MARCONI'S TRANSATLANTIC TRIUMPH
— a skip into history

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On the afternoon of December 12, 1901, Guglielmo Marconi heard the first radio signals (three "dots" of Morse Code) to cross the Atlantic Ocean. The Morse "S" of three dots was transmitted from England to Newfoundland using his new system of wireless telegraphy.[1] Graphics of Marconi's calendar [19], and that of his assistant, George Kemp [14], noting date and time they heard the pre-arranged signals, are reproduced here. (Fig. 1) Marconi noted "Sigs at 12:30, 1:10 and 2:20." Kemp notes "Got Sigs 3 Dots" and of their 500-foot long kite antenna "... kept it up three hours which appeared to give sigs good." (Fig. 2)

Figure 3 is an artist's conception of the lofting of that kite [13]. The antenna wire from which the kite flew was then affixed to a pole from which the kite remained aloft (Fig. 4) [16]. The site in Newfoundland, known as Cabot Tower, Signal Hill, is commemorated on a 1930s postage stamp (Fig. 5) [17].

Marconi thus opened the century of telecommunications. One hundred years has brought even hand-held transceivers (ironically, Nikola Tesla's dream) linking to the world's telephone systems. The world now enjoys world-wide, high-bandwidth data, video and voice links including broadcasting. Parabolic antennas, pioneered by Marconi [15], listen to radio telemetry from deep space probes.

It is, however, not at all clear, even now, how Marconi's spark signals managed to get across the Atlantic, from Cornwall in England (at Poldhu on the Lizard Peninsula) to St. John's in Newfoundland, more than 1,800 nautical miles, in the middle of the day. The leading authority, Professor Hugh G. H. Aitken in *Syntony and Spark*, notes the apparently poor propagation conditions, by most modern understandings of the phenomena: "... the transmission times and frequencies were, as later learned, the worst possible in view of propagation conditions on the North Atlantic path." [2]

Daylight does not promote propagation of Marconi's system of relatively low-frequency, long-wave wireless. Marconi himself found this out the next year. Using an inker and coherer for reception, he could no longer

[1] Marconi's story is, of course, well known. See, e.g., Baker, A History of the Marconi Company, [4] and Aitken, Syntony and Spark, The Origins of Radio, [2] at Ch. 5. It is perhaps most accessible in the 1984 illustrated pamphlet from the Maconi Company, compiled by Pam Reynolds, titled Guglielmo Marconi [19].

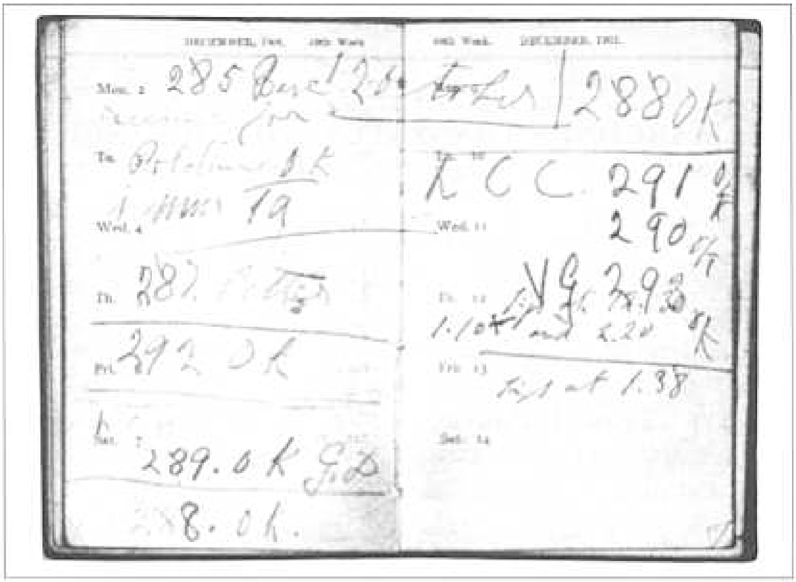


Figure 1. *Page from Marconi's diary for December 12,1901. In it he recorded the reception at Signal Hill of the three dots of the Morse code "S" being transmitted from Poldu in England.*

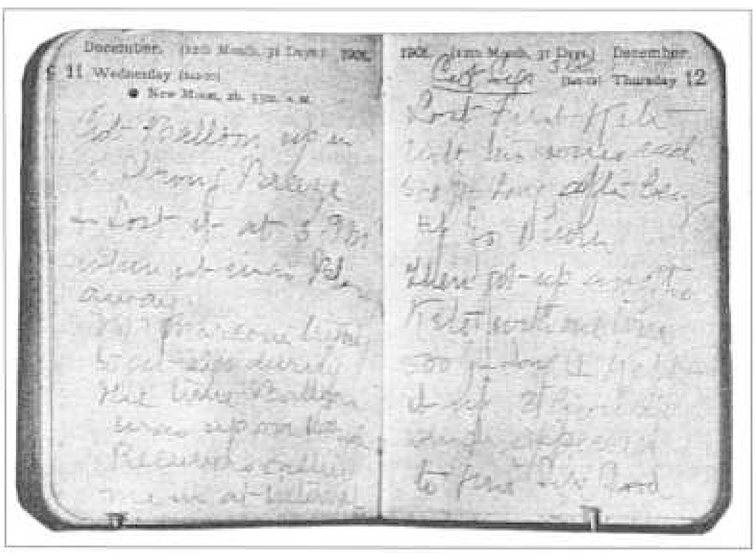


Figure 2. *Pages from the diary of George Kemp, Marconi's assistant, for December 12, 1901, recording the reception of the first transatlantic signals from England; "Got Sigs 3 Dots."*

record signals at sea at 700 miles, as he later recalled in his 1926 article *Looking Back Over Thirty Years of Radio* [14]. Yet, on that same 1902 voyage on the *S.S. Philadelphia,* Marconi replicated the more than 1,800 miles distance from Poldhu to St. John's with shore-to-ship reception, but only at night, reaching out 2,099 statute miles [14, 19]. He had thus first identified what he called this "night effect." Soon enough, higher power and longer wavelength stations regularly crossed the oceans.

Later familiarity with short-wave propagation by reflected sky wave has led to some speculation that perhaps Marconi managed to hear a high-order harmonic of his transmitter's fundamental frequency. This note will look at propagation conditions for the afternoon of December 12, 1901. Those conditions, taken together, suggest that Marconi enjoyed a rare confluence of circumstances. Unusual propagation conditions permitted his first transatlantic signaling on his likely fundamental frequency or close to it. Conversely, higher order harmonic propagation is unlikely.

The first issue is the frequency on which Marconi's Poldhu transmitter (Fig. 6) operated. The very question is misleading. A spark transmitter works by production of a radio frequency hash. This emission centers on a band of frequencies around its inductance- and capacitance-determined resonant-peak frequency. Perhaps the most widely known contemporary explanations of this technology are in Marconi engineer Elmer Bucher's 1917 *Practical Wireless Telegraphy* [6] and the U.S. Navy's *Robinson's Manual of Radio*

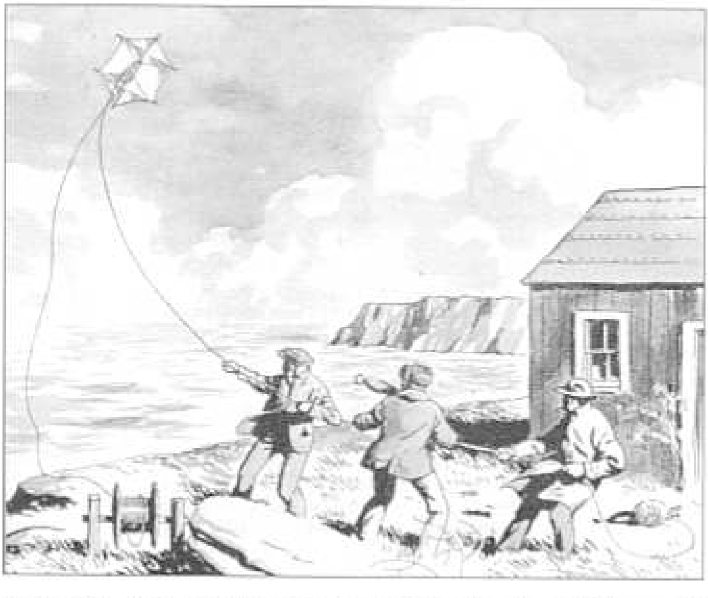


Figure 3. *The antenna supported by the kite at Signal Hill, Newfoundland, used on December 12, 1901 to receive the signals from Poldu.*

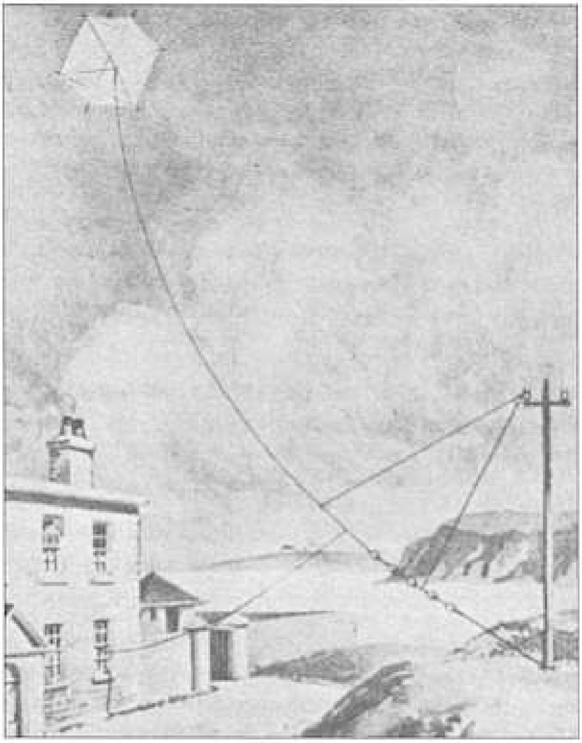


Figure 4. *The station location at Signal Hill, where Marconi set up his instruments for the historic first reception of the transatlantic signals.*

Figure 5. *The 1930s Newfoundland postage stamp showing the Cabot Tower at Signal Hill, St. Johns.*

Telegraphy [20]. The bandwidth of the hash is great, and measured logarithmically in terms of its "decrement" or spread [6]. Moreover, the antenna system often, if not usually, resonated on a different frequency. This "coupling" mismatch resulted in a second peak of a second band of frequencies, usually of a shorter wavelength than the transmitter's peak [20]. Engineers came to call this condition a "double hump" because it looked like a camel's back when graphed [20]. An illustration (Fig. 7) from Bucher's book shows the graphs resulting from close coupling an antenna to a transmitter [6]. It would be only in the period before the First World War that techniques of tuning regularly focused the radio-frequency energy of spark transmitters into a single relatively sharp peak [20]. Marconi enjoyed no such precision in 1901.

Marconi had set up a large antenna array of circular form to put his 25,000 watt spark signal into the ether; an illustration appears in Fig. 8 [16]. A storm took it down shortly before the tests, perhaps providentially. He then put up a jury-rigged antenna of about fifty nearly vertical wires in a narrow fan, illustrated in Fig. 9 [19]. The more fully reconstructed shoreside Poldhu site[2] is also illustrated in Fig. 10 for comparison [12]. It is likely that the resonant characteristics of the new antenna differed significantly from the earlier version, and likely that its resonant frequency was higher, because it was so much smaller [2]. This circumstance lends itself to a

[2] "Poldhu is the name of a small cove on the western side of the Lizard Peninsula, which has become one of the best known places in Cornwall [circa 1912], since the erection of Signor Marconi's telegraph station..." [12]

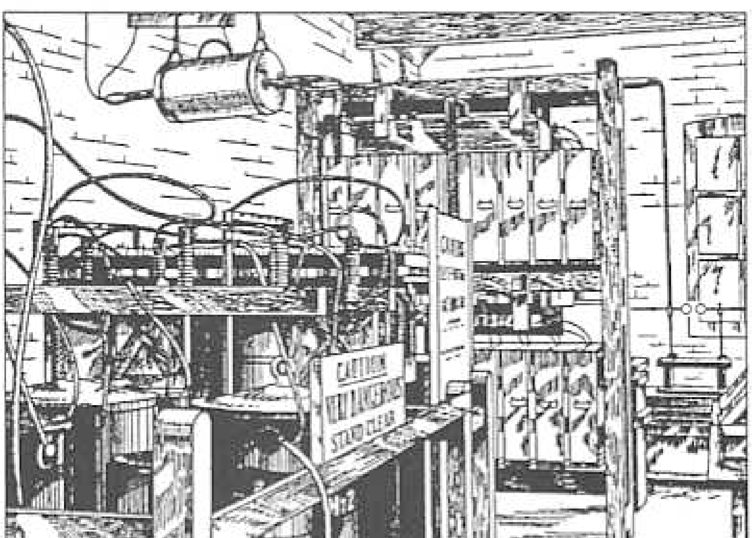


Figure 6. *The transmitter at Poldu in Cornwall, England from which the first transatlantic wireless signals were sent in December, 1901; (after a contemporary photograph, artist unknown).*

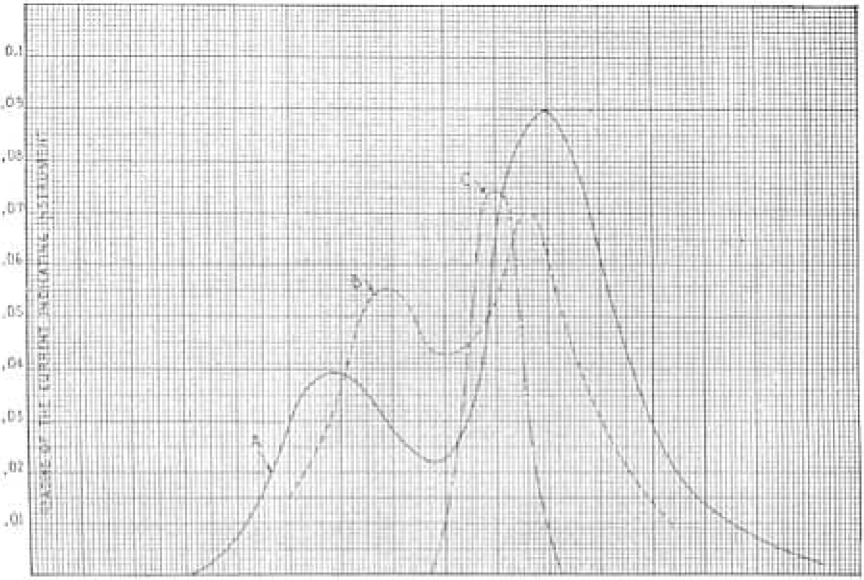


Figure 7. *Graph showing the effect of changing the coupling from the oscillation transformer to the antenna.*

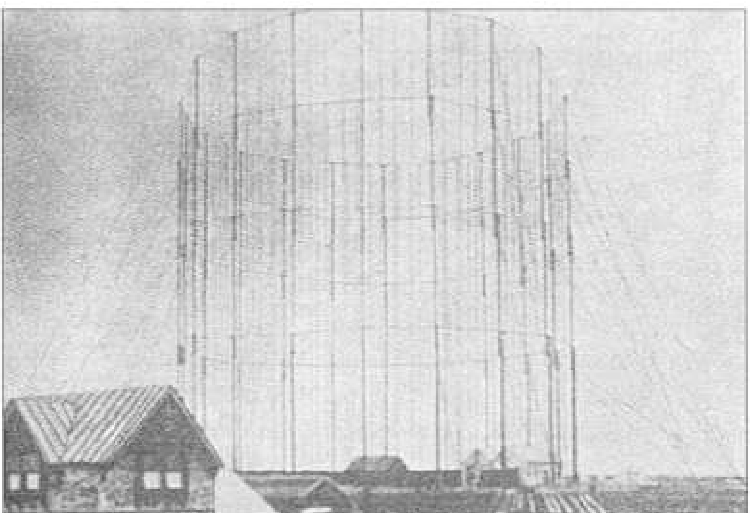


Figure 8. *The large circular antenna structure originally erected at Poldu, Cornwall, for the transatlantic tests.*

second, higher-frequency peak band being transmitted along with a fundamental peak band of frequencies. Moreover, the emitted radio-frequency electromagnetic waves perhaps took on a vertical polarization because of the accidental antenna configuration, which, if maintained, would have been good for reception by the kite wire.[3]

Still, the fundamental frequency is not known. Reports are 820 kilocycles per second (kilohertz, or kHz) (366 meters) and 100 kHz (3000 meters), a full order of magnitude disparity [2]. The 366 meter conclusion is that of H.M. Dowsett, a Marconi engineer at the time [2], as well as Marconi's later, 1908 report [4]. Harmonics and what were later called spurious and parasitic emissions were inherent in the nascent technology. Poldhu's signals were likely all over the ether, what would now be called the radio-frequency spectrum. On the other hand, there was hardly anyone to interfere with (perhaps only Tesla), and no one else "on the air" that winter day. Marconi's receiving circuits tuned very broadly, optimizing the chance of reception.

Engineers use the term "propagation" to describe the processes by which radio signals travel, particularly through the atmosphere. High-frequency propagation is mediated by the state of the ionosphere between the transmitter

[3]This is so because both the temporary transmitting antenna array and the kite-cable receiving antenna were in effect vertically polarized.

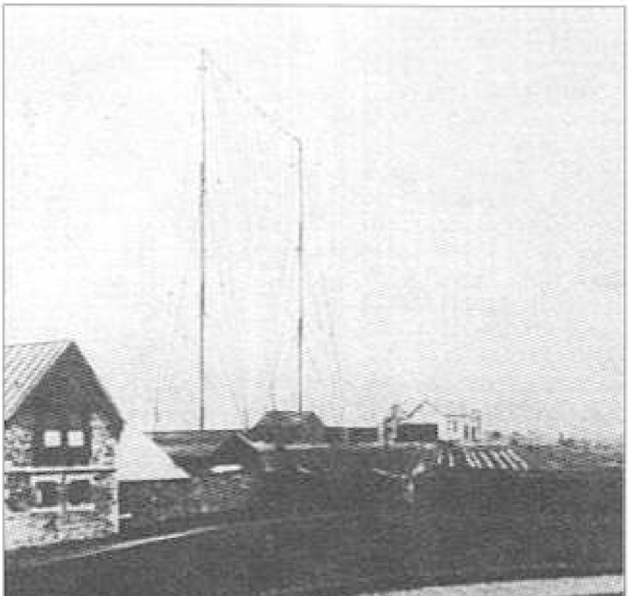


Figure 9. *The fan-shaped vertical antenna erected at Poldu as a replacement for the circular antenna shown in Fig. 7, which was destroyed by a storm.*

Figure 10. Another view of the reconstructed Poldu site, from a postcard.

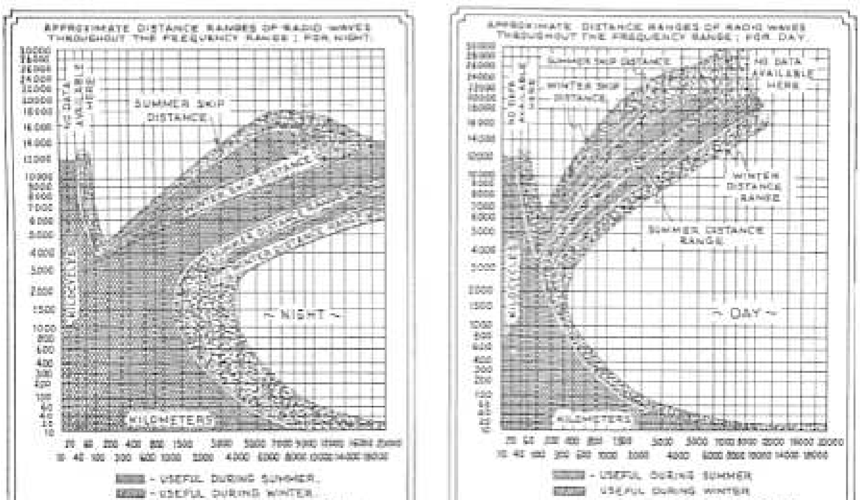


Figure 11. *Frequency vs. distance graphs compiled by the U.S. Bureau of Standards in 1932. Abstracted from* Short Wave Craft, *July, 1932.*

and receiver [5]. Modern concepts such as maximum useable frequency and minimum useable frequency were unknown and unanticipated in 1901. Indeed, they were not initially appreciated for another 25 years. Some of the earliest frequency *versus* distance curves, compiled by the U.S. Bureau of Standards in 1932, appears in Fig. 11 [10]. Marconi himself first came to believe that the longer the wavelength, the longer the distance possible for the same power and antenna height.

This is true enough, as the curves show, but misses the short-wave length, higher-frequency path of ionospheric "skip" propagation to which Marconi turned in the early 1920s, without identification of the physical mechanism. See, *e.g.*, his 1924 article *Results obtained over very long distances by Short Wave Directional Wireless Telegraphy* ... [15]. Physicists Oliver Heaviside and Arthur Kenelly had suggested an ionosphere as early as 1902, but not until 1925 or so was the mechanism of reflection suggested [2]. It was primarily amateur radio operators who explored the 200 meters-and-down "wasteland" to which they had been consigned by law. These radio amateurs first realized the power of these shorter wavelengths to reach great distances, *circa* 1920-'21, according to Professor Aitken (and the American Radio Relay League) [2].

Intensity of ionization in the upper atmosphere depends on the amount of solar (primarily ultraviolet) radiation from the sun. With the coming of darkness the ionized layers, denominated D, E, F, etc., shift and merge. Thus both season and time of day play roles in successful radio propagation.

The amount of ultraviolet radiation depends in turn on the number of sunspots from which the ultraviolet radiation emanates. For several centuries, it has been known that sunspots increase and decrease in approximately eleven-year cycles. Observation shows spots increasing then decreasing

Figure 12. *Sunspot records from a Bell System study, showing the situation in December, 1901. These are measured and computed sunspot numbers from 1800 to 2000 AD. The solid line represents measured values, while the dashed line is a computed projection from the measured values.*

in one hemisphere of the sun, then increasing and decreasing in the other hemisphere of the sun. In times of high sunspot activity, the frequencies useable for ionospheric or "skip" propagation increase. In a good cycle, such as number 19 which peaked in 1957-'58, world-wide, low-power communications as high as 28 mHz (megahertz) (10 meters) and sometimes higher, are common. 1999-2000 is similarly a peak year with sunspots already averaging more than 110.

Conversely, when sunspot numbers are low, only the lower frequencies lend themselves to ionospheric propagation. A sunspot minimum is a good time, for example, for the 160-meter amateur band (1800 kHz) to open up to distant parts of the world. Optimal propagation obtains in a band of frequencies, often between three and thirty mHz, which is higher or lower depending on whether there are more or fewer sunspots. The lower limit is known as the absorption frequency and the upper the maximum useable frequency. Frequencies either side of three to thirty mHz are, however, often useable at the valleys and peaks of the sunspot cycle.

Examination of sunspot records for a century ago shows a nearly unique datum: *on December 12, 1901 the number of sunspots was exactly zero, a dead-low minimum.* It was a transition year between the sun's hemispheres. A chart from a Bell System study appears in Fig. 12 [1]. Solar ionizing radiation on the atmosphere was at a minimum. Thus useable frequencies for skip propagation, bounded at the lower end by the absorption frequency, would be at near absolute minima. A zero sunspot number means ionospheric propagation at the lowest frequencies the band of useable frequencies ever reaches.

This effect was noticed as early as 1931, with the refinement that the more northerly the path, the longer the useable wavelength (i.e., the lower the useable frequency), by as much as a ninety percent increase for upper latitude paths as opposed to 10% for equatorial paths [18]. Nighttime skywave propagation at 800 kHz is common under such conditions, albeit detected on modern high sensitivity receivers.

A Branly metal filings coherer, connected to a direct-current circuit to actuate a landline or marine telegraph inker, is a low-sensitivity device. Marconi, however, used a highly sensitive "Italian Navy" self-restoring coherer, really a mercury oxide detector, a drop of mercury between two conducting rods of iron or carbon. [4] Marconi also listened on a telephone earpiece, rather than employing an inker. He did this deliberately to take advantage of the telephone earpiece's much higher sensitivity, as well as the extraordinary sensitivity of the ear itself. (Within about a dozen years, wireless operators using galena crystal detectors alone, and they were not much more sensitive that the Italian Navy coherer, would copy spark signals occasionally several thousand miles distant.) The historical price Marconi paid in 1901 was the absence of an inker's paper record, a fault he remedied in 1902 on the *S.S. Philadelphia*, but at the price of reduced sensitivity.

The season and time of day also lend themselves to enhanced lower-frequency propagation. December 12 is within 10 days of the winter solstice, leaving the Northern Hemisphere in maximum darkness. At this time of year, the thunderstorms of the tropics and temperate latitudes are farthest away. The likelihood of noise interference is minimum. Through an Italian Navy coherer, lightning-generated random static would not sound like the repetitive pattern of three clicks Marconi and Kemp listened for, the Morse Code "S."

At this depth of winter, the days are shortest as well, minimizing the cumulative effects of solar radiation on the lower, blocking, ionospheric layers. The lower, D, layer results from solar x-rays. It usually blocks reflection or refraction of radio waves or "skip," by the E or F layers above it. The winter D layer would have been relatively weak during the short day, having had less time to build. Moreover, Marconi himself noted in 1924 regarding his 3.25-mHz (92-meter wavelength) tests: "... the intensity of the signals vary... inversely in proportion to the mean altitude of the sun when above the horizon." [15] He is likely reporting a "D" layer phenomenon.

Newfoundland and Southern England are at about 50 degrees North latitude; the arctic circle is at 66.7 degrees North. Winter sunlight at this latitude is very low angle, even at Noon, is well filtered atmospherically and thus also less destructive of nighttime ionization patterns, especially to the North. Marconi noted the effect in his 3.25-mHz short-wave tests of 1924, out to 1,400 miles at sea: "... the signals' intensity is symmetrical to the mean altitude of the sun at all times...." [15]; in other words, the further North, the stronger was the reception.

Day and night come as sunrise and sunset, but from a global perspective, dawn moves around the world followed by sunset. The edge of daylight or darkness is often called the "terminator." It is necessarily a great circle, the light of the sun on a revolving Earth. As the axis of the Earth points towards the sun in summer, the terminator extends up to the far side of the arctic circle (the "midnight sun" phenomenon). Then, in winter, the terminator is tangent to the arctic circle, leaving the polar region without any daily winter sun.

The terminator may be visualized on a Mercator or similar projection map of the Earth as an inverted "U" shaped curve in winter. Radio propagation along the terminator is often enhanced by apparent refraction and long path "ducting." This phenomenon is familiar to amateur radio operators and short-wave listeners as "gray-line" propagation. It is experienced more as a band rather than a sharp line, with signals intensifying, peaking and then diminishing as the terminator approaches and then recedes. On the afternoon

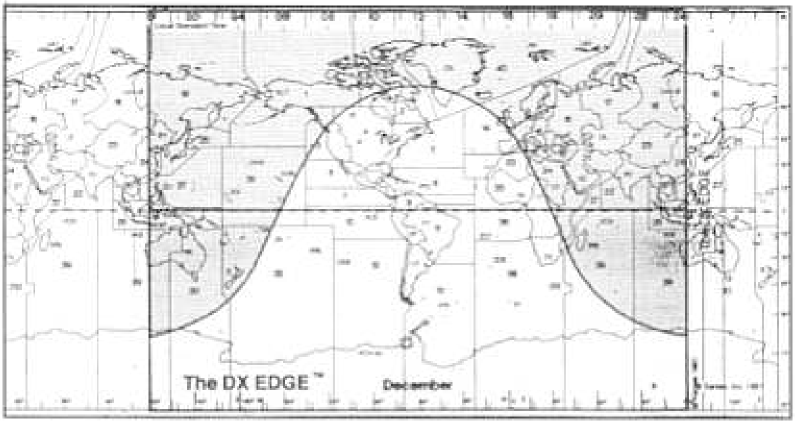


Figure 13. *The DX EDGE™ propagation mapping system for December.*

of every December 12, including 1901, the gray line runs just west of England and well west of Newfoundland. Between 12:30 PM and 2:20 PM both the Poldhu, England transmitter and the St. John's, Newfoundland receiver were within a few degrees of the terminator, with Poldhu on the sunset side. See the accompanying illustration (Fig. 13) using the DX EDGE™ propagation mapping system [9].

Marconi thus enjoyed

1) an optimal solar season of zero sunspots for enhanced lower frequency and daytime propagation,
2) an optimal Winter season of minimal atmospheric noise and as well as enhanced daytime propagation, and
3) a good time of day at his latitude for gray line propagation.

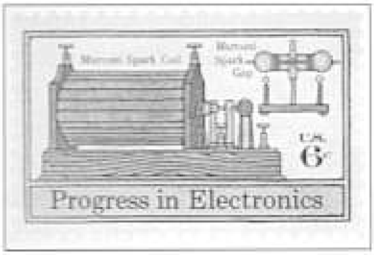
That Marconi heard the three clicks of his coherer in his telephone receiver earpiece has always been a matter of faith in the integrity of the man [2, 4], true enough borne out by all later successes. Yet Marconi could hardly have chosen a better time or place to make his attempt, knowing as he did that the human ear is a very sensitive instrument.

Recent work on radio propagation suggests the importance of these aspects of Marconi's triumph. In 1991 a group of experimenters traveled to St. John's, Newfoundland in November to listen for distant signals ("DX") in the broadcast band, 500 kHz to 1600 kHz, or roughly 600-meters to 200-meters wavelength, bracketing Marconi's likely 366-meter wavelength and 820-kHz frequency. With modern receivers and long-wire Beverage antennas, and despite auroral interference, even low-power stations in Europe, South America and Africa provided "a tidal wave of transatlantic DX" to the radios at St. John's, confirming that "the best medium wave location is next to the ocean." [8].

Figure 14. *Face of a present-day French phone card imbedded with a silicon chip, showing Marconi.*

Figure 15. *Face of a 2000 lira Italian banknote, commemorating Marconi.*

Figure 16. *The 1973 US postage stamp, showing the Marconi apparatus.*



Recent research also suggests that at lower frequencies (circa two mHz) signals from a transmitter newly within the sunset terminator may be enhanced for a receiver on the other side of the terminator [7], which was the situation between England after sunset and Newfoundland, between local 12:30 PM and 2:20 PM, at 50 degrees North in December. This is sometimes attributed to the temporary formation, just behind the terminator of an "F layer" in the ionosphere, providing a reflecting or refracting surface for low frequencies across the terminator into the areas not yet in sunset or darkness [7]. Such conditions, if indeed they did obtain on December 12, 1901, would have provided yet another etheric facilitation of the one skip needed by Poldhu's three dots to get the 1800 miles to St. John's and into history.

Marconi's achievement is still celebrated in many ways: two of the most interesting are a French "phone card" (Fig. 14) with a silicon chip on it [11], and on Italian money (Fig. 15) [3]. The United States Postal Service also honored Marconi in 1973 (Fig. 16) [21].

Sources and Notes

[listed alphabetically, inner citations also alphabetical]:

1. Anderson (C. N.), *A Representation of the Sunspot Cycle*, Bell Telephone System Radio Monograph B-1139 at 6; also XVIII Bell System Technical Journal 292 (April, 1939). The exact sunspot number of *zero* for December, 1901 is available from the NASA archive: www.science.nasa.gov and most specifically, http://science.msfc.nasa.gov/ssl/pad/solar/greenwch/spot_num.txt
2. Aitken, Hugh G. H., *The Continuous Wave — Technology and American Radio, 1900 - 1932*, John Wiley & Sons, 1976; Princeton Univ. Press, 1985;

Amateur priority on short waves, at 512 and n. 53

Syntony and Spark — The Origins of Radio, John Wiley & Sons, 1976; Princeton Univ. Press, 1985

Dowsett, at 296 in n. 89; Baker [4] says Marconi agreed, at 71 fn.
Integrity of Marconi, at 295 at n. 86, citing [4] Baker at 71
Ionosphere and reflection, at 243
Marconi, Chapter 5 at 179ff
Propagation at its worst, at 295 in n. 86; *accord* Baker [4] at 71
Smaller wire array antennas resonate at higher frequencies, at 267
Wavelengths for 1901 test, at 269

3. Banca D'Itala, *Duemila Lire* (2,000), October, 1990. Marconi's yacht *Y.S. Elletra*, a magnetic detector and a four tower wireless station appear on the reverse. Marconi also appears on the obverse of two Italian coins.
4. Baker, W. J., *A History of the Marconi Company*, London, Methuen & Co., 1970, New York, St. Martin's Press, 1971

Integrity of Marconi, at 71
Italian Navy coherer, at 68
Propagation at its worst, at 71

But was the coherer in Newfoundland self-restoring? "Suddenly, there sounded the sharp click of the 'tapper' as it struck the coherer, showing me that something was coming" Marconi is reported to have recalled later. See Giancarlo Masini, *Marconi*, 1976, [translation in English, 1995, Marisilio Publishers, New York], at 158, quoting unsourced but apparently written "recollections" of Marconi of the events of December 12, 1901.

5. Brown (Robert R.), *A Brief History of Ionospheric Studies*, Fine Tuning's Proceedings, 1994-1995, at P6.1ff; see also Ian Poole, *Radio Waves and the Ionosphere, QST* Magazine (November, 1999) at 62.

6. Bucher, Elmer E., *Practical Wireless Telegraphy*, Wireless Press, 1917
Decrement §169 in Part XI Practical Radio Measurements, at 200
"Double hump" graph of wavelengths, at §182 at 219
Marconi engineer, title page, at [i]

7. Clark (David) and John Bryant, *Additional Notes on Tropical Band Propagation*, Fine Tuning's *Proceedings*, 1991, at P4.1ff

8. Connelly, (Mark; WA1ION), *The Newfoundland 1991 Medium Wave DXpedition*, Fine Tuning's *Proceedings*, 1992-1993, at F32.1ff

9. DX EDGE™ copyright Xantek, Inc. 1981 using the Miller Cylindrical Projection and a different sliding terminator overlay for each month of the year

10. [Editors], How Far on What K-C [kilocycle, kHz]? *Short Wave Craft*, July, 1932, 160. This graph exactly predicts Marconi's 1902 night distance of 2,000 some odd miles, assuming a frequency of 800 kHz and comparable sensitivities in receivers

11. France Telecom, *Télécarte 50*; Guglielmo *Marconi* (1874-1937), *Les Grandes Figures Des Telecommunications*, which goes on to say, in French, that Marconi "... primed the birth of wireless telegraphy [*la TSF*] by copying his first signals in 1896 [and that] in 1901, he sent the first radiotelegram between England and the New World"

12. Gilette (artist), painting of Marconi Telegraph Station and Poldhu Hotel..., Tuck's Post Card No. 7740, circa 1912

13. Lee (Manning DeV.) (artist), drawing of kite lofting, in Joseph Cottler, *Marconi*, Calif. State Department of Education, 1956, at 28

14. Marconi, Guglielmo, Looking Back Over Thirty Years of Radio, *Radio Broadcast*, November, 1926 at 28
700 and 2200 miles on *S.S. Philadelphia*, at 29 (see also LXX Proceedings of the Royal Society, June 12, 1902)
Kemp's calendar, at 29

Marconi's earliest theory of propagation may be found, curiously, in a 1901 story by Rudyard Kipling titled "Wireless" in *Mrs. Bathurst and Other Stories* (ed. Lisa Lewis, in The World's Classics, Oxford, 1991 at p. 23). Marconi had visited Kipling at his home in 1899 and explained how signals penetrated the ether. Kipling opens his story with dialogue starting "It's a funny thing, this Marconi business, isn't it?" Later, he quotes the wireless operator. "Grand, isn't it? That's the Power — our unknown Power — kicking and fighting to get loose," said young Mr. Cashell. "There she goes — kick — kick — kick into space..." I am indebted to Professor Thomas Gavin for his insight and initiative in making this material available to me.

15. Marconi, Guglielmo, *Results obtained over very long distances by Shortwave Directional Wireless Telegraphy more generally referred to as The Beam System* — paper read at the Royal Society of Arts on the 2nd July, 1924 by Senator Guglielmo Marconi... Reprint from the Journal of the Royal Society of the Arts [privately, presumably for the Marconi Company]

Altitude of the sun, at 6 (seasonal), 8 (daily)

Parabolic reflectors, at 4, Fig. 3

It was Marconi's deep conviction that the explorer of a new technology should always reach beyond the limits suggested by the "experts" of the day, and not permit such expertise to constrain experiment or ambition.

16. McNichol, Donald, *Radio's Conquest of Space*, Arno Press reprint, 1974 of Murray Hill Books, 1946

Poldhu circular antenna, illustrated at 138

Kite antenna, illustrated by an unidentified artist, attributed to Radio Corporation of America, at 140.

17. Newfoundland [Postal Authority], 1937 green nine-cent postage stamp of Cabot Tower on Signal Hill, noting: "First Trans-Atlantic Wireless Signal Received [in] 1901"

18. Noack, (F.), How Sun Affects S-W [Short Wave] Reception, *Short Wave Craft*, December, 1932, 400 at 507

19. Reynolds, Pam, *Guglielmo Marconi*, The Marconi Company, 1984.

Jury rigged fan antenna, at 9, item 21(photo); Baker [4] says 50 wires, at 66, Fig. 6.2 but the photo suggests fewer

Marconi's calendar, at 10, item 22

S.S. Philadelphia 1902 tests, at 10, items 23, 24

20. Robinson, Capt. S.S., Capt. D. W. Todd, and Cmdr. S.C. Hooper, *Robinson's Manual of Radio Telegraphy and Telephony ...*, Annapolis, U.S. Naval Institute, 1919

Graphs of double hump wavelength emissions,
at 242 see Fig. 135, and at 250 see Fig. 139

Humps of differing wavelengths, at 238

Shorter wavelength for second hump, at 238

Tuning for sharp peaks, at 239ff

21. United States Postal Service, six-cent multicolor postage stamp of the 1973 series (of four) denominated "Progress in Electronics," designed by Walter and Naiad Einsel, illustrating a Marconi induction coil and an early spherical spark gap

[END]