DOI. No. 10.1109/MAES.2017.160076

Historical Article:

Coltano: The Forgotten Story of Marconi's Early Powerful Intercontinental Station

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INTRODUCTION

> *"There, do you see Admiral?" Marconi stated. "On that far plain, behind Leghorn, a large Italian radio station could be built, even larger than the British station in Poldhu." [1].*

On September 8, 1902, at the dawn of the wireless telegraphy age, Marconi was looking at the Tuscan coast from the cruiser "Carlo Alberto," back from a long trip where he successfully carried out many radio experiments in the northern seas. While passing in front of Leghorn, Marconi expressed to the Admiral Mirabello his intention to build a powerful intercontinental station in the plain behind that city. The station, which would be the first in Marconi's home country (and one of the first in the world, too), was intended to provide radiotelegraphic connections with Africa and America in the very low-frequency (VLF) band, i.e., using carrier frequencies below 100 kHz, which, at the time, were believed to be the sole option for long-distance radio communications.[1]

The selected site for this purpose was Coltano, a marshy rural area between Pisa and Leghorn, near the Tyrrhenian Sea (Figure 1). The station was inaugurated by Marconi himself in 1911 with transmissions to Clifden (Ireland) and Glace Bay (Canada) (Figure 2), followed by a pioneeristic link reaching Massawa (Eritrea), across more than 2000 km of Sahara's dry soil; which, until then, was considered an insurmountable obstacle for the propagation of low-frequency ground waves. This was just the first of a series of successes obtained by this once worldwide renowned, but now completely forgotten, radio station, born from Marconi's genius.

[1] Though the standard definition of VLF band refers to the range 3–30 kHz, for simplicity in the following we denote as VLF the whole frequency interval below 100 kHz.

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Manuscript received March 23, 2016, revised July 13, 2016, and ready for publication July 23, 2016.
Review handled by M Greco.
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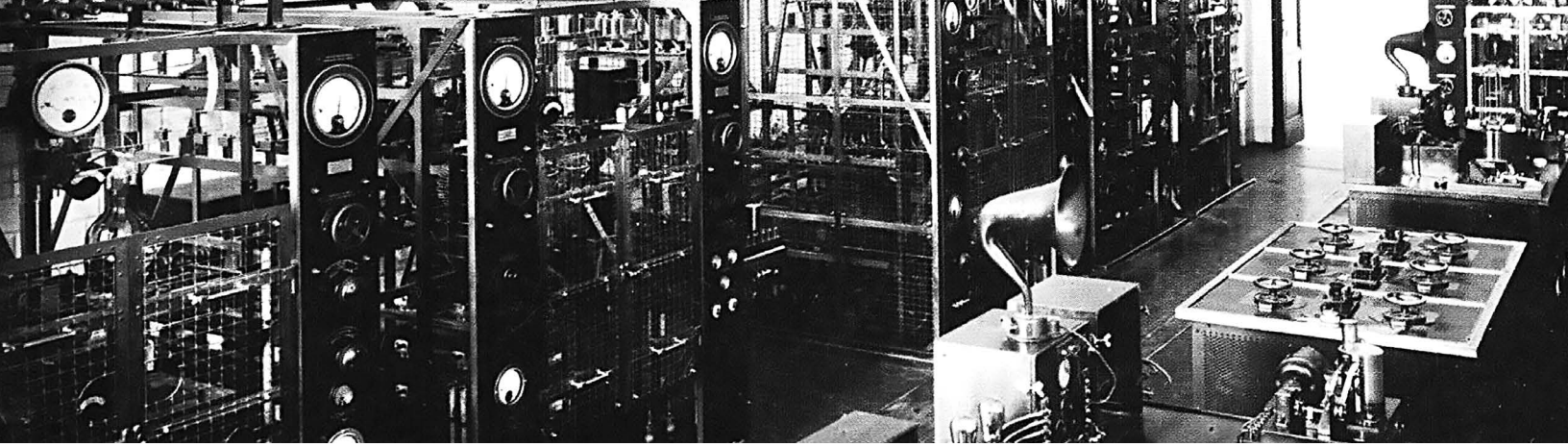
CONCEIVING A NEW POWERFUL INTERCONTINENTAL RADIOTELEGRAPHIC STATION

In September 1902, after the successful validation of his wireless transmissions across the Atlantic and a subsequent extensive test campaign carried out in the North Sea and the Baltic Sea on board the "Carlo Alberto" cruiser of the Italian Royal Navy (IRN), Guglielmo Marconi expressed his intent to build a powerful intercontinental radiotelegraphic station in Italy. Such a decision did not stem from a sudden intuition of the great scientist, but rather was the first step of a strategy that was devised by Marconi's Wireless Telegraph Company for a commercial expansion in Italy. This is clearly testified by a document conserved in the Marconi's Archives of the Bodleian Library, at the University of Oxford, dated August 25th, 1902, wherein Guglielmo Marconi is appointed as the company's representative in *"the negotiations with the Government of the Kingdom of Italy [...] for the erection, establishment and maintenance [...] of a high power Marconi station for the purpose of reception and transmission of messages by means of the Marconi system of wireless telegraphy."* [2].

The original intent of Marconi, as illustrated to King Vittorio Emanuele III, was to build a radio station capable of connecting Italy with South America (see [3, pp. 109–110]), which hosted a large number of Italian emigrants. However, this goal was soon abandoned, probably because of the technical difficulty of a wireless transmission over such a huge distance. The station was then proposed with the aim of providing radio links with North America and the Italian colonies in East Africa. Being conceived for intercontinental services, this new radio station belonged to the category of so-called "ultra-powerful stations." In 1903 there were only three operational ultra-powerful stations: one in Britain, one in the U.S. and one in Canada ([3, p. 101]).

Coltano, a swampy rural area about 10 km south of Pisa, in Tuscany (Figure 1), was the selected site due to a number of favorable factors, listed in Box 1. One outstanding feature orienting Marconi's choice was the high electrical conductivity of Coltano's damp soil which allows ground waves to glide along the surface of the Earth, especially at lower frequencies, thus easing the propagation of radio signals (see [4, ch. V, sec. 11], and [5]). The map in Figure 3 illustrates the electrical conductivity of the soil in Tuscany, obtained from a nation-



wide measurement campaign carried out in 1948 by the Italian public broadcasting company (RAI) [6]. As apparent from the map, the area south of Pisa exhibits a conductivity (denoted as σ) as high as 60 mS/m. See Box 2 for a better understanding of the transmission benefits provided by the highly conductive soil. Apparently, even without the aid of this postwar map, Marconi found the best place for his antennas!

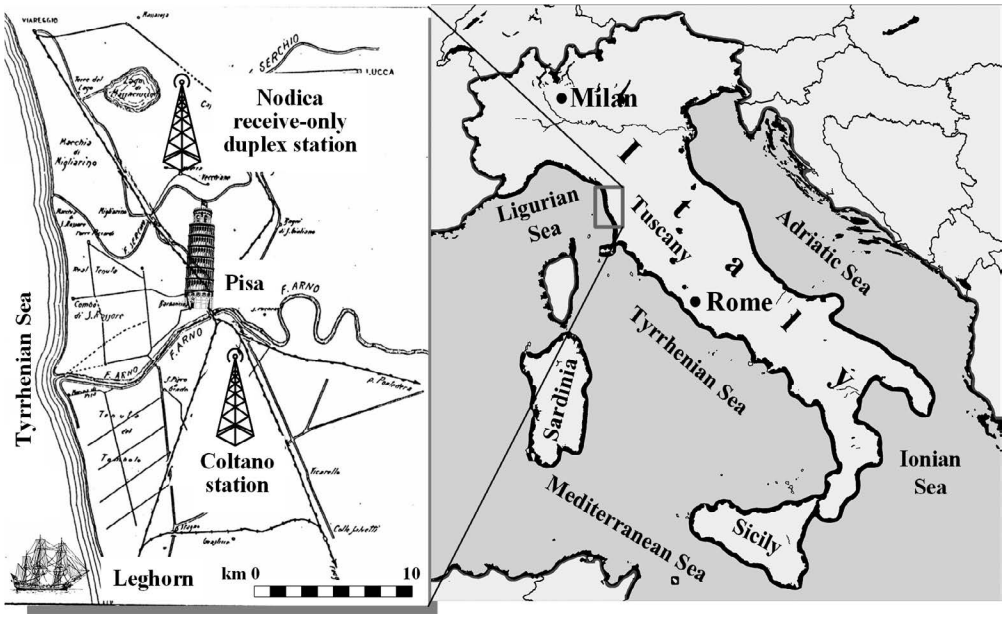


Figure 1.
Location of Coltano transmit site in the Italian peninsula.

Figure 2.
Radio links established during the inauguration of Coltano radio station, Nov. 19-20, 1911.

Box 1

Why did Marconi choose the Coltano site?

- Coltano is a flat and scarcely populated area.
- Its wet soil has a high electrical conductivity, which eases the radiation of ground waves, especially at VLF.
- It is located near the Tyrrhenian Sea's shoreline, in a very favorable position for communications with Italian colonies in Africa and with the Americas.
- It is located almost halfway from Rome, Italy's capital, and Milan, Italy's main industrial city, and it could be easily connected to both of them via terrestrial telegraph lines.
- Nearby cities, Pisa and Leghorn, have good connections with the rest of the country.
- Leghorn hosts the IRN's Academy.
- The Coltano area was an estate of the King of Italy, Vittorio Emanuele III, who enthusiastically agreed to make it available for Marconi's project.
- In his youth, Marconi spent some periods in Leghorn, where, at the age of 14, he took lessons on electrical science from Prof. Vincenzo Rosa. Thus, Marconi was quite familiar with the area between Leghorn and Pisa.

Box 2

How does the soil conductivity influence the ground wave coverage of a radio transmitter?

The benefits of the highly conductive soil on the transmission of radio signals can be quantified by the "range factor" (ρ) for ground waves [10], which is graphically illustrated in Figure 4, where the transmitter (Tx) operates at frequency f, with power P and antenna gain G, and the receiver (Rx) has sensitivity S. First, let us assume that, given f, the set of parameters (P, G, S) is such that over a soil with conductivity 1 mS/s (dubbed the "reference" scenario) the received signal level is S for a Tx-Rx separation D_{ref} = 10 km (Figure 4a). In the case of propagation over a soil with generic conductivity σ the received signal level will be S for a Tx-Rx separation D, also termed transmitter's "range" (Figure 4b), and the range factor is defined as $\rho = D / D_{ref}$. Figure 5a (from [10]) shows the values of ρ relevant to Coltano for f =2, 5, 10 MHz, and Figure 5b plots ρ vs. f.

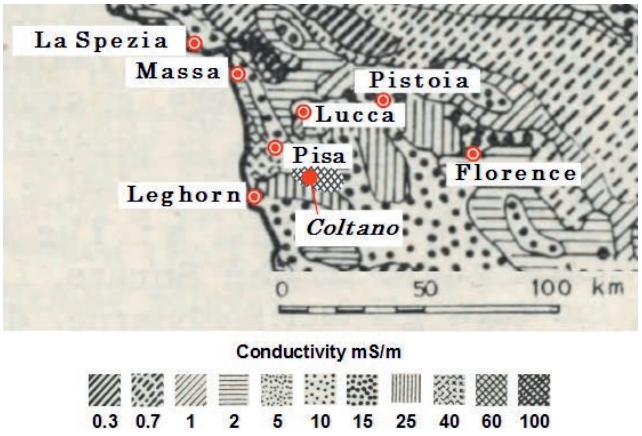


Figure 3.
Electrical conductivity of the soil in Tuscany (from [6]).

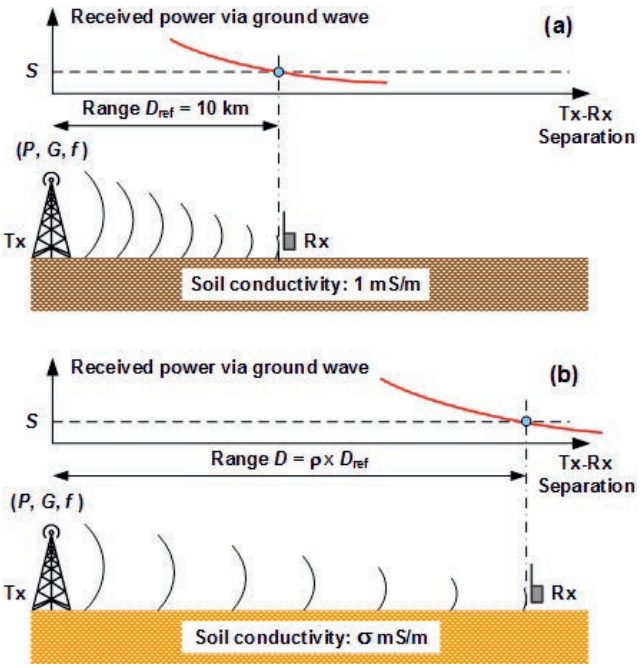


Figure 4.
Graphical definition of the range factor ρ for ground waves.

BIRTH AND INFANCY OF COLTANO STATION: THE MARCONI ERA

In 1903, the Italian Parliament approved Marconi's initiative for the construction of the radiotelegraphic station in Coltano and passed a bill providing the financial support, which amounted to 800,000 Italian Lira[2] [3]. Then, Marconi visited the site a few times in 1903–1904 to select the most appropriate location for the radio station. The design included a main building, which was to host the transmitter together with the relevant control equipment, and a couple of long horizontal-wire antennas: one for links with North America and one for East Africa.

[2] Roughly 3,500,000 Euro in 2016 [7].

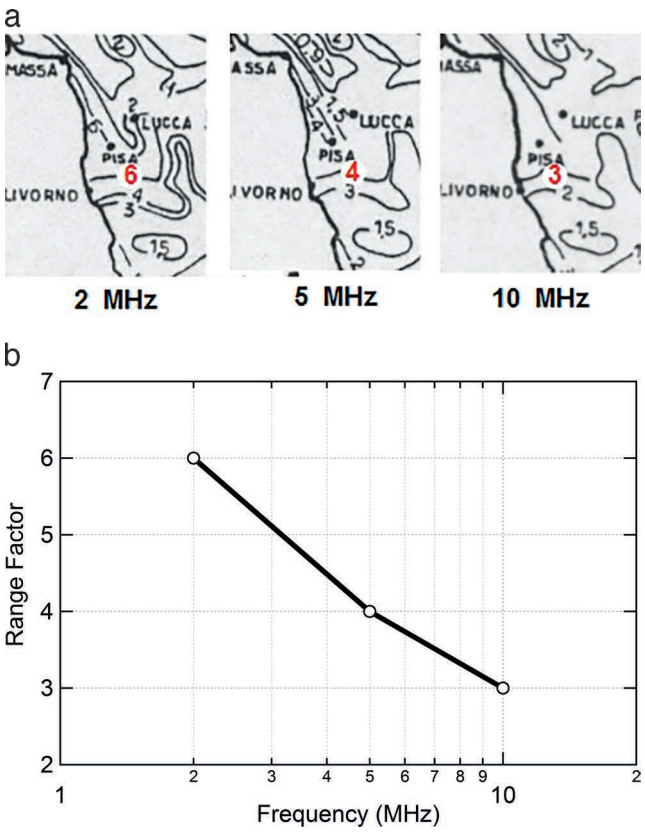


Figure 5.
(a)Values of the range factor ρ (in bold red) for ground waves radiated from Coltano at different frequencies (from [10]). (b) Range factor ρ vs. frequency for ground waves radiated from Coltano.

The construction started in 1905 under the supervision of Marquis Luigi Solari, Marconi's most trusted assistant. The work, however, proceeded at a slow pace due to workers' strikes [8], but mainly due to the harsh and wet environment that caused the station's wooden roof to rot and metal structures to rust, so impairing the stability of the high antenna towers. The photo in Figure 6a shows Marconi (fifth from left) in front of the station building, almost completed, during a visit on June 6, 1910. The building was completed in October 1910 (Figure 6b) and was named "Palazzina Marconi" (Marconi's House). The whole station, depicted in the bottom-left part of the plan in Figure 7 (from [9]), was ready in November 1911.[3]

The Palazzina Marconi (labelled "1" in Figure 7) hosted an asynchronous rotary spark gap transmitter, like that available in the Clifden station (Ireland) [11], [12]. Coltano's transmitter operated at 43 kHz (7000 m wavelength) [11], [13], and fed two VLF bent antennas (labelled "7" and "8" in Figure 7), whose design concept is described in Box 3. The power consumption of the station was about 300 kW [14] and the transmit power is estimated to be 14 kW [15].

[3] It is worthwhile to notice that the Palazzina Marconi in Figure 6a (dated 1910) has a roof terrace with a balustrade, while in Figure 6b (dated 1911 or later) it exhibits a hip roof. This modification was adopted on-the-fly during the final phases of the construction in order to provide better protection against humidity.

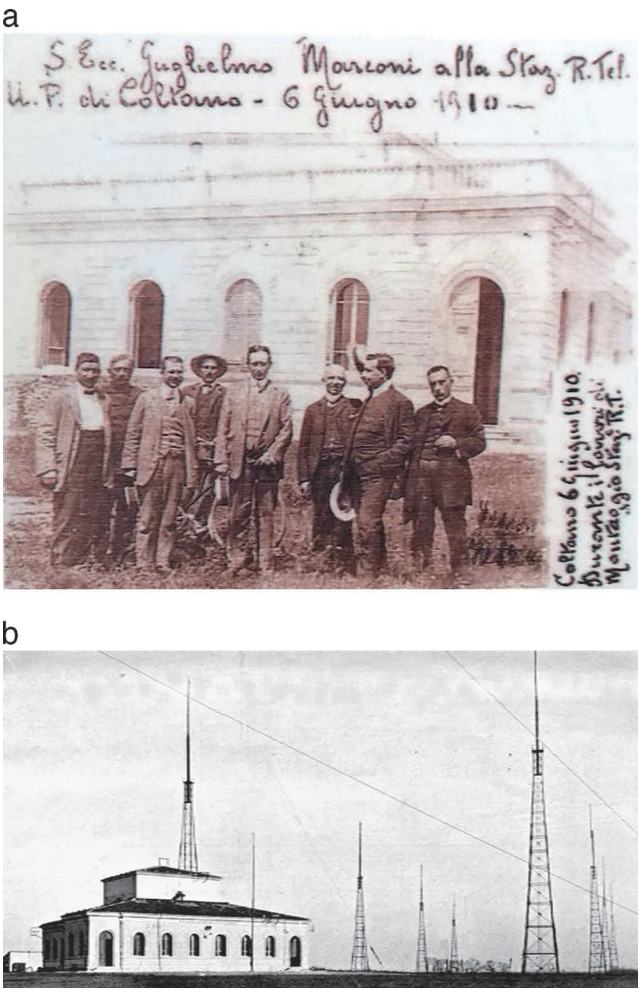


Figure 6.
(a) Marconi (fifth from left) in front of the Coltano station building on June 6, 1910. (b) The Palazzina Marconi (old radio) and the 8 pylons of the VLF continental aerial.

Each VLF antenna extended for 530 m and had 4 pairs of towers with transversal riggings that suspended 24 horizontal parallel wires. Each of the 8 towers was made of a 45-m high trellis (somehow resembling the Eiffel Tower), surmounted by a 30-m high wooden mast, so that the antenna wires hang at 75 m above the ground. A special team of skilled sailors of the IRN was engaged for working at such a considerable height during the installation and maintenance operations. In the illustration in Figure 6b the Palazzina Marconi and the 8 Eiffel Tower-like pylons of the so-called continental aerial are depicted. Each VLF bent antenna had a natural wavelength of about 3000 m, a static capacitance of 17 nF, and, for a wavelength of 5800 m (corresponding to 51.7 kHz), the impedance was about 5 Ω [9].

In November 1910, some tests were carried out [20]. First, on Nov. 13, 1910, at 12:00 p.m., a test signal (not a telegram) was transmitted from Coltano station, which was not yet completed at this time, and was clearly received by the Marconi station in Glace Bay (Canada), 5360 km away, and by the newly-built Italian colonial station in Massawa (Eritrea), 4160 km away. The result was impressive since the experiment was per-

1. – Marconi's station for colonial and continental services
2. – Barrack
3. – Garage and storage facility
4. – Non-commissioned officers quarter
5. – Officers quarter
6. – Vallauri's station for trans-continental service
7. – Aerial for colonial service
8. – Aerial for continental service
9. – Aerial for trans-continental service

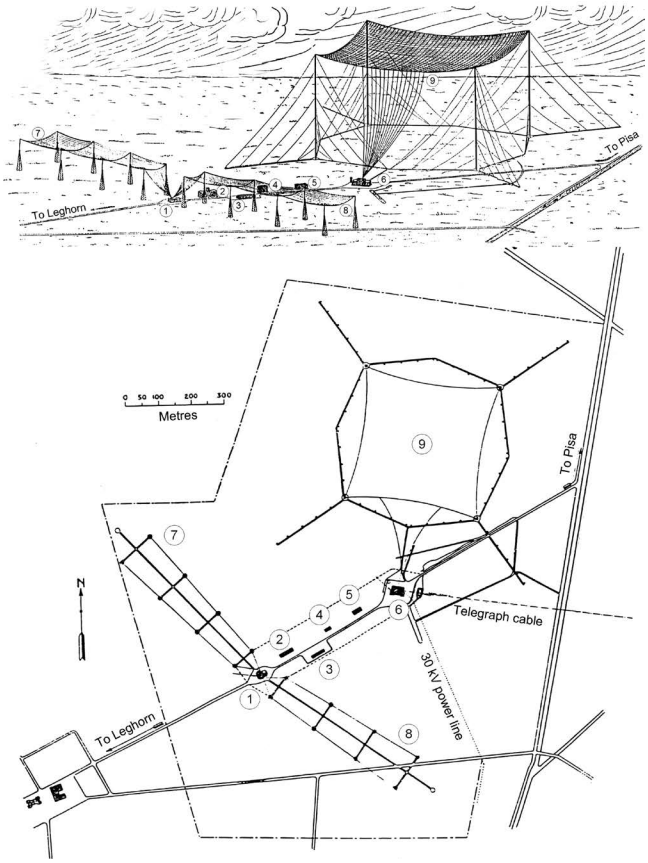


Figure 7.
Sketch and plan of the Coltano radio center in 1923 [9]: Marconi's 1911 station (1) and two VLF bent antennas (7), (8); Vallauri's 1923 station (6) and the VLF curtain antenna (9).

Box 3

Marconi's bent antennas: directive or deceptive?

Since the early 1900s Marconi began experimenting on antenna structures capable of concentrating the radiation in a narrow sector [11]. During an experimental campaign carried out in 1904 in some coastal sites of the British Islands [16], Marconi verified that, for frequencies below 2 MHz, a bent antenna like that in Figure 8, has a directional behavior [17]. In 1905, he promptly patented this new antenna [18]. The radiation pattern depicted in Figure 8, from [17], was derived using a 60 m-long bent antenna at 600 kHz (500 m wavelength). A couple of such bent antennas were thus installed in Coltano (Figure 9): the Colonial Aerial ("7" in Figure 7) was aimed at Massawa (Eritrea) (Figure 9a), and the Continental Aerial ("8" in Figure 7) was aimed at Glace Bay (Canada) (Figure 9b). (The name, "Continental Aerial," was assigned later in the 20s, when this aerial was only used for links toward West Europe.) It is worth noting, however, that the pattern in Figure 8 was measured 260 m (about half wavelength) far from the transmitter, i.e., in the near-field region (which was a concept not yet understood at the time). Therefore the "eight-shaped" directive pattern in Figure 8 is not valid for long-distance communications. In this connection, Professor Ambrose Fleming [19] analytically confirmed the directivity feature discovered by Marconi, but also remarked that "*theory points to the fact that at extremely large distances the asymmetry [of the radiation pattern w.r.t. the isotropic one] tends to vanish, and that any bent oscillator has no asymmetry of radiation [i.e., directive behavior] for very large distances.*" [4].

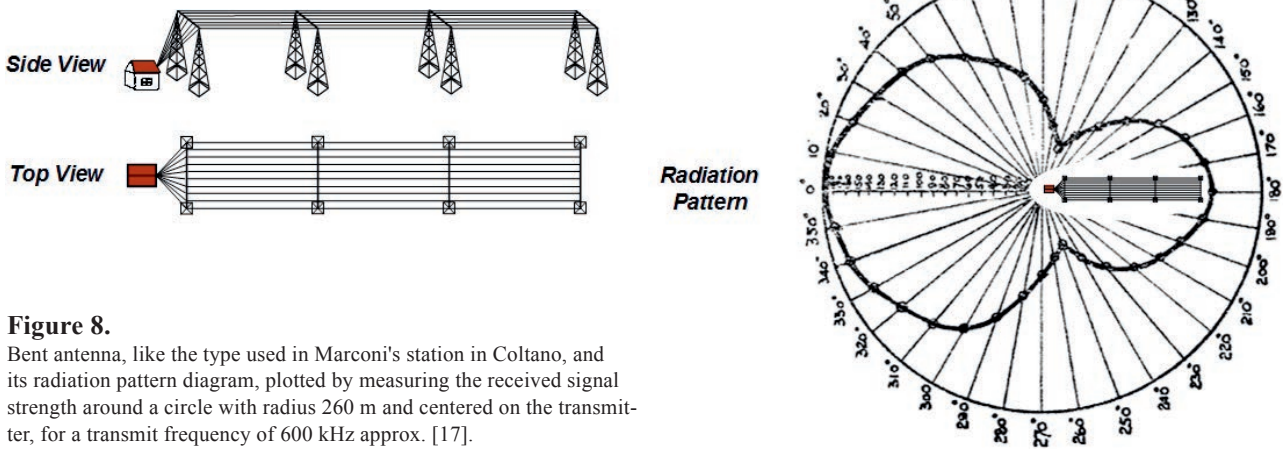


Figure 8.
Bent antenna, like the type used in Marconi's station in Coltano, and its radiation pattern diagram, plotted by measuring the received signal strength around a circle with radius 260 m and centered on the transmitter, for a transmit frequency of 600 kHz approx. [17].

formed during daylight, i.e., the most unfavorable conditions for radio propagation. Further tests were carried out in the night at 12:00 a.m. and gave even better results. On the evening of the next day, Marconi himself attended a final session of tests in Coltano, in the presence of the King Vittorio Emanuele III. Massawa station acknowledged the reception of the test signal, and sent back a wireless telegram to Coltano using a carrier wavelength of 6000 m (50 kHz) [21]. That evening, Gino Montefinale[4] (Figure 10), then a young IRN officer and a brilliant radio engineer, was on a ship in Massawa's harbor and noted in his diary [22] that the high pitched hiss and the purplish lightning generated by the transmit equipment were clearly detectable from a distance of 2 km! At the end of the tests, the King enthusiastically congratulated Marconi on his outstanding achievement.

One year later, on Nov. 19, 1911, again in the presence of the King, Marconi successfully inaugurated the station by sending the following telegram to the Director of the New York Times: *"My best greetings transmitted by wireless telegraph from Italy to America. G. Marconi. Pisa 5.47 p.m."* [13]. The message was transmitted from Coltano to Glace Bay (Canada), and was relayed to New York via land lines. Another telegram was sent to Clifden station (Ireland), 1850 km away. The acknowledgment of message reception was sent back to Coltano via land and submarine cables. A report on these inaugural transmissions can be found in the newspaper excerpts collected in [3, pp. 110–112]. Then, at 2 a.m. of Nov. 20, 1911, a further telegram was sent to Massawa. In this way, the Coltano station became a sort of "gateway" providing interconnection between the wired telegraphic network connecting mainland Italy and its African colonies. Transmission experiments terminated at 6 a.m. and were all successful, despite the unfavorable weather conditions [23].

In a speech held in Rome in 1914 about the progress of radiotelegraphy, Marconi said that, *"even though the station in Coltano had not yet installed the latest improvements in radiotelegraphy particularly appropriate for commercial communications, the signals of that station were clearly received within a range of about 5000 km."* [24]. Some remarkable records set by Marconi's Coltano station are listed in Box 4.

In September 1912, Marconi went to Pisa and visited again the radio station in Coltano; there he met the King and was his guest in the nearby San Rossore royal estate. On Sept. 25, 1912, Marconi left Pisa driving his FIAT 50 HP towards Genoa. In Borghetto Vara, near La Spezia, he had a terrible crash with another car. He was badly injured by windshield fragments from his car and lost his right eye (further details on this accident are reported in [3, pp. 137–138]).

Right after the inauguration, the management of the Coltano radio station, which meanwhile got the call sign *ICI*, was handled by the IRN and this opened a new era for the Coltano station.

[4] Gino Montefinale (1881–1974) was an Italian admiral of the IRN, a radio pioneer and a writer. He is renowned for his active collaboration and friendship with Guglielmo Marconi. In the early 1930s, he designed a renovation of the Coltano transmit site in cooperation with rear admiral Giuseppe Pession, another eminent IRN scientist.

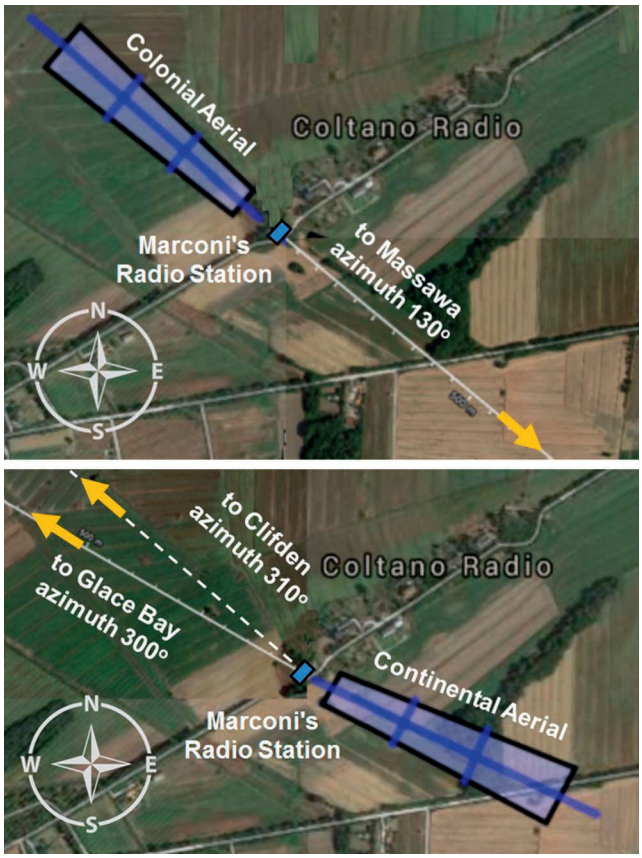


Figure 9.
Aiming of VLF colonial (top) and continental aerials (bottom).

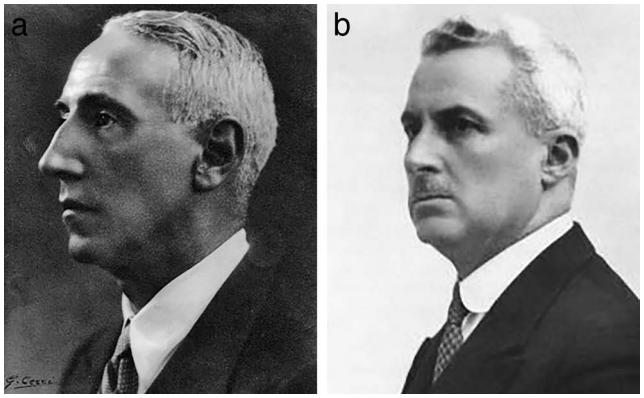


Figure 10.
(a) Admiral Gino Montefinale (1881–1974). (b) Professor Giancarlo Vallauri (1882–1957).

GROWTH AND DEVELOPMENT OF COLTANO STATION: THE VALLAURI'S ERA

Despite the successful inauguration and the effective support to the IRN during Italian military operations in Africa (1911–1912) and during WWI (1915–1918), the Coltano station did not meet the expectations in terms of reliability for regular intercontinental service.

Box 4

Coltano: An outstanding record-setting station.

1. It has been the first intercontinental radiotelegraphic station in Italy.
2. It was considered the "most powerful in the world" (see [25], [26]).
3. On Nov. 19, 1911, the maiden transmission from Coltano to Glace Bay (5360 km away) set a new distance record for wireless communications [25].
4. Assuming a uniform radiation pattern, the distance between the furthest points at which the signals could be received was 10720 km, i.e., more than one-fourth of the Earth circumference.
5. The area around Coltano covered by station's signals was equivalent to about one-sixth of the Earth surface.
6. The transmission from Coltano to Massawa went through more than 2000 km of Sahara and was the first across a desert. This proved wrong the belief that ground wave propagation is impossible over dry (poorly conductive) soil.

So, as early as 1919, the radio station was judged obsolete by the IRN and a more powerful and efficient VLF station was planned for transcontinental commercial service with North America. A renovation of the Coltano radio center was designed and personally supervised by Prof. Giancarlo Vallauri[5] (Figure 11), a prominent scientist and director of IRN's Electrotechnical and Radiotelegraphic Institute, based in the nearby city of Leghorn (see [27, p. 322]). Work started in 1920 and went on smoothly until early 1923, when the Italian Government decided to entrust the management of the new VLF station (referred to as the "new radio") to a private company from 1924. As a consequence, the IRN suspended its commitment and, though the main transmit facility was already operational, some planned upgrades were left unfinished.

The new radio, which is described in great detail in [9], consisted of a main building (labelled "6" in Figure 7 and also shown in Figure 12), which hosted the transmit and control equipment, and a huge curtain-type antenna ("9" in Figure 7), and some subsidiary buildings for the accommodation of the IRN personnel in service at the station and a garage (items labelled "2"–"5" in Figure 7). Following the evolution of radio technology, spark gap technology (like that used in the old Marconi's station) was abandoned in favor of newer and more efficient solutions. So, the station was equipped with a couple of modern VLF transmitters: *i*) a 250 kW transmitter based on a Béthenod–Latour alternator, i.e., a rotating machine which generated a sinusoidal current, to be employed for producing a continuous wave in the VLF band, while fine frequency tuning was carried out via a rotation speed control; *ii*) a 350 kW transmitter, featuring two static Poulsen converters that used an electric arc to convert direct current into a radio frequency continuous wave. Any of the two transmitters, whose nominal frequency was 18.750 kHz (16,000 m wavelength), could be selected to feed a huge curtain antenna (labelled "9" in Figure 7), having a square base with 420 m-long sides, supported by four masts; each one was 250-m high and 80-ton heavy (Figure 12a and b), with a spherical-shaped bottom end. The antenna's pavillon consisted of a net of phosphorous-bronze wires 3.4 mm thick and spaced about 15 m apart from each other. The net was reinforced with steel cables for the outer wires, yielding a total weight of about 4 tons [11]. The radiating pavillon net was linked to the transmitters in the station building by a fan-shaped descent. The antenna was designed so as to provide at least 35,000 meter-ampere,[6] which was the minimum strength of the transmitted signal for establishing the service with North America. Assuming a radiation height of 165 m, the effective current intensity resulted 212 A. Therefore, in order to radiate a signal with wavelength of 16,000 m, using a voltage of 70,000 V, the antenna was designed so as to yield also the required static capacity which amounted to 25 nF.

The four masts were quickly erected in the summer of 1922. The construction of this audacious structure in such a short time represented a formidable challenge that amazes even today. The assembling procedure consisted in raising and putting in place 5 m-high trunks, one by one, for each mast. This was done by using a special platform that was placed on top of the incomplete mast,

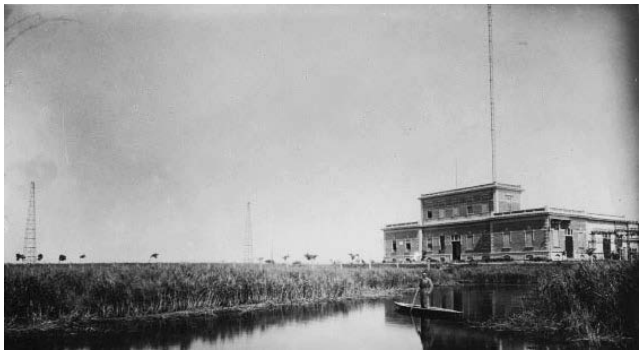


Figure 11.
The new radio. Left: the two 60-meter pylons of the SW antenna (1930); right: the station building (1923) in front of one of the 250-meter masts of the VLF curtain antenna.

[5] Giancarlo Vallauri (1882–1957) was an Italian admiral of the IRN, a researcher in radio electronics and a university professor. In 1916, he founded the Electrotechnical and Radiotelegraphic Institute of the IRN, in Leghorn, and was in office as director until 1926. From 1920 to 1923 he directed the design and construction of the new VLF radiotelegraphic station in Coltano. Later, he was the dean of the Faculty of Engineering at the University of Pisa (1923-1926), the president of the Turin Politechnic, chairman of EIAR (the former Italian public broadcasting company), and of CNR (the National Research Council). Vallauri was also a talented researcher. He achieved fundamental results on ferromagnetism and derived the "Vallauri's equation" for vacuum tubes.

[6] This coefficient, which was once a popular measure of the strength of a radio transmitter, is given by the product between the radiation height of the antenna and the maximum antenna current.

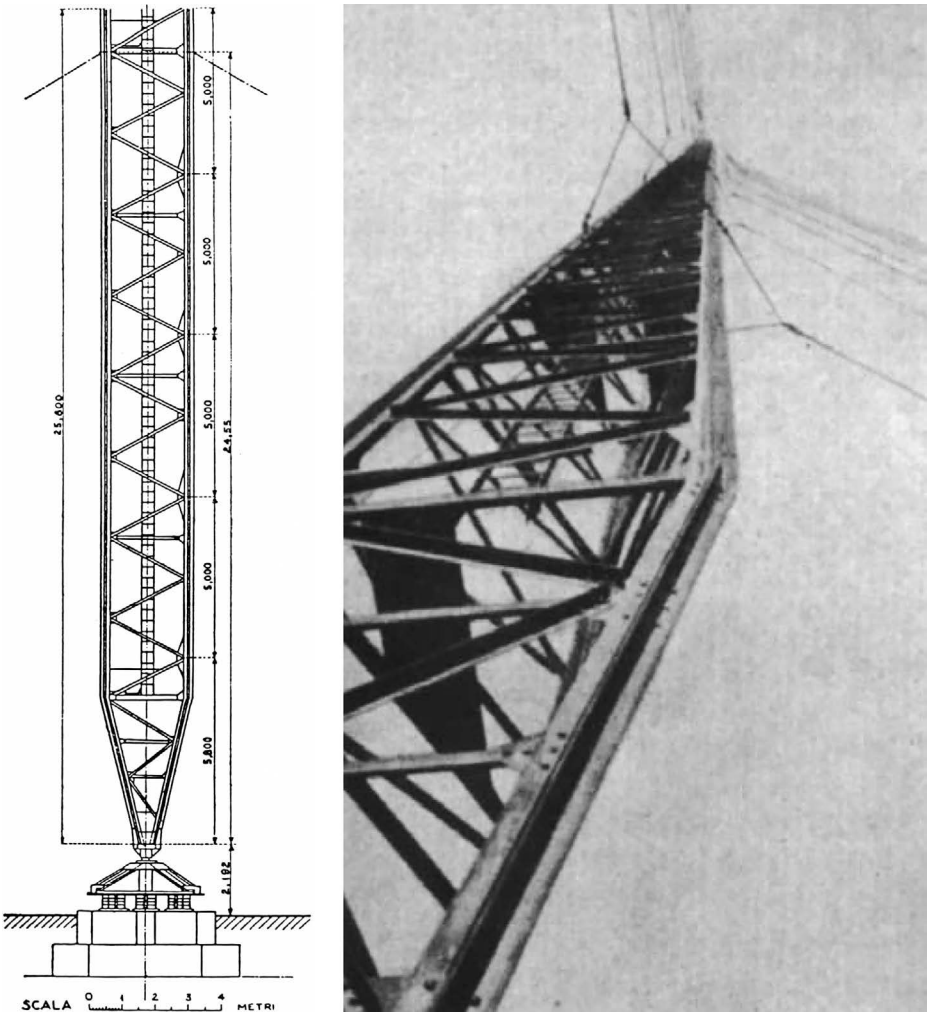


Figure 12.
The 250-m high masts of the VLF curtain antenna. Left: sketch of a mast's basement, with spherical-shaped bottom end; right: upside view from the bottom of a mast (from [9]).

and then gradually raised. The picture in Figure 12 shows one of the masts top towering from behind the new radio building, with the marshy environment clearly visible in the foreground.

The new radio, which got the call sign *ICC*, became fully operational on Apr. 15, 1923, and was operated by the IRN until December 1923, providing intercontinental radiotelegraphic services between Coltano and fixed points in North America, in East Africa Italian colonies (Massawa and Mogadishu), and in Turkey. In addition, the station provided telegraphic service to a limited number of ships during their navigation. In this period the overall monthly traffic grew up to about 140,000 charged words per month. For a simple assessment of the station's traffic capacity, assume an average word length of 10 characters and recall that using a Baudot coding 5 bits are sufficient to encode a character. Then the station's traffic was equivalent to about 7 Mbit/month. Also, for a telegraph transmission speed of a few tens of words per minute, the equivalent transmission bit rate was in the order of tens of bits per second.

In the early 1920s, in parallel with the construction of the new radio, Marconi's station (dubbed the "old radio") was upgraded. The obsolete spark transmitter was dismantled and replaced by a 50 kW Poulsen-type arc converter, made by IRN, which operated at 51.7 kHz (5800 m wavelength) and fed the continental aerial with a current of 50 A. The refurbished Marconi station was then used for radiotelegraphic service with some European cities (Berlin, Moscow, Oslo, Poznan, etc.), still retaining the call sign *ICI*. From 1920 to 1923 the old radio was also equipped with a 6 kW VLF vacuum-tube transmitter, produced by Marconi Co. Due to its limited power, however, it turned out to be unsuited for long-range continental service and it was therefore used only for links with Barcelona, Spain. Also an upgrade of the colonial aerial was planned, but it was not realized, due to the abovementioned handover of the Coltano radio center to a private company in 1924.

The IRN inquired about a location suited for the installation of a receive station so as to enable full-duplex radiotelegraphic connections. As a matter of fact, according to the design criteria of the 1920s, the receive station had to be kept at least 20 km away from the transmitter (i.e., outside the dotted circle in Figure 13), so as to preserve the receivers from the massive radio frequency interference caused by the transmit equipments. Being the service mainly intended for North America, the location of the receive station was chosen on a line (dashed in Figure 14) that was perpendicular to the great circle connecting Coltano to New York [9] and in the proximity of the sea, where reception was better. Again, the incumbent handover forced the IRN to a straightforward solution, i.e., to temporarily set the receive station inside the Navy Academy's premises in Leghorn.

As planned, in 1924 the Coltano radio center was entrusted to the privately-owned company Italo Radio which, until 1928, provided both continental services (to Prague, Budapest, Bucharest, Sofia, and Belgrade) and intercontinental ones (to North and South America, and the Far East) [28]. Furthermore, in the subsequent years, the company did some upgrades of the Coltano transmit site, under the management of Vittorio Gori, the Director of Italo Radio's Experimental Lab since 1924 [29]. According to [8] in 1926 Italo Radio built a new curtain antenna; witnesses refer to four 180 m-high masts located in a neighboring field, north of the area occupied by the Vallauri's large curtain antenna.[7]

[7] According to a comprehensive list of radiotelegraphic stations compiled in 1927, i.e., during Italo Radio's management period, Coltano hosted Vallauri's *ICC* station and two more stations, with call signs *ICM* and *IDG* (see [30, p. 1154]). It is not clear if these call signs refer to some new transmit facility that was built in Coltano by Italo Radio.

Figure 13.
Location of the receive stations (triangles) for full-duplex operation.

Italo Radio also built a new receive station in Nodica, north of Pisa, about 15 km away from Coltano, and not very far from the shoreline (see Figures 1 and 14). The Nodica receive facility hosted both listening and transmit operators who sent telegraphic traffic to Coltano via wired line.

FAREWELL TO VLF. WELCOME TO SHORTWAVES: THE GOLDEN ERA OF COLTANO STATION

In 1929 all the commercial traffic, which so far was sent via Coltano, was assigned to the newly built station of Torrenova, near Rome. As a consequence, the site of Coltano came under the direct management of the Post and Telegraph Ministry, which decided to use it for medium- and long-range service to merchant ships. Thus, the Coltano station underwent a further upgrade, which incorporated the latest innovations in radio transmission techniques. Actually, the era of boisterous and power-hungry VLF transmitters (such as the spark gap, Poulsen or Béthenod–Latour types) was coming to an end, and the advent of "high frequency" communications (i.e., with carrier frequencies above 1 MHz) was already a solid fact, thanks to the progress in vacuum-tube electronics. The renewal of Coltano's transmit facility was carried out under the technical supervision of two qualified IRN scientists: the admirals Gino Montefinale and Giuseppe Pession.[8] See [31] for a detailed technical description. From late 1929 to the early 1930s, vacuum-tube transmit equipments were installed in Coltano for both oceanic and coastal service (see Table 1 for the band designations).

- The two main transmitters were supplied by Marconi Wireless Co. London and operated in the 15–50 m band with 14 kW output power; they were used for long-range service on the following frequencies: 6650 kHz (45.10 m), 8380 kHz (35.80 m), 12795 kHz (23.45 m), 17750 kHz (16.90 m).
- During low-traffic hours, two auxiliary SW transmitters, model SWB4 "Pechino" by Marconi Wireless, operating in the 15–50 m band with 2 kW output power, were employed for low-priority communications, on the following frequencies: 8380 kHz (35.80 m), 12795 kHz (23.45 m).
- One MW transmitter operating in the 600–800 m band with 1.5 kW output power, was employed for medium-range service on the international distress frequency 500 kHz (600 m) and on 428.5 kHz (700 m).
- One LW transmitter, made by IRN, operating in the 2000–2400 m band with 5 kW output power, was employed for medium- and long-range service on 142.8 kHz (2100 m) and 125 kHz (2400 m). An auxiliary transmitter operating in the same band, with only 1.5 kW output power, was also available.

All the transmitters were hosted in the new radio building (Figure 14) and were remotely operated from a receive station located in Nodica. This was the old receive station, built in the 1920s by Italo Radio, which was suitably expanded and updated for pro-

Table 1.
Designation of the Radio Bands Adopted in this Article

Band Designation	Frequency Range	Wavelength Range
VLF (Very Low Frequency)	< 100 kHz	> 3000 m
LW (Long Wave)	100–300 kHz	1000–3000 m
MW (Medium Wave)	300–3000 kHz	100–1000 m
SW (Short Wave)	3–30 MHz	10–100 m

[8] Giuseppe Pession (1881–1947) was a rear admiral of the IRN and a physicist. He was a professor of electromagnetism and radiotelegraphy and succeeded Marconi in the Chair of Electromagnetism at the University of Rome. Together with admiral Gino Montefinale he designed the upgrade of Coltano radio station in the early 1930s. He was also the general director of Italian Postal Service and he wrote a biography of Guglielmo Marconi.

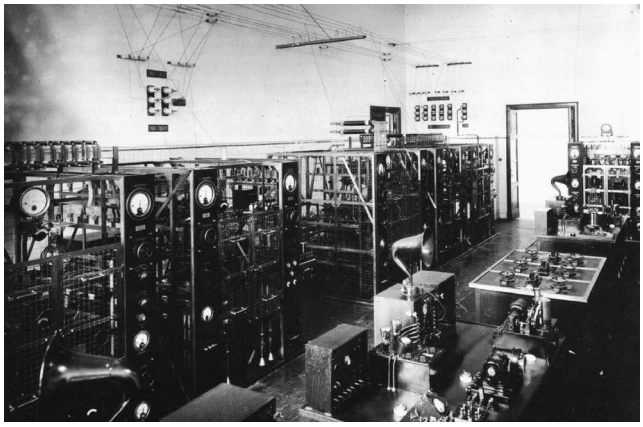


Figure 14.
Transmit equipments inside Coltano radio station in the 1930s.

viding adequate support to the new services. Nodica was linked to Coltano by an armored buried cable with multiple pairs of copper wires: 12 pairs from Nodica to Pisa and 8 pairs from Pisa to Coltano.

The antenna of the main SW transmitters consisted of 4 omnidirectional Franklin-type (i.e., meandering line) vertical aerials, one for each frequency of the main service (Figure 15). The aerials hung from a 180 m horizontal rigging, suspended between two 60 m-high towers, 300 m away from the station building. The two towers are clearly seen in the left side of Figure 12. A similar solution was adopted for the 2 kW auxiliary SW transmitter. In this case, two Franklin antennas, one for each frequency of the auxiliary transmitter, were suspended from a rigging connecting the station building to one 250 m-high mast of the old curtain antenna. The antennas of the LW and MW transmitters were installed on another mast.

The main SW transmitters were activated on July 1, 1930, and ensured long-range radiotelegraphic service to merchant ships, using the call sign *ICA*. This marked the beginning of Coltano's "golden age," but the most spectacular event of this period happened on Oct. 12, 1931, on the occasion of the 439th anniversary of the discovery of America. From his office in Rome, Guglielmo Marconi (Figure 16)

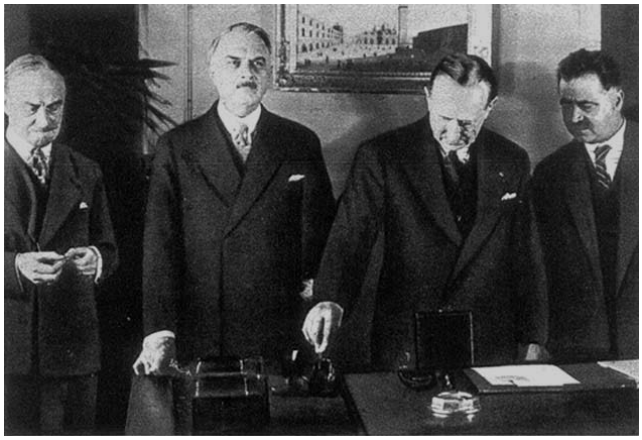


Figure 16.
Oct. 12, 1931. Marconi, from his office in Rome, remotely switches on the lights of the great statue of Christ the Redeemer in Rio de Janeiro, Brazil, using an SW radio signal sent from Coltano. From left to right: Marquis Luigi Solari, the Ambassador of Brazil Prof. Marpicati, Marquis Guglielmo Marconi, and the Rear Admiral Giuseppe Pession, General Post Master of the Italian Post Office.

remotely switched-on the lights of the great statue of Christ the Redeemer in Rio de Janeiro, Brazil, 9200 km away [32]. Marconi pressed a key that sent the command via landline to Nodica, where it was relayed to Coltano. Then, the 2 kW SW transmitter sent a signal to a radio station in Rio. From Rio, the command was eventually transferred via landline to the floodlighting switchgear, on the Corcovado Mountain [33]. The SW transmitter used on this occasion is now on display at the Historic Museum of Communication of the Ministry for the Economic Development in Rome, Italy (Figure 17).

In late 1931 the main SW transmitters were upgraded by adding amplitude modulation functionality. This enabled radiotelephonic service with ships as from early 1932. Thus, for almost a decade (1930–1940), Coltano was the key Italian (and one of the main European) long-range radiotelegraphic and radiotelephonic station providing wireless connections with both ships and fixed points all around the globe. Since 1932 regular public connections were held

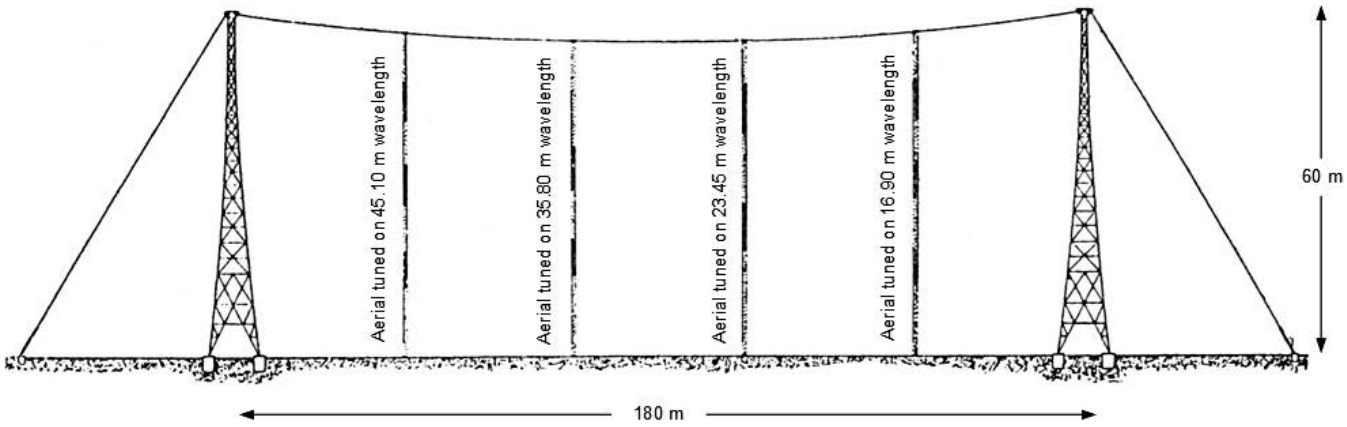


Figure 15.
Coltano SW antenna, featuring 4 omnidirectional Franklin aerials (1930).

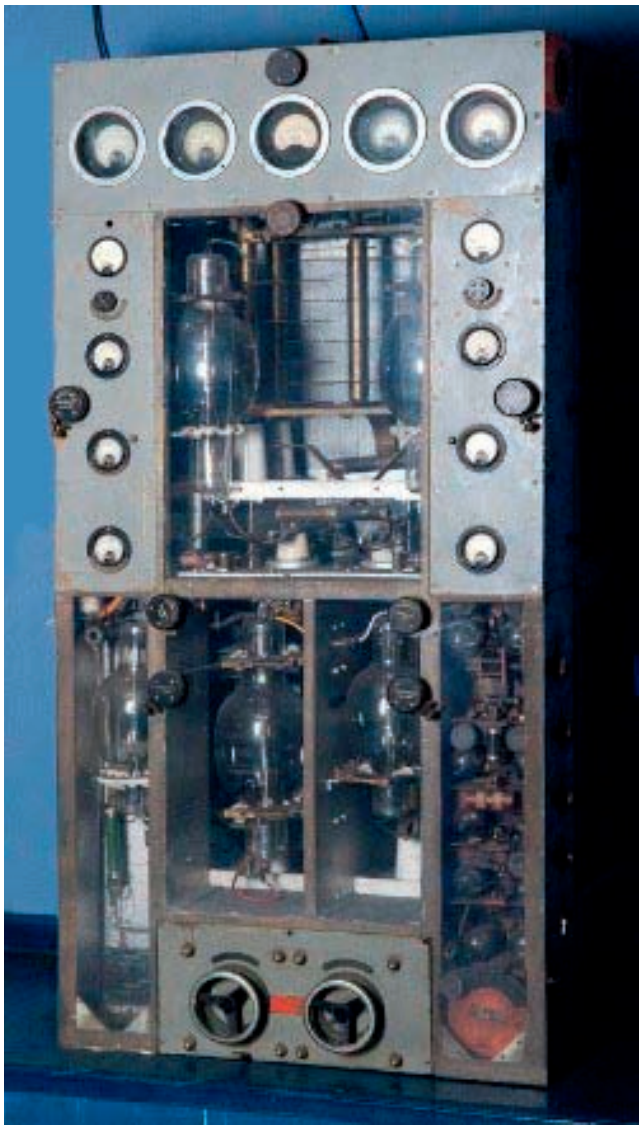


Figure 17.
The original 2 kW SW transmitter mod. SWB4 "Pechino" by Marconi Wireless Co., London, that sent the signal from Coltano to Rio de Janeiro in 1931. Now displayed at the Historic Museum of Communication, at the Ministry for the Economic Development, in Rome, Italy.

with the Italian concession in Tianjin, China, 8250 km away. In the same year, the first public service from land to vessels was activated. The first served ship was the Italian liner Conte Rosso, which kept regular contact with Coltano while sailing to Shangai, 9200 km away. The service was soon extended to the Rex and the Conte di Savoia liners, sailing to New York, 6650 km away, and to the Duilio and the Giulio Cesare liners, sailing to Cape Town, South Africa, 8670 km away [11], [34]. The map in Figure 18 shows the areas served worldwide by the SW transmitters. In 1935, two new shortwave transmitters, supplied by Marconi Wireless Co., were installed: a 56 kW transmitter for radiotelegraphic services and a 35 kW transmitter for radiotelephonic services [35].

The Coltano radio center was regularly used for SW service until the early 1940s. WWII was already raging however and the Coltano saga was approaching its dramatic end.

WWII AND THE END OF COLTANO STATION

Only scarce information is available on the calamitous events that happened in Coltano during WWII. The most reliable source is a brief report containing the memories of Narciso Baroni, a technician of the station who was an eyewitness of the events, later transcribed by his daughter Matilde [36]. According to Baroni's narration, when the war broke out all the station's staff was militarized and the whole facility was under armed surveillance. A team of military technicians went to Coltano, trying to restore the old VLF equipment and use them for communications with submarines. The attempt was unsuccessful, however. Next the station went under complete control of German forces and the civil radio service was interrupted. The station was never used by the Germans, but remained partially operative for military and government communications. Oddly enough, the Coltano center was spared during the heavy Allied bombings that severely hit Pisa more than 50 times, during 1943–1944. In summer 1944, under the pressure of the advancing Allied army, Germans withdraw from Pisa and moved north. Prior to leaving Coltano, however, they blew up the building of the new radio and all the antenna towers of the radio center.[9] The building of the old Marconi station, which had not been operated for a long time, was spared. On July 20, 1944, the Germans mined and blew up the Solferino bridge over the Arno river, in downtown Pisa. The telegraphic cable that passed under the bridge, joining Coltano with Nodica, was cut off. This was the final act marking the death of the Coltano center. Curiously enough, that day coincided with the death of Guglielmo Marconi (in 1937), and the birthday of his daughter Elettra (in 1930).

In those difficult war days, metal wreckage was a valuable good and therefore the site was sacked: the fallen antennas were dismantled and the metal sold on the black market, together with wires, cables, and equipment parts. Even the metal wiring of the antenna grounding systems was dug up and sold. Nothing was left.

POSTWAR

The disgraceful destruction and the subsequent postwar events doomed the Coltano radio center to an undeserved oblivion. Actually, the maritime radio service was transferred to the Prato Smeraldo site, near Rome, and the abovementioned Narciso Baroni was appointed as its first director. Coltano's antennas and station, instead, were never rebuilt and the site was finally abandoned. After more than three decades of distinguished service, the Coltano radio center ceased to exist. In 1946, the monarchic regime ended in Italy and the Republic was established. The former royal estate of Coltano, which included the survived Palazzina Marconi, became a state-owned land, located within the municipal area of Pisa.

However, an adjacent area was chosen again to host some important telecommunication infrastructures. After all, the site had been personally selected by Marconi and this was sufficient motivation!

[9] Sources from the Italian resistance movement refer that the antennas were destroyed on June 14, 1944, but do not report the date of destruction of the main station building.

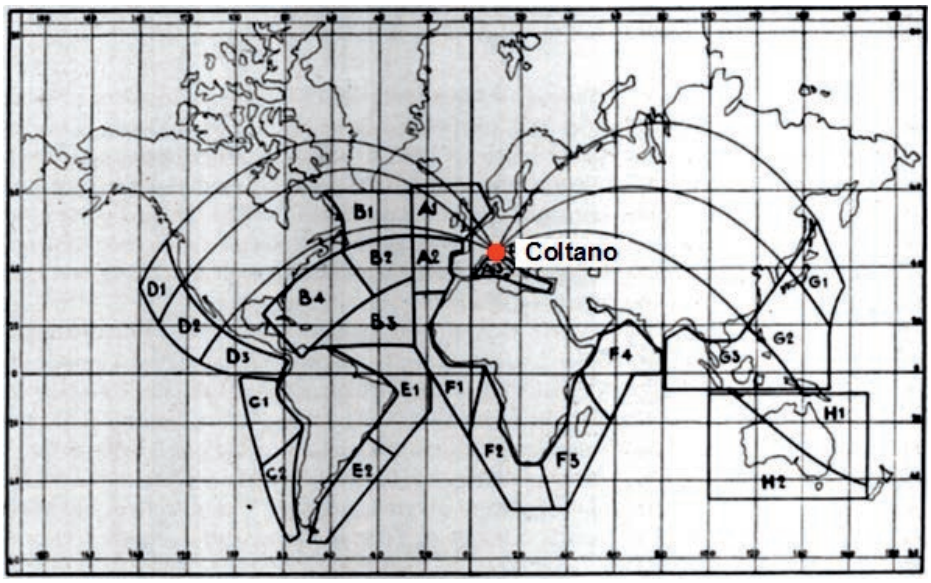


Figure 18.
Worldwide coverage map of long-range SW service from Coltano (1930–1940). Alphanumeric codes denote target areas served by given frequencies in given time intervals, due to ionospheric propagation.

Actually, in 1955 the U.S. Air Force (USAF) established a radio site in Coltano, about 1 km east of the old radio center [37]. In 1962, the U.S. Army built another radio site in the area formerly occupied by the curtain antenna of Italo Radio in the 1920s and installed there a 1 kW tropospheric communication system. Shortly after, the USAF too moved to the Army's site and installed there the Germany Italy Microwave System (GIMS) and a 10 kW tropospheric communication system linking Coltano with Spain, Greece, and Turkey. In 1973, a marble monument to Guglielmo Marconi was erected at the U.S. site. In 1976, the 509th Signal Battalion assumed the responsibilities of the communication activities in Coltano. Later, the communication equipments were upgraded: the Army's GIMS was replaced by the Digital European Backbone (DEB) system, while the USAF installed an Automatic Voice Network (AUTOVON) switch. Some satellite terminals in support of worldwide tactical missions were also installed. In the early 1990s, the DEB was upgraded to incorporate modern digital radios and multiplexers, and the Digital Switch Network (DSN) replaced the AUTOVON switch. The U.S. communication site in Coltano was deactivated in 2000 and converted into an NSA/Echelon monitoring station [38]. The site was eventually closed in May 2008 and the Marconi monument was moved to the Leghorn Army Depot in 2012.

In 1952 the Italian public broadcasting company RAI installed a MW transmit site in Coltano, in the area formerly occupied by the new radio building. Later, the antenna site was moved to another location, about 1.5 km southeast of the old Coltano radio center. Today the RAI site hosts a MW transmitter carrying Radio 1 programme on 657 kHz, with 50 kW, and a 130 m-high mast.

COLTANO TODAY

Only a few vestiges today witness the past splendors of the once-famous Coltano radiotelegraphic and radiotelephonic center: the concrete basements of the great antenna towers, still visible in the fields; a few small portions of brick walls of the new radio building; the barracks and the quarters of the service staff; surviving WWII's devastation. Unfortunately, it suffered badly the effect of time and this historic building fell into disrepair: what the German troops did not do, the inactivity and carelessness of Italian administrations did. Actually, the Ministry of National and Culture Heritage, which has to manage a huge amount of Italian historical sites, never took care of Coltano (due to lack of resources and/or interest), while the owner institution, i.e., the Italian State Property Office ("Demanio dello Stato"), was almost exclusively concerned with leaving the site untouched while denying any intervention to other institutions. On the other side, until recent years, the municipality of Pisa, which is the competent authority for the area surrounding the building, did not do enough to improve the accessibility of the site or promote tourism at Coltano.

The Pisa section of the Italian Amateur Radio Association (A.R.I.) recently moved its offices into the "Villa Medicea" of Coltano, an ancient fortified rural residence built by the Medici family of Florence in the late XVI century, located just 800 m away from the Palazzina Marconi, and occasionally operates a commemorative radio station with call sign IY5PIS.

The current status of the Coltano site can be visited in a virtual tour using Google Maps. The ruined Palazzina Marconi is easily found at coordinates 43.643140 N, 10.402751 E, while the basements of the large antennas are spotted in the fields (Figures 7 and 9 can be of some help in locating the antenna basements).

In the last decades, several committees and many people, including Princess Elettra Marconi, in vain complained about the abandonment of Coltano radio center and called for the restoration of what is left.

The most effective action for the conservation of Coltano's memory carried out so far is a permanent exhibition, organized at the Pisa City Library by Paola Bernardini, the daughter of Pietro Bernardini, a former technician of the radio station. The exhibition consists of a set of twelve panels illustrating the whole history of the the Coltano radio center, with a number of vintage photos, pictures, drawings, and documents [39].

In recent years, a new bill allowed the State Property Office to hand the ownership of the Palazzina Marconi to the municipality of Pisa on condition that a complete (and expensive) recovery project was proposed. The Coltano radio center deserves to be a serious project for restoration and promotion. It would be a too-long awaited act of gratitude to a genius who worked in this place and brought mankind into the modern era.

END NOTES

"The Coltano area is just a natural antenna", said Dale Ellenbarger, former officer in charge at the U.S. communication center in Coltano [37]. *"With mountains on three sides and the sea to the west, it forms the shape of a bowl or a dish similar to satellite antennas. The shape of the area enables the signals to bounce off the mountains and down to the antennas. Marconi recognized that fact when he first built his station. The terrain features helped him in transmitting signals to the continents of North America, Africa and Europe via radio signals. When Marconi first began his experiments at Coltano, radio communication was in its infancy, so it proved to be the test bed for the entire world of radio communication."*

ADDENDUM: A HAWAIIAN TWIN

It is rather surprising to know that Marconi's radio station in Coltano has a twin in the other hemisphere, at Kahuku (21.706199 N, 157.973107 W) on the North Shore of Oahu, Hawaii [40]. This station was built in 1914 by Marconi Wireless Co., and since 1916 it provided regular radiotelegraphic services to North America and Asia, using a 300 kW transmitter. Similarly to Marconi's radio station in Coltano, the Kahuku's station featured a couple of large bent antennas, each made of 12 trellises: one antenna was aimed toward San Francisco and the other toward Japan. And, similar to Coltano, this radio center had a sad fate. The importance of the radiotelegraphic services provided by Kahuku's station rapidly declined after Hawaii was linked to the Mainland by undersea cable in 1957. The station was therefore closed and the antennas were dismantled. Today the buildings of the Marconi station in Kahuku are vacant and in disrepair, just like the Marconi station in Coltano.

ACKNOWLEDGMENTS

The author greatly acknowledges Dr. Luigi Cobisi, General Secretary of Italradio, for his fruitful comments and suggestions, and Prof. Umberto Mengali, Professor Emeritus from the University of Pisa, for his patient revision of the manuscript. The author also expresses his greatest appreciation for the information provided by Prof. Matilde Baroni and Dr. Paola Bernadini, daughters of two former Coltano's technicians, for the passion and commitment they provide in uncovering, spreading, and preserving the memory of this historic site. This article is dedicated to them, to their fathers and to all the people, from the most illustrious scientists to the humblest laborers, who worked in Coltano and contributed to an exciting, though unrecognized, chapter in the history of radio communications.

BIBLIOGRAPHICAL NOTES

Information about the Coltano site is rather scarce and is provided by a multiplicity of sources which are often inaccurate from a technical and historical point of view. Also, many documents are written in Italian, have a very limited distribution, and are difficult to find. The preparation of this study required then a major effort to collect, analyze, critically revise, and organize in the best possible way such a sparse bibliographical material.

The reader interested in investigating Marconi's life and work is referred to the following comprehensive resources: *i*) the archive of the Guglielmo Marconi Foundation (FGM) [41]; *ii*) the Marconi-Calling archive created by Marconi Corp. plc, [42]; *iii*) the Marconi Archives of the Bodleian Library at the University of Oxford [2]. Concerning the latter archives, the material relating to Coltano wireless station consists of some papers, relevant to years 1902–1905, in Shelfmark MS. Marconi 197 (32 pages), and in a photograph of Coltano station in Shelfmark MS. Photogr. b. 63, fol. 142.

Reports of Marconi's public activities can be found in the old issues of some Italian newspapers. In particular, the on-line archives of Turin's newspaper "La Stampa" [43] and Bologna's newspaper "Il Resto del Carlino" [3], [44], have proved valuable sources of information about the history of the Coltano site.

The most comprehensive collection of Marconi's scripts was published posthumously (in Italian) by the Italian Royal Academy, in 1941 [45]. This anthology of Marconi's papers, speeches, and notes is now freely available on-line. In the collection [45] there are three papers dealing with Coltano: one is [24] and the other two are the Italian translation of [5] and [17].

The State Archives of Pisa conserves a comprehensive collection of documents concerning the construction of the Palazzina Marconi, including the building's drawings and blueprints, site maps, and some correspondence about the work progress [46].

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