KN4LF puts it: "Why is medium frequency propagation poor the majority of the time? At daytime the D layer, which is at an approximate height of 30-60 miles in the mesosphere, totally absorbs medium frequency RF signals the majority of the time ... the majority of the time because at higher latitudes during the winter season and especially at the low part of a sunspot cycle, daytime penetration of RF signals through the weakened D layer and then refraction via the E layer and sporadic E (Es) does occur." [10] Luetzelschwab posits that E-layer skip was Marconi's likely transatlantic conveyance. This is based in part on the strength of today's E-layer. [5] What the E-layer was like in December, 1901 is an open question; if it were then sufficiently weak, F-layer reflection or refraction comes onto play.

There are several factors that could affect the D-layer. One is the amount of very short wavelength radiation from the sun. This radiation is at a minimum at the winter solstice for Marconi's path and at a minimum at the sunspot minimum. Another is the related amount of ionizing nitric oxide in

Fig. 7. The actual Mercury Detector used by Marconi at St. John's, now on display at the Science Museum, London (photo Bart Lee). Lane Upton functionally replicated Marconi's detector based in part on this photo.

the D-layer, which has been measured to be lowest at the sunspot minima such as winter, 1901. [11] It is an open question whether a greater amount of nitric oxide in today's atmosphere, from industrial, vehicular and similar sources, relative to 1901, makes today's daily D-layers more of a filter than the D-layers of 1901. But according to Luetzelschwab, the data suggest a weaker D-layer in 1901 and hence less absorption. [5]

Moreover, the time of day may be of much less relevance than hitherto appeared: Marconi was close to gray-line (sunset terminator) at Poldhu, transmitting into daylight but not from much daylight. In the terminator map (Figure 8), the signal path paralleled the northern terminator at 14:00 GMT/UTC, then the terminator came to Poldhu from the east. Gray-line enhancement of transmitted signals is a well known propagation phenomenon, and in particular of medium wave transatlantic broadcasts received in Newfoundland in December, even in not-so-low sunspot years.

THE IMPETUS OF THE 2001 MARCONI CENTENARY AND THE RESULTING BEACON EXPERIMENT

Marconi and his legacy enjoyed much celebration in 2001, at the centenary of his triumph. Amateur radio operators regularly communicate these days between Poldhu via GB2GM and St. John's via VO1MRC and did so in 2001 in the 20 meter band. Two of us (BL and KM), were present at GB2GM and JC was at VO1MRC for the centenary contact.

But sunspots are not respecters of decades or even centenaries; theirs is the eleven year cycle. That gave rise to the question of when the next sunspot number of zero would occur. The best predictions at the time for the end of cycle 23 turned out to be about December of 2006. (Very low sunspots numbers have continued into 2008, permitting further research). Enthusiasm is contagious, and when one of us (BL) suggested (at St. John's and at Poldhu) partially replicating Marconi's experiment, both the Poldhu and the St. John's clubs went to work. Our notion that "Continuing cooperation between Canadian and British amateur radio operators can thus play a part in verification of one of the most interesting events in the history of our technology" [12] provided the foundation for our work.

One of us, KM, summarized the experiment in early 2006: "The winter of 1901 coincided with a sunspot minimum, and it was realized that this coming December 2006 should show similar conditions to those of December 1901. The beacon will help understand the possibility of low sunspot number transatlantic medium wave propagation 24 hours a day, but especially 14:00 through 18:00 UTC. It was realized that a clear channel would be necessary on the nearest amateur band, and a temporary license to operate a beacon on 160 meters was obtained." [2] As he explained to *QST*, the broadcast band was not available and full of other signals, but the 160 meter amateur band is close. He and John Gould, G3WKL, obtained permission of the British authorities (Ofcom) to put the 160 meter beacon on the air as GB3SSS. The Poldhu club replicated the transmission pattern of the 5 MHz 60 meter beacon, with step-downs of power, CW identification and PSK-31 digital signal as well. The beacon sent out its S signals from November, 2006 through February, 2007.

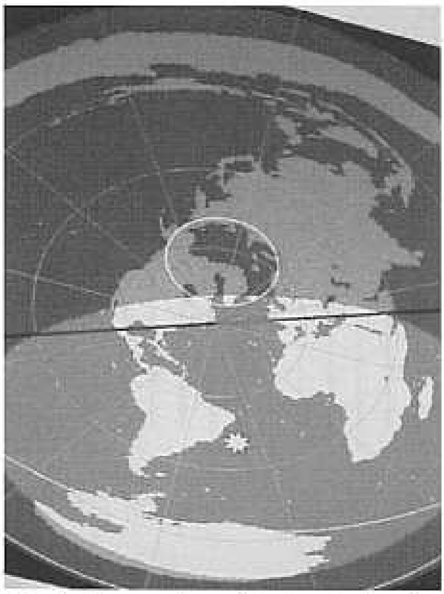

Fig. 8. The earth as illuminated by the sun on December 12, 2006 at 14:00 UTC. As the earth rotates counter-clockwise (East) towards sunset in the U.K., the edge of darkness, the terminator, approaches Poldhu; the Poldhu to St. John's path is both nearly parallel to and close to the terminator. This graphic was generated by Sheldon Shallon's W6EL propagation program.

JC in Newfoundland captured that signal 24 hours a day – even at 100 watts of power, it crossed the pond in daylight, just as Marconi's signals had. A 160 meter (one wavelength) long unterminated Beverage antenna at an average height of about one meter gathered the signals and the noise. A 4mm hardline coaxial cable connected it to the receiver. A Yaesu FT817 receiver with the automatic gain control (AGC) off, the pre-amplifier also turned off, and a 500 Hz filter selected, put the signals into the computer. Careful tuning of the radio produced a 500 Hz tone with a received carrier of 1960.000 KHz. An IBM A20m 500 MHz Pentium III computer operated from a linear power supply ran the software. JC "decoupled" the transmission line to the antenna at each of the line's ends about 1 meter above ground because feedlines can act as antennas and reduce the signal to noise ratio and performance, (as well as pick up noise from computers). At each end of the transmission line he inserted a 1:1 transformer to reduce the coupling of the noise to the antenna and receiver. JC also took a radio to the top of Signal Hill, and also captured there, for the first time in over 100 years, a medium wave signal from Poldhu – GB3SSS.

The 24-hour graphs (Figures 9, 10) display the result of every day's signals, averaged. The top curve is the signal, the middle curve is the noise level, and the lowest the difference. The signal exceeds the noise by an apparent six decibels (dB) in full daylight and many dB on the average. The shape of the middle graph shows that the noise level replicates the signal level; the shapes are similar. The signal level is, of course, the result of transatlantic propagation. That the noise curve is similar in shape implies that it too is propagated from the east of Newfoundland, *i.e.*, Europe. That noise is the man-made radio frequency noise of modern electrical civilizations; from motors in factories to thyristors in dimmers. In 1901, such man-made noise did not exist to any substantial extent. Marconi at St. John's enjoyed a very quiet ether. Winter atmospheric noise, as it happens, is at its lowest for the relevant frequencies between 800 KHz and 3 MHz, as appears in Figure 11, derived from the work of Crawford MacKeand, VP8CMY/ WA3ZKZ. [13]

The ether in 1901was indeed both quieter and calmer: "... the overall level of magnetic disturbance from year to year has increased substantially from a low around 1900. Also, the level of

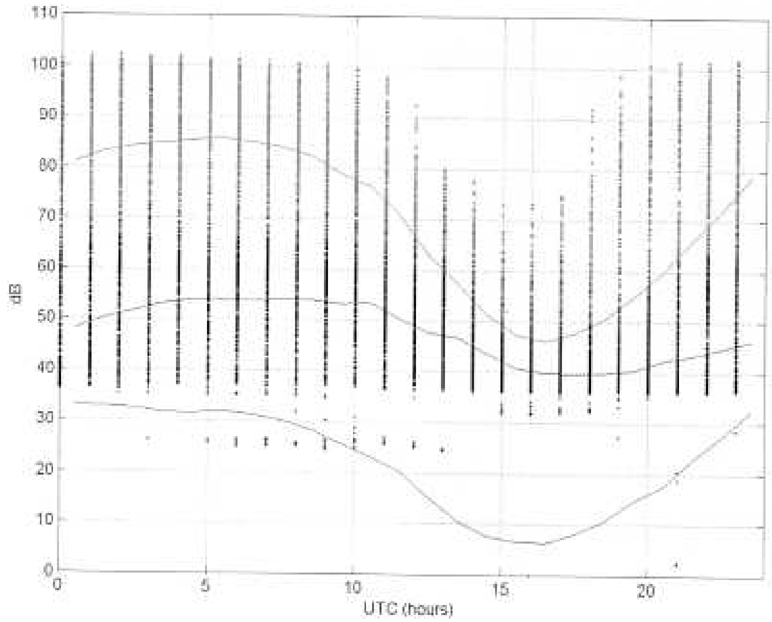

Fig. 9. Craig's graphic record of the signal strength over noise of GB3SSS for three months, set out by time of day averaged for all days.

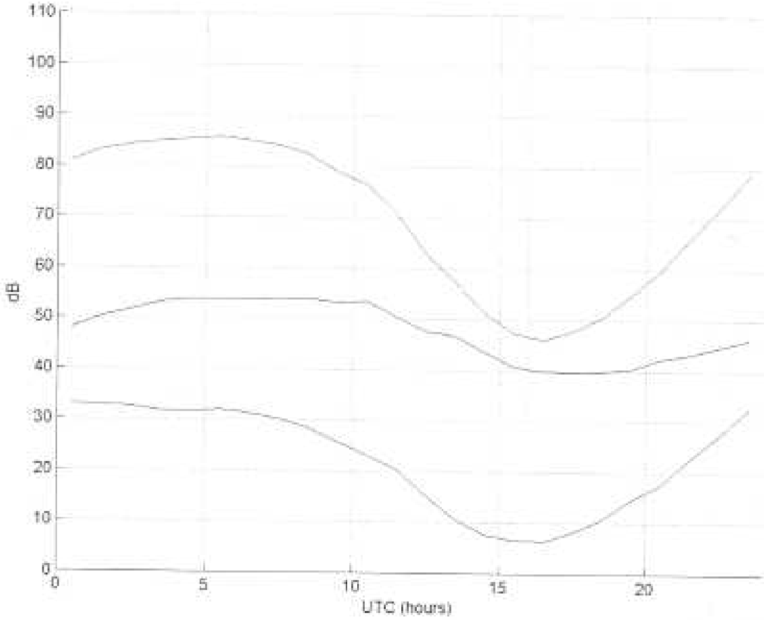

Fig. 10. A graph of only the averaged signal and noise data, and the difference, from Craig's record of the signal strength over noise of GB3SSS for three months. These graphs of Daytime Transatlantic MF Propagation, Preliminary Results, by Joe Craig first appeared in the Poldhu Amateur Radio Club Newsletter, No. 52, 02 July 2007.

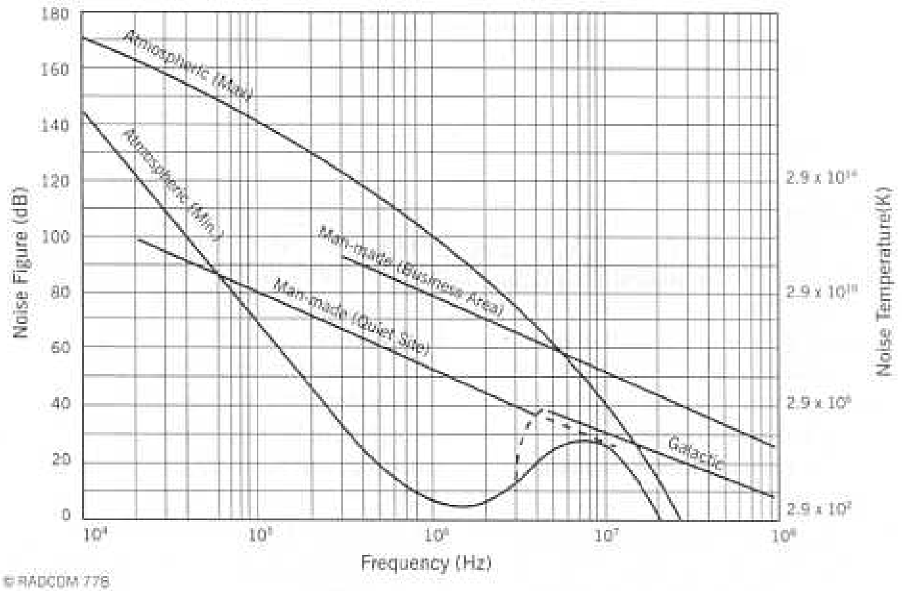

Fig. 11. Graph plotting noise levels and frequencies, showing atmospheric noise least at relevant frequencies. (Source: RadCom, RSGB, after MacKeand).

mean yearly [index] aa [the oldest magnetic ionospheric disturbance index] is now much higher so that a year of minimum magnetic disturbances now is typically more disturbed than years at maximum disturbance levels before 1900" says the National Aeronautics and Space Administration. [14] On December 12 and 13, 1901 the aa index varied between 2 and 5, a very low disturbance level, promoting skip reception. [15] Another graph from JC's analysis shows signal strength daily over the several months, between 15:00 UTC and 17:00 UTC (Figure 12).

The best signal strength measurements correlate inversely with the polar A-index, similar to the aa index, which also measures the quiet or disturbance of the ionosphere. It would be expected that an ionospherically propagated signal would be stronger the lower the A-index. For example, for the first nine days of November, the A-index averaged 3.4 and the graph (the bottom clusters) shows a grouping of high signal to noise differences. Similarly the period from about January 6, 2007 through the 14th shows clusters of good reception. In this period the A-index averaged 3.75. [16] Alan Melia, G3NYK, a propagation expert, has stressed that the maximum signals are of more interest in the context of this experiment. The maximum levels varied considerably between 14:00 and 18:00 UTC at daily and weekly time scales. Marconi, after all, had only to hear, even episodically, three clicks, not copy complex data over time, such as a message.

In early November, Jeff Briggs, operating as VY2ZM, monitored GB3SSS from PEI, west of St. John's. He first logged the beacon on November 3 and 4, 2006 during the day, UTC (and London time) 11:31 through 17:45 (average A-index 4.5) and again November 22 through December 4. He measured the signals' strength repeatedly as -91dBm at 17:00 UTC, sunset at Poldhu and afternoon

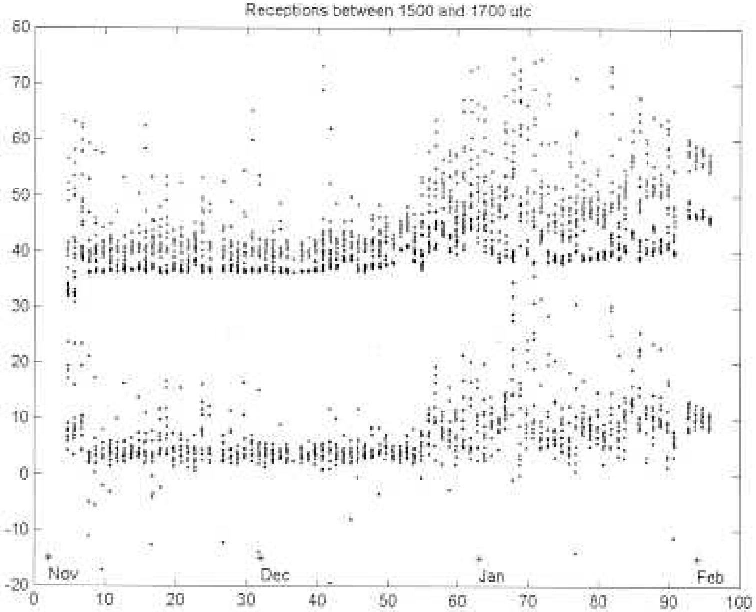

Fig. 12. Craig's three month record of daily GB3SSS signals and signal to noise ratios.

in Canada (keeping in mind an approximate 8 dB antenna gain). Briggs reported to us an absence of noise at PEI: "There is No Noise at all ... no man-made at all and at 1750z [UTC], the noise floor at my RX [receiver] is close to zero. In other words, when the beacon sounds, it is like Black Ink Spots hitting a clean white sheet of paper [his emphasis]." Nighttime signal strength came in about 30 dB better. Briggs also replicated earlier medium wave broadcast station monitoring: "At 1730z [UTC], UK Sports/Talk on 1089 KHz ... and Doha (Qatar) on 1521KHz were perfectly readable with enjoyable programming content on PEI - and at 1800z RNE Spain down around 835 KHz was in as well as was Radio Switzerland - somewhere in the 745 KHz range."

Further reports came back to the Poldhu club from as far away as New Zealand (Mike McAlevey, ZL4OL) with several from North America. It is also interesting to note that a year later (sunspots and winter static remaining very low), amateur radio experimenters effected a 500 KHz aural Morse code transatlantic contact between GI4DPE in England and WE2XGR/2 in New York, a distance of 3039 miles. In the winter of 2007-'08, the Poldhu and Newfoundland experimenters have run another GB3SSS beacon in the 80 meter band, which JC is monitoring. The 80 meter results may shed further light on the 160 meter results.

The question is now *how* Marconi succeeded, not *whether* he did. The way all of this translates to 1901 is a matter primarily of qualitative analysis.

THE RECEIVERS

The Beacon Experiment uses modern high sensitivity receivers. JC logged and recorded the GB3-SSS low-power signals consistently. Jeff Briggs told *QST*: "My own conclusion suggests that Marconi may well have heard what he said he did – if his receiver was about 25 dB more sensitive..." [2] Modern receivers are highly selective. Marconi's receiver, even assuming use of the "four-sevens" patent tuning circuit, tuned broadly – but then the signal had to have been fairly broad itself.

Marconi used what has long been regarded as a passive receiver, the mercury detector, and he also reported use of carbon filings coherers at St. John's. [17] The mercury detector was invented by the Indian physicist Sir Jagdish Chandra Bose and then improved by Italian Navy electricians. [18]

Whether Marconi's receiver was "passive" is an open question. BL has pointed out that a Branly filings coherer provides gain, as can a relay. Each pulse of radio frequency (RF) energy from the antenna makes the filing cohere or stick together, and conductive. The coherer provides gain because it is a monostable multivibrator [19] when used in the feedback circuit of the tapper that re-sets the filings to non-conductance after each initial pulse of radio frequency (RF) energy from the antenna. The power that flows through the coherer as direct current (at the DC bias voltage) to work the tapper and inker exceeds the RF power that alters the state of the coherer filings. This is amplification in the cybernetics sense of control of one higher power process by another of lower power [20] although it is not and need not be linear.

The mercury detector restores itself after each pulse without a tapper. It was called an autocoherer and a self-restoring coherer. The Branly filings coherer acts as a pulse amplifier because the weak RF from the antenna gates a pulse of the circuit's direct current bias voltage, strong enough to both activate (often through a relay) the tapper and the paper tape recorder stylus. In theory, the mercury detector does the same thing, *i.e.*, acts as a monostable multivibrator pulse amplifier, although at much lower levels of RF, because Marconi's circuit for it uses the same bias voltage arrangement as a coherer, as shown in his patent. The resulting DC pulse is heard as the click in the earpiece. [21] Early work on the mercury detector measured a 3:1 ratio between high resistance and low ("cohered") resistance after a pulse of RF energy. [22]

In the circuits that Lane Upton used to show that the mercury detector operates as a diode comparable to a germanium diode (*e.g.*, 1N34), he did not observe a gating of bias voltage even when shocked by a pulse of RF, but the bias, to permit measurement, was in series with the detector, not in parallel as in Marconi's circuit. A germanium diode may be said to have a sensitivity in the range of -25dBm, and the series-biased mercury detector operating as a diode somewhat less. Work a hundred years ago put the sensitivity of the mercury detector as "a thin-film breakdown device" (a monostable multi-vibrator, not a rectifier) as low as ten nanowatts and less than a microwatt when used with sensitive earphones. [23] (In relative terms, that's -50dBm and -30dBm). Marconi engineer Elmer E. Bucher said: "Some receiving detectors rely upon the *principal* [sic] *of rectification* ... and will convert an *alternating current of radio frequency to a uni-directional current*." This, of course, is the function of a diode; but Bucher goes on: "others have the property of rectification combined with the *ability to vary* *a local source of battery current* in a manner much similar to the working of an ordinary telegraph relay...." (All emphasis Bucher's). [24] This last is "gain."

Detectors in general supply as audio 1) less power than received, or 2) the same amount of power, or 3) more power, depending on type, circuits and configurations. In the early days of wireless, "gain" was not an operative notion but rather the question was whether one or another detector was or was not more "sensitive." (This was so at least until the capacity of the DeForest Audion to amplify was understood). Bucher's analysis of the carborundum detector suggests many dB gain when biased and operating at the steepest part of its characteristic (non-linear) curve. Wireless pioneer Robert Marriot in Colorado (circa 1904) used biased zinc oxide as a detector. Oleg V. Lossev and others made biased zinc and galena crystals oscillate in the 1920s and earlier. [25]

THE ANTENNAS

In this Beacon Experiment, JC used a directional beverage antenna, which diminishes omnidirectional noise; Jeff Briggs on PEI (Figure 13) used a vertical high gain (8 dB) directional array. Marconi used a more or less vertical 400 to 450 foot wire hanging from a kite. The modern antennas have a big advantage, especially in diminishing overall noise, both man-made (mostly from the southwest) and atmospheric (largely from the southern hemisphere). On the other hand, Marconi's vertical wire, running into his receiver at the fever hospital near Cabot Tower, may have been planned to be, and may actually have been, near resonant at a quarter wave length on Marconi's intended wavelength.

It is undetermined the extent if any to which Marconi's 1901 vertical transmitting 50+ wire fan antenna may have been directional. The 2006 Poldhu antenna was omnidirectional. The transmitting antenna in 1901 may well have been as difficult to ground as the 2006 Poldhu Amateur Radio Club antenna, which required a counterpoise, as Davey-Thomas found out. JC has looked at this in terms of whether the 1901 antenna could radiate at higher frequencies. He concluded: "If the earthing system at Poldhu was not elaborate, the bandwidth of the antenna would be broad, and the fan configuration would tend to have a broadening effect." Davey-Thomas reported that at Poldhu "...it is difficult to get an effective earth because the soil structure is a deep layer of shale." [8]

THE FREQUENCIES

A signal of about one half the frequency of another (Marconi's 800 KHz relative to the beacon's 1960 KHz) can be expected to come across with about one fourth the strength. This is a propagation rough square law at work and it may not be all that predictive at medium frequencies. This does, however, suggest about a 12 dB advantage to the higher beacon fre-

Fig. 13. Jeff Briggs, K1ZM, operating as VY2ZM on Prince Edward Island, Canada.

quency. On the other hand, Fleming's transmitter could well have emitted its three dots signals on a frequency higher than 800 KHz as well as near 800 KHz, and his wire fan antenna, poorly grounded, would not have acted as much of a low-pass filter.

TRANSMITTER POWER

In this Beacon Experiment, Poldhu put out only 100 watts power (ERP). On the other hand, Marconi's transmitter has long been understood to have a roughly measured power of about 15 kilowatts (KW) for a more than 20 dB advantage to the 1901 transmitter.

THE IMPLICATIONS OF MARCONI ENGINEER FLEMING'S PULSE TRANSMISSIONS

Looking at these qualitative factors a passive receiver could seem like an unlikely candidate for transatlantic reception even in the quietest moments of the ionosphere, especially given Lane Upton's results. On the other hand, transpacific reception of the long-wave spark signals of Marconi spark station KPH in California, by way of crystal detectors, at least 5,000 miles, was several times reported in the 1916 period. [26] KPH ran a 300 kilowatt rotary spark transmitter. Marconi engineer Bucher reported that the initial Marconi transatlantic stations *circa* 1907 initially employed crystal detectors in a balanced noise canceling circuit developed with Marconi engineer H. J. Round [24]. These stations also employed very large antennas and 300 KW spark transmitters.

All of these rough counterpoints may, however, be offset by other

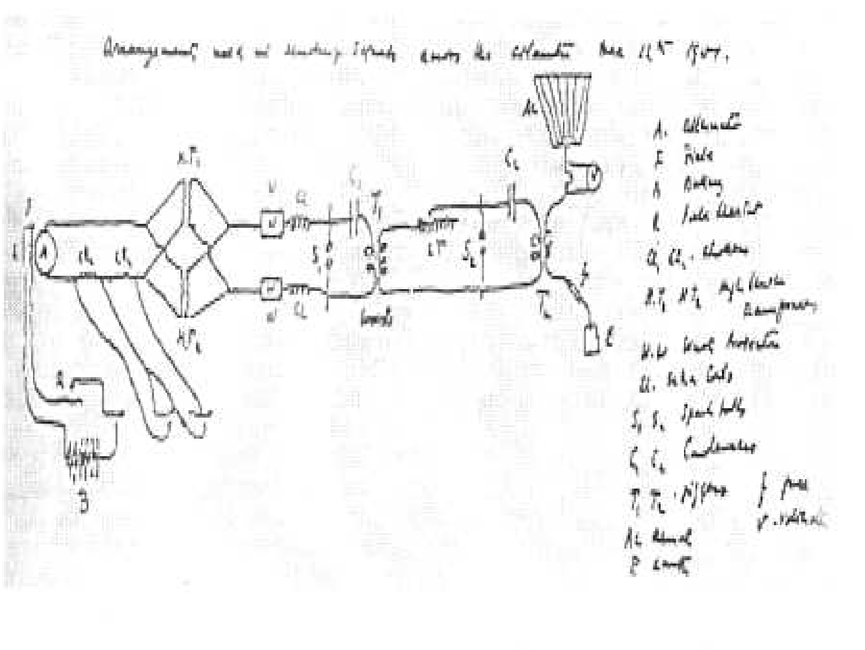

Fig. 14. John S. Belrose presents this hand drawn diagram from Probir Bondyopadhyay's research [17], captioned by Belrose as: "The circuit diagram of the December 1901 Poldhu transmitter in J.A. Fleming's handwriting." Fleming wrote on it: "Arrangements made for sending signals across the Atlantic Dec 12th, 1901" [28, 29].

considerations of many orders of magnitude. Marconi's 15 kilowatt figure is the result of known factors such as the alternator's power, reliable calculations and an antenna ammeter, by reason of its own electro-mechanical structure, integrating the power over time, in effect averaging it. The time-average power of the pulses measured at about 15 KW, consistent with the station's generator's capacity, but the individual pulses were very short and very high-power spikes. Marconi engineer John Ambrose Fleming's circuit was a double-spark system designed to put out pulses of milliseconds if not microseconds duration, (see schematic diagrams, Figures 14, 15). The 1901 transmitter has been thoroughly analyzed by Desmond Thackeray (in 1992) for AWA, who concludes that about 450 joules per second of power could be had at the spark gap. [27] This translates as 450 watts averaged over one second, but 450,000 watts for one thousandth of a second, and so forth. It is, however, also true that very short pulses would have been highly damped and therefore of wider bandwidth. JC has expressed reservations about the ability of the 1091 Poldhu aerial to effectively radiate a pulse on the basis of bandwidth arguments.

The pulses from Fleming's double-spark transmitter have been estimated to have been in the megawatt range, albeit very, very briefly. [31] But all Marconi had to hear for success was three timed pulses, not any further intelligence: *the timing* was *the intelligence*. The relationship of a 100 watt beacon even to a one-megawatt pulse is four orders of magnitude, or 40 dB (subject to bandwidth, antenna and other caveats). This implies that Marconi's receiver could have been 100,000 times less sensitive than a modern radio and still have heard Poldhu's pulses in 1901. (Figure 16).

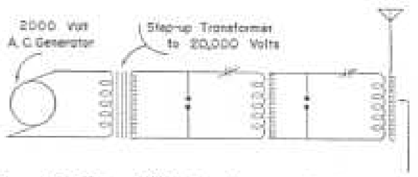

Fig. 15. Simplified schematic diagram of Fleming's double spark transmitter [30]; the first spark discharge charges the second stage spark circuit to very high power for a very short duration spark.

MacKeand [13] and Lee [32] independently analyzed the measured 15 KW figure as an average of much stronger pulses. MacKeand writes: "... the received signal ... would be enhanced by 40 dB...." relative to a constant carrier, figured on a 5 micro-second pulse. On the other hand, senior Radar engineer Don Toman, K2KQ, cautions that a very short pulse will spread its energy over a wide band of frequency, complicating the analysis of what he points out are difficult-to-model transients. MacKeand also suggests significant gain from the response to pulses by the human ear, relative to a coherer and inker. As a result of his own engineering study of what is known of Fleming's Poldhu transmitter, MacKeand suggests peaks of radiation between 500 and 800 KHz, around 2 MHz and around 10 MHz. He further suggests that the Maximum Useable Frequency (MUF) in December 1901 could have been as high as 10 MHz, and that higher frequency skip, not skip at the fundamental frequency, put the three dots into St. John's. In this he joins both Henry Bradford [4] and an earlier analysis by Craig [33]. The maximum useable frequency in December, 2006 approached 10 MHz, and would have in 1901 as well. MacKeand

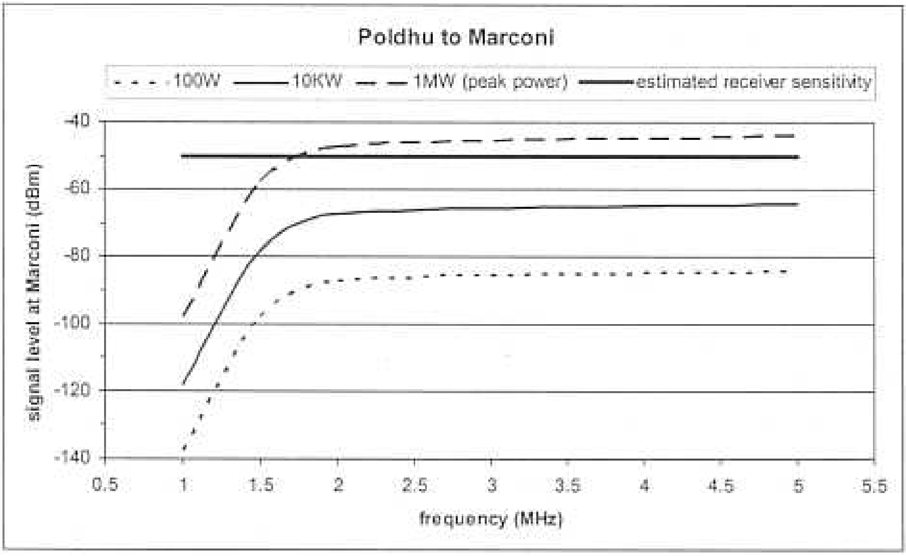

Fig. 16. Graphic analysis of the relation of various assumed Poldhu power levels to receiver sensitivity and frequency, showing reception by a relatively insensitive receiver at high transmitter power [5]. (Source: Carl Luetzelschwab, K9LA, by permission).

also points out that ionospheric "fading" is additive about 10% of the time. Marconi, after all, did not have to hear all of the Poldhu signals all of the time, just some of them some of the time.

If, however Marconi employed his syntonic tuning circuit of the "four-sevens" patent (patented in April, 1901), he would hear only in the vicinity of the fundamental frequency he was tuning for (as demonstrated during his 1902 voyage [30]). Moreover, although Marconi's temporary antenna at Poldhu (Figure 17) is reported to provide a take-off angle of 45 degrees, it resonated at less than one MHz. Davey-Thomas suggests Marconi's fan could radiate a third harmonic around 2.5 MHz [2]; this would be consistent with MacKeand's estimate of a power peak around 2 MHz. Thackeray [27] notes that in 1901 Marconi engineer Fleming brought the antenna into resonance with the transmitter circuits and measured a maximum antenna current of 17 ½ amperes. Thackeray suggests a "double-hump" signal [9] was likely at resonance given the tight coupling of the circuitry, ranging between about 200-400 KHz and about 700-1,000 KHz and that Marconi's vertical kite antenna at 400 feet would be a quarter wave at 600 KHz, well within this range.

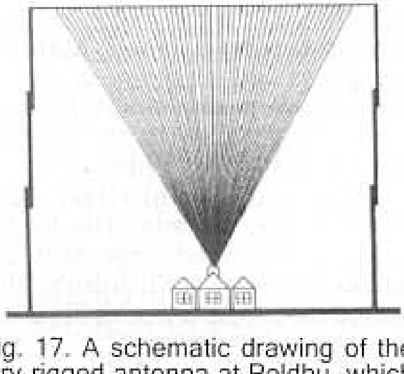

Fig. 17. A schematic drawing of the jury-rigged antenna at Poldhu, which was a vertical fan of about 54 wires [30] erected after a storm took down a larger, planned cone-like multi-wire antenna.

CONCLUSION

The Marconi Beacon Experiment of 2006 does not prove that Marconi and his assistant George S. Kemp told the truth in asserting that they heard three dots from Poldhu some 38 times in two days, December 12 and 13, 1901. But our Experiment, and the analyses it has both engendered and unearthed, shed mathematically precise and highly favorable light on the claim. The replication today of the signal path by careful experiment at low power, an appreciation of the power inherent in Fleming's design for the Marconi Company's Poldhu pulse transmitter, a deeper understanding of the receiver technology, and of the geophysics of the time, all come together nearly to compel the conclusion that Marconi did exactly what he claimed. That is, he succeeded in using the nascent technology of wireless telegraphy to signal across the Atlantic for the first time. Moreover, he likely did it at the wavelength he posited, about 360 meters or 800 KHz or perhaps up to two MHz above that inferred frequency. In February, 1902, as is well known, he did it again on the *SS Philadelphia*, likely at the same frequency, or at a lower frequency used later in 1902. By October 17, 1907 (now a century ago), using a passive crystal receiver, Marconi employed low frequencies and a spark system of 300 KW to initiate regular transatlantic wireless service between Clifden, Ireland (callsign MFT) and Glace Bay, Nova Scotia, Canada. The bright morning of the radio age, as it had dawned in 1901 at St. John's, illumined the modern world. Figuring out (beyond conjecture) how transmitters and receivers that haven't existed for a hundred years actually worked at specific times and places taxes both the imagination and engineering skills.

ACKNOWLEDGEMENTS

We are grateful to the leaderships and memberships of the Poldhu Amateur Radio Club and the Marconi Radio Club of Newfoundland for their support, and to the California Historical Radio Society as well, especially Mike Adams, Chair and Webmaster, and John Staples, W6BM, a physicist at a National Laboratory, for his critical insight. The Antique Wireless Association has generously provided forums for publication, presentation of and valuable discussion of Marconi-related research. Many other people have contributed to the success of this experiment and its analysis. We have tried to name each of them in the article and notes, and hope that any we may have failed to identify will accept our apologies and that all will accept our gratitude.

REFERENCE NOTES

1. International Telecommunications Union (ITU) *Regulations*, Sec. III, ¶1.56; emphasis added; the U.S. Federal Communications Commission (FCC) adopts the ITU definition at 47 Code of Federal Regulations (CFR) Part 97 at §97.3.
2. Steve Nichols, G0KYA, GB3SSS – Marconi's Transatlantic Leap Revisited, *QST*, December, 2007, p. 40 reports the success of the experiment and quotes Dr. Belrose. The Radio Club of America recently awarded Dr. Belrose its Armstrong Medal – Belrose amplified his skeptical remarks, as a result of Mr. Nichol's article, in the March issue of *QST*, Technical Correspondence, pp. 53, 54: "So let us give Marconi credit for the bold attempt he made to achieve transatlantic communications, but from my point of view he did not hear what he thought he did." See also Belrose [28], *infra*.
3. Professor Hugh G. H. Aitken, *Syntony and Spark — the Origins of Radio*, (New York: John Wiley & Sons, 1976) at page 295 in note 86;

accord W. J. Baker, *A History of the Marconi Company*, (London: Methuen, 1970) at page 71.

4. Henry M. Bradford, Did Marconi Receive Transatlantic Radio Signals in 1901?, Antique Wireless Association *Old Timer's Bulletin*, 2002, 44(1), 40-42, and 44(2), 64-65. See also Joe Craig, [33] *infra*.
5. Carl Luetzelschwab, K9LA, *WorldRadio*, propagation column, Marconi Revisited (February, 2008). As a result of the Beacon Experiment, he revised the model by "a bit less than one order of magnitude" for a sevenfold *decrease* in predicted D-layer absorption for the Poldhu to St. John's path in December, 1901. He summarized: "The reason people say Marconi couldn't have happened is because our model says there was too much absorption for it to have happened. So the model has to be shown to not accurately represent what was going on in 1901 .... it's [not] a trend issue - it's more one of overall accuracy" (personal communication). This experiment led him to revise a leading model, Proplab Pro, by insertion of more accurate ionospheric data for the path, to account for the result, thereby strengthening Marconi's claim.
6. Author of *DXing on the Edge – the Thrill of 160 Meters* (ARRL), 1997.
7. Carl Luetzelschwab, [5] *supra*; see also his December, 2007 *WorldRadio* propagation column accounting for Briggs's reception in 2006.
8. Steve Nichols, [2] *supra*; Pat Hawker, Technical Topics, Marconi and his 1901 'S' Clicks, Radio Society of Great Britain [RSGB] *RadCom* magazine, April, 2007, page 84 (with technical explanations by Davey-Thomas including the poor ground); also News, *RadCom* magazine, January, 2007, page 10; and Luetzelschwab, [5] *supra*.
9. Bartholomew Lee, Marconi's Transatlantic Triumph – a Skip into History, *Antique Wireless Association Review* (2000), Volume 13, page 81. A graph of a "double-hump" spark signal appears on page 86.
10. Thomas F. Giella, *2008 Kn4lf Daily Solar Space Weather & Geomagnetic Data Archive*, available at http://www.kn4lf.com/kn4lf8.htm.
11. Student Nitric Oxide Experiment (1997 - 2003) (SNOE) satellite at the University of Colorado, http://lasp.colorado.edu/snoe/index.htm "[O]bservations of thermospheric nitric oxide [NO] from the Solar Mesosphere Explorer ... observations show that the nitric oxide density at low latitudes varies with the 27-day solar rotation period and with the 11-year solar cycle. The variation of nitric oxide correlates with two solar indices, the solar Lyman alpha irradiance which was measured from the SME spacecraft and the solar 10.7 cm radio flux which is a solar index that is measured from the ground." One of the instrumentation workers on SNOE has summarized nitric oxide generation in the ionosphere: "There is a source of NO in the troposphere, but that NO does not reach the D-layer. All of that NO is created naturally [in the D-layer by radiation]," according to a personal communication from Scott Baily, Professor Electrical Engineering at Virginia Polytechnical Institute (Virginia Tech). Carl Luetzelschwab analyses the D-layer thus: " ... the daytime D region is the result of two sources of radiation. The first is a spectral line of hydrogen at 121.5nm ionizing nitric oxide. The second is extremely short wavelengths (0.1 - 1nm) from sunspot activity ionizing all atmospheric constituents. It appears that the radiation from the hydrogen spectral line is constant over a solar cycle, so there will always be residual daytime D region ionization from this source. The short wavelength radiation obviously increases as a solar cycle increases, but it doesn't appear to add any more until the sunspot number is above 50 or so. D-layer absorption is proportional to the product of the electron density times the electron-neutral collision

frequency. The electron-neutral collision frequency does not vary significantly over season, location, or sunspot conditions." (Personal communications).

12. Bartholomew Lee, Reflections: Marconi and Ionospheric Propagation, and a Plea for Timely Experiments, (CHRS – 2005) www.californiahistoricalradio.com/photos53.html.
13. Crawford MacKeand, *The Friendly Ionosphere – Signals, Noise and Propagation*, (Montchanin, DE: Tyndar Press) 2001; Figure 7.10, page 53; the detailed graph here comes from the RSGB magazine *RadCom*. Such distant noise is heard as a dull roar not sharp spikes (MacKeand, page 73) if heard at all. Generally speaking, lower noise and higher power are equivalent in permitting conveyance of intelligence by a signal, and narrow bandwidth as well as a slower rate of sending information are the equivalent of higher power or lower noise (see generally Claude Shannon & Warren Weaver, *Mathematical Theory of Communication* (Illinois, 1949).
14. NASA at http://www.ngdc.noaa.gov/stp/GEOMAG/aastar.shtml. Geophysical circumstances do change over decades; for example, in 1901 the magnetic north pole was about 1,100 km closer to Newfoundland, although what effect if any this may have had is undetermined.
15. Centre d'Etudes des Environnements Terrestre et Planétaires – International Service of Geomagnetic Indices, http://isgi.cetp.ipsl.fr/cgi-bin/isgi/sm1.exe; see the musical diagram (octave) presentation at /musicald.htm. By contrast, during the 2006 tests the aa index ran fairly high during most of December, although it was lower in early November and January. According to Tad Cook, K7RA, ARRL propagation columnist, in quiet times the polar A index generally runs lower than the planetary A index (personal communication), consistent with reports as early as the 1930s of enhanced high latitude propagation and the same finding as early as the 1920s by Marconi (see Lee, [9], *supra*).
16. Data from Thomas F. Giella, KN4LF http://www.kn4lf.com/kn4lf8.htm; [10] *supra*.
17. Henry Bradford, quoting Marconi: "The coherers which gave the signals were one(s) containing loose carbon filings, another designed by myself, contained a mixture of cobalt and carbon filings, and thirdly the 'Italian Navy Coherer,' containing a globule of mercury between two (conducting) plugs" citing to: Probir K. Bondyopadhyay (a satellite and communications engineer at the NASA Johnson Space Center in Houston), "Investigations on the Correct Wavelength of Transmission of Marconi's December 1901 Transatlantic Wireless Signal, Part 2," *IEEE International Antennas and Propagation Symposium Digest*, Seattle, Washington, June 19-24, 1994, pps. 217-220; [4] *supra*.
18. Pallava Bagla, The Wireless Dispute http://frontlineonnet.com/fl1506/15060810.htm, reports that Probir Bondyopadhyay has so determined ("Sir J. C. Bose's Diode Detector Received Marconi's First Transatlantic Wireless Signal of December 1901 (The 'Italian Navy Coherer' Scandal Revisited)") – that assertion is now persuasively demonstrated; Italian Navy Lt. Luigi Solari acknowledged reading about a mercury detector in the British scientific press, and Bose had so published, presenting a paper in London in 1899.
19. Wikipedia, "Multivibrator" at http://en.wikipedia.org/wiki/Monostable: "There are three types of multivibrator circuit: ... [one is the] monostable, in which one of the states is stable, but the other is not - the circuit will flip into the unstable state for a determined period, but will eventually return to the stable state. Such a circuit is useful for creating a timing period

of fixed duration in response to some external event. This circuit is also known as a one shot."

20. W. Ross Ashby, *An Introduction to Cybernetics* (London: Chapman & Hall) 1956; webpublished 1999 at http://pespmc1.vub.ac.be/books/IntroCyb.pdf): "Gain (of anything) = Final quantity minus initial quantity" page 178; "... [W]e can have, simultaneously, a law saying that energy cannot be created, and also a power-amplifier" page 240; "What is an amplifier? An amplifier, in general, is a device that, if given a little of something, will emit a lot of it. A sound amplifier, if given a little sound (into a microphone) will emit a lot of sound. A power-amplifier, ... if given a little power ... will emit a lot of power.... And a money-amplifier would be a device that, if given a little money, would emit a lot. Such devices work by having available a generous reservoir of what is to be emitted, and then using the input to act as controller to the flow from the reservoir. Rarely an amplifier acts by directly magnifying the input, as does the cine-projectionist's lens; but more commonly it works by supplementation. Thus the power-amplifier has some source that will provide power abundantly ..., and it is this source that provides most of the power in the output..." page 265.

21. See Bartholomew Lee, A Meditation on Marconi's Mercury Detector ... Nothing Ventured, Nothing Gained (CHRS – 2006) www.californiahistoricalradio.com/photos63.html.

22. V.J. Phillips, *Early Radio Wave Detectors* (London: Institute of Electrical Engineers) 1980, page 57.

23. MacKeand, *supra*, [13], p. 73, citing studies by Marconi engineers W.H. Eccles, On Coherers, Vol. 65 *Electrician* pp. 724-27 & 772-73 (1910), and J. A. Fleming (published in London in 1923).

24. Elmer E. Bucher, *Practical Wireless Telegraphy* (New York: Wireless Press) ed. 1918, page 140; analysis of the carborundum detector at page 138 and graph; passive crystal receivers at Marconi stations *circa* 1907, page 286.

25. *Radio News*, September, 1924, pps. 294-295, 431: The Crystodyne Principle, available at http://earlyradiohistory.us/1924cry.htm; recent work suggests negative resistance in many early detector minerals, not unlike the effect of a tunnel diode: Nyle Steiner, K7NS, Zinc Negative Resistance Oscillator (2001) available at http://home.earthlink.net/~lenyr/zincosc.htm.

26. Bartholomew Lee, West Coast Wireless (CHRS – 1992, 2006), http://www.californiahistoricalradio.com/photos69.html and http://www.trft.org/TRFTPix/CHRSWirelessWestCoast2006.pdf: In 1916, Dick Johnstone, a Marconi operator at KPH at Bolinas, California and Tom Lambert on the tanker *SS J.A. Moffett*, call sign WRE, communicate for an entire voyage to China, 5,000 miles, each using only a galena crystal set for a receiver, according to recollections published by the Society of Wireless Pioneers. Johnstone was a popular operator at KPH with a distinguished career including the rank of Commander in the Navy during World War II; he later wrote an engaging memoir of his early days in wireless. Also in 1916, Howard Seefred (W)6AE, heard and logged Funabashi, Japan (6,000 miles) on a Galena crystal, according to his logbook preserved in the Perham Foundation collections (History San José). One of us (Lee) once logged short-wave Radio Moscow on a Philmore Crystal Set with a random wire antenna in New Jersey about 1958 at the peak of solar cycle 19. Steve McDonald (VE7SL) Crystal Radio DXing http://imagenisp.ca/jsm/Crystal.html, provides detail on other long distance passive detector reception by hobbyists.

27. Desmond Thackeray, The First High Power Transmitter at Poldhu, *Antique Wireless Association Review* (1992) Volume 7, pp. 29, 34; he notes Fleming's measurement of

17 ½ amperes antenna current at page 41; the suggestion of a double hump appears at page 42 and see Lee, [9], *supra*, for a diagram; Thackeray suggests Marconi's kite antenna was intended to be a quarter wavelength at his intended frequency, page 42.

28. John S. Belrose, Fessenden and Marconi: Their Differing Technologies and Transatlantic Experiments During the First Decade of this Century (1995) http://www.ewh.ieee.org/reg/7/millennium/radio/radio_differences.html
29. The 1901 Fleming transmitter photo #5583 comes from the GEC-Marconi archive (now at Oxford University's Museum of the History of Science), in Thackeray [27] *supra*; the drawing comes from an English Pye Radio publication. Thackeray says the spark gap is retouched in the photo; Marconi company photos were occasionally retouched presumably for proprietary reasons, *e.g.*, Marconi sitting at a table at St. John's in 1901 and perhaps the photo of the fan antenna [30].
30. Douglas Coe, *Marconi, Pioneer of Radio* (New York: Messner) 1943, circuit diagram, page 120; fan antenna, page 122.
31. Karl-Ludvig Groenhaug, Experiments with a Replica of the Bose Detector http://www.geocities.com/mumukshu/bose_detector_groenhaug.pdf (*circa* 1992): "The mean power of such a complex pulse ha[s] been estimated to 40 MW" [megawatts], citing J. A. Ratcliffe, Scientists' reaction to Marconi's transatlantic radio experiment, *Proc. IEE*, Vol 121, no. 9, page 1033, Sept. 1974; others estimate as little as just over one megawatt. Henry Bradford [4], *supra*, and Crawford Mackeand [13], *supra*, also cite Ratcliffe.
32. Bartholomew Lee. A review of last year's replication of Marconi's 1901 transatlantic tests. Presented at the Annual Conference of the Antique Wireless Association, Rochester, NY, August 22-25, 2007.
33. Joe Craig, Marconi's First Transatlantic Wireless Experiment, *The Canadian Amateur* November/December 2001, pp. 40-41, available at www.ucs.mun.ca/~jcraig/marconi.html.

This article was peer-reviewed.

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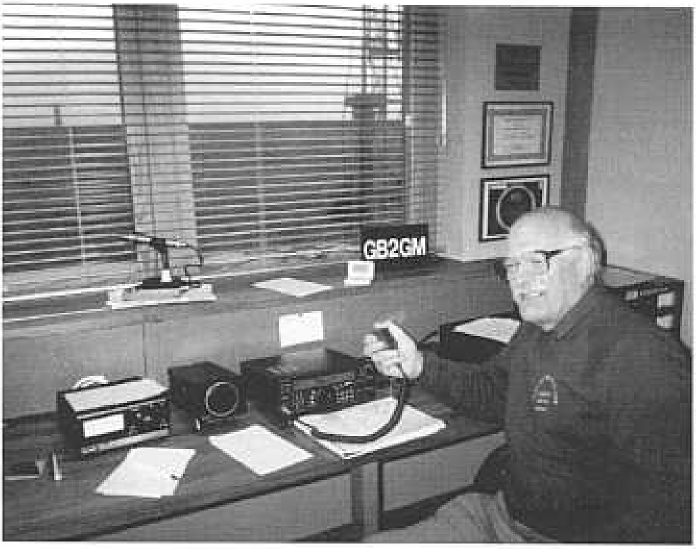
Joe Craig, VO1NA, was first licensed in 1976. He is the son of VO1FB, husband of VO1RL, and father of Julia. Joe completed his Bachelors and Masters degrees at Memorial University of Newfoundland and works with the Government of Canada as a physicist. He has lectured at the University and at conferences on radio and physical science and has authored dozens of technical and research papers as well as several publications in the primary literature. Joe is a member of the Baccalieu and Poldhu Amateur Radio Clubs, the Marconi Radio Club of Newfoundland, Radio Amateurs of Canada and a life member of the Quarter Century Wireless Association. He was the first Section Manager of the Radio Amateurs of Canada Newfoundland and Labrador Section, from which he retired after 12 years of thoroughly enjoyable service. He has both CW and 160 meter DXCC. Joe also enjoys swimming and fitness, music, traveling, photography and astronomy. He can be contacted at jcraig@mun.ca.

Keith Matthew, G0WYS, has been for many years a principal of the Poldhu Amateur Radio Club, Cornwall, U.K. acting as Secretary and overseeing its Newsletter. He is a now retired physics teacher in Helston, and coincidentally lives on a pleasant little street called Marconi Close. He has been instrumental in linking Poldhu with Marconi -related sites around the world, such as Sasso Marconi in It-

Author Joe Craig, VO1NA, standing at the Marconi memorial plaque near Cabot Tower, above St. John's, Newfoundland. (Photo Bart Lee).

aly, and in generating international goodwill by amateur radio and shared interests in radio history. Wireless history as well as amateur radio are now interests to which he can devote more of his time.

Bartholomew Lee, KV6-LEE, holds a U.S. extra class amateur radio license. He has enjoyed radio and radio-related activity including radio history in many parts of the world. The AWA presented its Houck Award to him in 2003 and CHRS gave him its Herrold Award in 1991. He has written widely on, and made many presentations on radio in intelligence operations (including the CIA on Swan Island), wireless



Author Keith Matthew, G0WYS, operating GB2GM at Poldhu on December, 2005. (Photo Bart Lee).

history, short wave radio, radio ephemera and radio in emergency response. In 2001 during "9/11" he acted as the New York City Red Cross Deputy Communications Lead from September 12 through September 20. Bart is a trial lawyer by trade, in San Francisco, California and an adjunct professor in Law & Economics at a San Francisco university.

Joe Craig's radioshack VO1NA in his home near St. John's, enjoyed by author Bart Lee, KV6LEE, in the operator's position, in August, 2005. (Photo Joe Craig).