

TESLA'S DREAM: THE WORLD SYSTEM OF WIRELESS

— Part 1. Electrical Communication Through the Earth —

In 1900, Nikola Tesla described in a brochure his plans for a world system of wireless. Among his claims for the system were: "the instantaneous and precise wireless transmission of any kind of signals, messages or characters, to all parts of the world." Also, "... an inexpensive receiver, not bigger than a watch, will enable him (a user) to listen anywhere, on land or sea, to a speech delivered, or music played in some other place, however distant."¹ At the time such claims seemed fantastic, but now many of these services are available through the medium of radio.

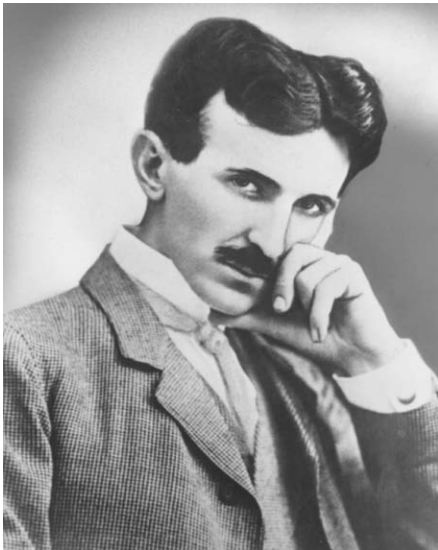


Fig. 1. Nikola Tesla in a thoughtful pose circa 1904. From early manhood to old age, Tesla had an arresting appearance, almost the stereotype of an electrical genius.

What was unique about Tesla's system was that he intended to accomplish all this by transmitting electrical signals through the earth. In 1901 he began building the transmitting station for his "world system of wireless" on Long Island, New York. Unfortunately he ran out of money before he could complete it, and his revolutionary ideas were never put to the test.

What were the principles of his system? Would it have worked? Would wireless communications have evolved along different lines if this transmitting station had been completed, along with whatever receiving facilities he had planned? It is difficult to give definitive answers to these questions, but I will try to clarify what he was trying to do, as I understand it.

Nikola Tesla was born in 1856 in Smiljan, Croatia, of parents of Serbian origin. He received a good education, both classical and technical, followed by electrical engineering work with the American Telephone Company in Budapest and Societe Continentale Edison of Paris. A portrait of Tesla from about 1904 is shown as Figure 1.

He emigrated to the United States in 1884, carrying a glowing letter of recommendation, and for a time worked with Thomas Edison in New York City. Shortly after leaving his job with Edison, who was then promoting the commercial use of direct current, he worked with George Westinghouse, who was interested in alternating current. Here Tesla was able to develop his earlier ideas for an alternating current motor, and beginning in 1888 he was granted patents on a.c. motors, generators, and the transmission of polyphase alternating current.

Tesla sold his patents to Westinghouse and was well on his way to fame and fortune. The fortunes he earned through his research were spent to finance further laboratory work. Tesla's

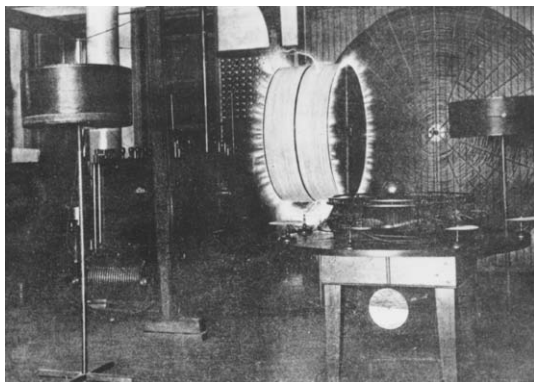


Fig. 2. The interior of Tesla's laboratory on Houston Street in New York, showing various experimental coils. The coil in the centre of the photograph is illuminated by high voltage electrical discharges, probably generated by resonating with the magnetic field of a large primary loop, one corner of which is visible behind and above it.

reputation was further enhanced when Niagara was harnessed to generate alternating current in 1895, and the Westinghouse alternating current system, rather than Edison's direct current technology, became the common method of electric power distribution.

In 1888 Tesla opened the first of a series of four laboratories in New York City, in which he extended his alternating current experiments to higher voltages and frequencies. (See Figure 2.) In the next few years he developed high frequency alternators, and methods of converting direct or low frequency alternating current to high frequencies with the aid of capacitor discharges, "breaks," (interrupters), and resonant circuits. Apparatus of this type would later serve as the oscillator for his wireless transmitters. He also invented the "Tesla Coil," which was a resonant, high voltage, high frequency transformer.

During these experiments he noted that alternating currents do not necessarily require complete circuits, but can flow along single wires if "drawn" by a capacitance. For example, if one terminal of a high voltage, high frequency source, were grounded, and a wire were connected to the other ("hot") terminal, current could be drawn along the wire by the capacitance of a conducting body connected to the other end of it.

If the voltage and frequency were high enough, the capacitance of a light bulb was suf-

ficient to draw enough current to light it. Such phenomena are familiar to radio workers. The capacitance of an isolated conducting body is often called its "self-capacitance," and the current is called "charging current." This is the current that flows in an open-circuit transmitting antenna, or gives you a burn if you touch the electrically "hot" parts of a radio transmitter, even if you are isolated from the ground.

Following this line of thought, Tesla considered using the earth as the single conductor and transmitting currents through it for purposes of wireless communication and perhaps even power transmission. His basic idea, as described in lectures at Philadelphia and Saint Louis in 1893², was to connect a high frequency generator (or oscillator) between the ground and a spherical elevated conductor.

The e.m.f. of the generator would apply alternating charges of equal magnitude and opposite sign to the sphere and the Earth, and the charging current would spread out through the earth from the ground terminal. It is this current, and/or its associated electrical disturbance, that Tesla intended to use for wireless signalling and possibly power transmission.

Tesla believed that the entire Earth could be set into oscillation by this means with little dissipation of energy. Although the conductivity of soil and water is orders of magnitude smaller than that of a metal, the resistance between the transmitter ground terminal and a distant point would be very small on account of the large cross-sectional area of the Earth. Tesla apparently was aware that the high frequency currents would be confined to a layer near the surface of thickness equal to the "skin depth," but even this layer would have an enormous cross-sectional area. He thus concluded that energy could be transferred efficiently from the transmitter to a resonant receiver anywhere on the globe, and that surface anomalies such as mountains and buildings would absorb little of this energy because they would be non-resonant.

The current that would flow to the transmitter sphere and also spread out in the earth from the ground terminal would be given by:

$$I = 2\pi r f C V,$$

where I is the current in amperes, f is the fre-

All photographs are courtesy of the Tesla photo archive of The Wardencliff Project.

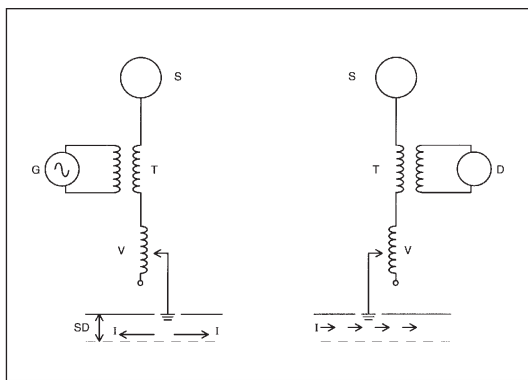


Fig. 3. Basic circuits of Tesla's transmitter and receiver. S: elevated spherical conductor; T: radio frequency transformer; G: generator or oscillator providing a radio frequency current; D: detector; I: earth current. SD: skin depth.

quency in hertz (cycles per second), C is the self-capacitance of the sphere and Earth in series (approximately equal to that of the sphere alone) in farads and V is the voltage between the sphere and the ground. In this expression the relatively small impedance of the ground connection has been neglected. The self-capacitance of a sphere is approximately one picofarad per centimetre of radius.

For example, using numbers appropriate to the Long Island station that he built later, a generator e.m.f. of ten million volts would produce a transmitter sphere current of about 700 amperes at a frequency of ten kilohertz. (Actually, the earth current might be many times larger, as will be explained in Part 2 of this article). The high voltage required to obtain a large current motivated Tesla to produce ever greater voltages in his laboratories, resulting in spectacular electrical discharges several yards in length.

During this period, Tesla dressed elegantly, ate at night in the best restaurants, and hobnobbed in high society, partly to attract the attention of potential investors.³ In spite of allowing himself these few worldly pleasures, he never married, and maintained an ascetic devotion to his work.

Tesla's ideas about the form that his wireless transmitters and receivers would take were now crystallizing. They were described in patents applied for in 1897 and granted in the United States in 1900.⁴ A simplified version of his apparatus is shown in Figure 3.

Basically, the transmitter consisted of a source of high voltage, high frequency, alternating current applied between an elevated conducting

sphere and the earth via an air core transformer. The receiver was like the transmitter in reverse. An elevated sphere was connected to the earth through the primary coil of a transformer, and the secondary coil was connected to the detector. Presumably the primary and secondary circuits of both the transmitter and receiver were tuned to or resonated at the generator or oscillator frequency in communications applications.

Tesla did not expound on the principles of his receiver, but he apparently expected the alternating potential or electric field associated with the earth current to generate a voltage between the ground and the elevated sphere of the receiver. In his patent drawings Tesla showed large loads connected to the output of the receiver because he was still considering the wireless transmission of useful amounts of electric power.

Tesla also considered the possibility of utilizing electrical conduction through the rarefied strata of the upper atmosphere, an idea reminiscent of the experiments of Mahlon Loomis⁶, and

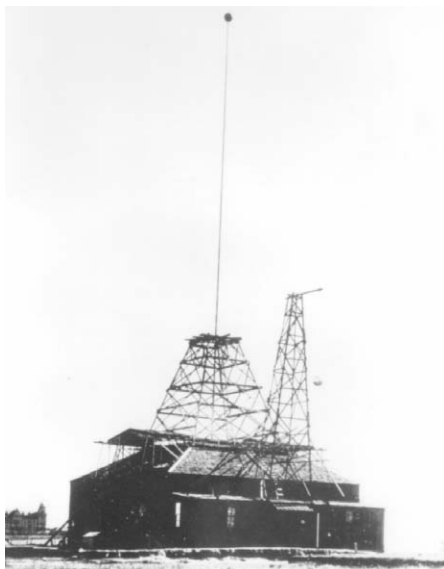


Fig. 4. Tesla's laboratory at Colorado Springs. Note the 30-inch diameter metal covered sphere on top of the central pole, and the structure on the near side of the building from which a conducting sphere could be elevated various distances above the ground.

even conjectured that a transmitter for this purpose would produce an artificial aurora. These ideas were reinforced by his experiments on the conduction of electricity through gases at low pressures. However, he did not try to follow this up seriously, probably because it would have required balloons or other access to the upper atmosphere, and he continued to focus his main efforts on conduction through the earth.

Tesla was not the first to try signalling through the earth electrically. Samuel Morse transmitted telegraph signals across a canal eighty feet wide in 1842⁵, and William Preece bridged the Solent, a channel several miles wide in England, in 1882⁷. Nathan Stubblefield demonstrated a wireless telephone that worked by earth conduction circa 1892⁸.

However, unlike Tesla's transmitter with its "monopole" ground terminal, the transmitters in these systems all utilized a complete circuit that passed a current between two ground terminals, and the receivers detected the voltage between a second pair. The main limitation of such systems was that the dipole electric field set up in the earth by the pair of transmitter terminals had an intrinsically short range, and with the instruments then available, signals typically could not be received at distances many times greater than the spacing between the transmitter terminals. Of the early earth conduction schemes, the wireless telegraph and telephone systems of Amos Dolbear, developed in Boston and patented in 1882, most closely resembled Tesla's concept in principle because they utilized single ground terminals at the transmitter and receiver⁹.

All of the foregoing systems transmitted raw telegraphic or telephonic signals, what would now be called the "baseband signal." In Tesla's system, the alternating e.m.f. supplied by the transmitter was a carrier, and information was to be transmitted on it via amplitude modulation. His plans included modulations carrying telegraphic, telephonic, stock market, picture, time, and coded signals. How well his proposed electromechanical methods of modulation would have worked is debatable, but his ideas certainly were ahead of their time.

Tesla built his last laboratory for wireless experiments near Colorado Springs in 1899 (Figure 4). Here he constructed a metal-covered wooden sphere, about 30 inches in diameter, that could be raised to the top of a 168-foot iron pipe that was

insulated from the earth. The primary and secondary coils of his transmitter were made of thick cable. They were fifty-one feet in diameter, and their combined height, or that of their coil form, was nine feet (Figure 5).

An additional resonant coil likely was used to achieve a high sphere voltage, the whole arrangement being called by Tesla a "magnifying transmitter." (Further details will be included in part 2 of this article.) According to Tesla, up to four million volts could be applied to the sphere, generating earth currents of one thousand amperes. The power was not as large as these numbers suggest because the current and voltage were approximately 90 degrees out of phase.

Tesla did various experiments inside and outside of the transmitter building using resonant coils that would pick up the transmitted energy, lighting bulbs or generating electrical discharges. He later described the signals detected by ungrounded coils as due to induction and of no real value, whereas he attributed signals received by grounded coils to transmission via the earth, and described them as important.

These experiments were carried out within a few miles of the transmitter, and Tesla appar-

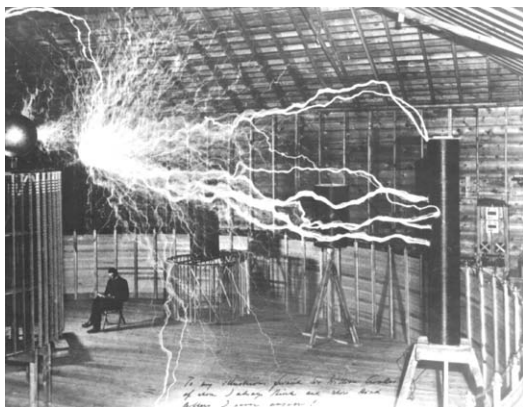


Fig. 5. High voltage electrical discharges inside the Colorado Springs laboratory, with Tesla seated in a chair (double exposure). The frame encircling Tesla and various experimental coils was about 50 feet (15 metres) in diameter, and supported the primary and secondary turns of his main oscillator coil. The coil in the centre, termed an "extra coil" by Tesla, generated multi-million volt electrical discharges when resonating to the oscillator frequency or a low order harmonic.

An inscription at the bottom, signed by Tesla, reads: "To my [word unclear, looks like "unknown"] friend Sir William Crookes of whom I always think and whose kind letters I never answer! June 17, 1901."



Figure 6. Tesla's unfinished Wardenclyffe station for his world system of wireless at Shoreham, Long Island, New York, circa 1903. The building in the foreground housed the power plant, laboratory, and workshops for the station. The tower and top structure in the background was about 187 feet (57 metres) high, and was never completed. The roughly hemispherical top was to have been covered with iron plates (the "elevated conducting body"), and the supporting structure presumably would have contained the "magnifying transmitter," and would have been covered by an outside wall.

ently did not attempt to observe how far away his signals could be received. Consequently, although his Colorado transmitter undoubtedly could have done far better, the greatest distance he ever recorded was thirty miles — observed during earlier experiments at his Houston Street laboratory in New York City.¹⁰

Although this was a significant accomplishment, Tesla did not attempt to exploit it commercially, preferring to wait until he had achieved his real goal, worldwide wireless. In retrospect this probably was a great mistake. The lack of demonstrated success in long-range wireless communication or power transmission made it difficult for him to obtain needed financial support later. It also denied him a more prominent place in the history of wireless.¹¹

In Colorado, Tesla also used a receiver like that shown in Figure 3 to record natural electrical disturbances. According to Tesla: "The earth was found to be, literally, alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation."¹²

During these experiments he made an observation that impressed him greatly, and reinforced his belief in the practicality of transmitting signals or power through the earth. A thunderstorm

that was moving away from him produced many maxima and minima on his record, and continued to do so even after it had receded to a distance estimated to have been about 200 miles. Tesla interpreted these variations as stationary (standing) waves, possibly due to electrical disturbances generated by the lightning travelling around the whole planet. If this interpretation were correct, global ranges for his system seemed feasible.

Tesla completed his Colorado experiments and returned to New York in 1900. He now felt ready to build a commercial installation to provide the worldwide wireless services quoted at the beginning of this article. The well-known financier, J.P. Morgan, advanced him \$150,000 in return for a 51% interest in Tesla's patents and inventions, and in any future ones related to electric lighting or wireless telegraphy and telephony.¹³

Tesla obtained a piece of land at Shoreham, Long Island, New York, and in 1901 began construction of a powerful transmitting station called Wardenclyffe, named after the real estate development in which it was located. A one-story brick building about 100 feet square was constructed and equipped as his laboratory, workshop, and power plant for his transmitter.

A sturdy wooden latticework tower about 154 feet (47 metres) high was built, topped by a roughly hemispherical structure, 68 feet (21 metres) in diameter, which was to have been covered with metal plates (the elevated conducting body). See Figure 6. The tower was located about 350 feet (100 metres) from the station building so that there would be no risk of an electrical discharge between the hemisphere and the chimney of the building!

Beneath the tower was a deep shaft containing the ground terminal. This was an iron pipe driven about 300 feet (90 metres) into the ground and well into the water table to provide the transmitter with "a grip on the earth so that the whole of this globe can quiver" (electrically speaking, of course). Presumably, the apparatus which Tesla called a magnifying transmitter, "a peculiar transformer specially adapted to excite the Earth" would have been located in the tower, and the tower covered with an outside wall as shown in an artist's illustration.¹⁴

This is as far as the project got. Tesla had spent all of his money, and could not raise more from Morgan or other financiers. Construction ceased in 1903, and Tesla mortgaged the property. The mortgages were eventually foreclosed, the equipment was stripped from his laboratory, and the tower was blown down with dynamite in 1917.

So ended a dream and a fascinating chapter in the history of communications. Tesla's last significant work was on a turbine that he invented, but he was unable to exploit it commercially to save the Wardencllyffe project. He died in his hotel room in New York City in 1944. Although the Wardencllyffe tower is long gone, the station building was used commercially until recently, and its restoration for use as a science centre is the goal of the "Tesla Wardencllyffe Project."¹⁵

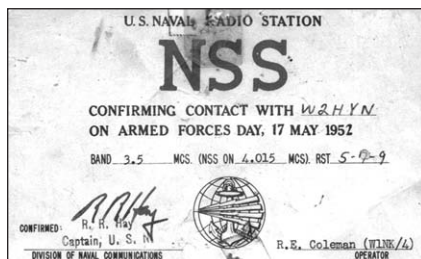
The premature demise of Tesla's world wireless system leaves us haunted by what might have been. Would it have worked? If so, would early wireless have evolved along entirely different lines? These and other questions will be examined in Part 2 of this article.

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7. *Pioneers Of Wireless*, by Ellison Hawks: Arno Press, New York (1974), originally published by Methuen & Co. Ltd., London (1927); p. 160.
8. "'Forgotten' Pioneers of Wireless, Part 1 – Nathan Stubblefield" by James P. Rybak: *The Old Timer's Bulletin* (Antique Wireless Association), vol. 38, No. 2, May 1997.
9. Hawks, *ibid.*, p. 134ff., and Blake, *ibid.*, p. 47ff.
10. Anderson, *ibid.*, p. 26ff.
11. Tesla alludes to a range of about six hundred miles on page 209 of his article "The Problem Of Increasing Human Energy," in *The Century Magazine*, June 1900, but he gives no details. Whether 30 or 600 miles, the fact remains that he did not make a point of publicly demonstrating the ranges of his equipment or marketing small scale systems, and this probably was detrimental to his success in the long run.
12. "Prodigal Genius, The Life of Nikola Tesla," by John J. O'Neill: Ives Washburn, Inc., New York (1944), p. 179ff, quoted from an article in *Electrical World and Engineer*, May 5, 1904.
13. *Lightning In His Hand – The Life Story Of Nikola Tesla*, by Inez Hunt and Wanetta W. Draper: Omni Publications, California (1964), p. 136.
14. Johnston, *ibid.*, p. 89.
15. For more details, see the "Tesla Wardencllyffe Project" website <<http://pages.nyu.edu/~jas4/>>.

A BLAST FROM THE PAST

After reading our story on NSS ("Station NSS: A Decommissioned Giant") in the November OTB, Bill Shaw remembered he had worked the station on 17 May, 1952. He contacted stations AIR and WAR on the same date (an Armed Forces Day event, maybe?) and received QSL cards from all 3. Here's the NSS card, which Bill was kind enough to scan and e-mail to us.



TESLA'S DREAM: THE WORLD SYSTEM OF WIRELESS

— Part 2. Would It Have Worked? —

Part 1 of this article described how Nikola Tesla developed a “world system of wireless,” in which signals were to be transmitted through the earth by electrical conduction. His efforts culminated in the construction of a large transmitting station called Wardencllyffe on Long Island, New York. Construction began in 1901 and halted a few years later when Tesla ran out of money. The premature demise of his system left many questions unanswered. How well would his system have worked, especially in comparison with low frequency radio, which was making rapid progress at the time? Would wireless communications have evolved along different lines if he had been successful?

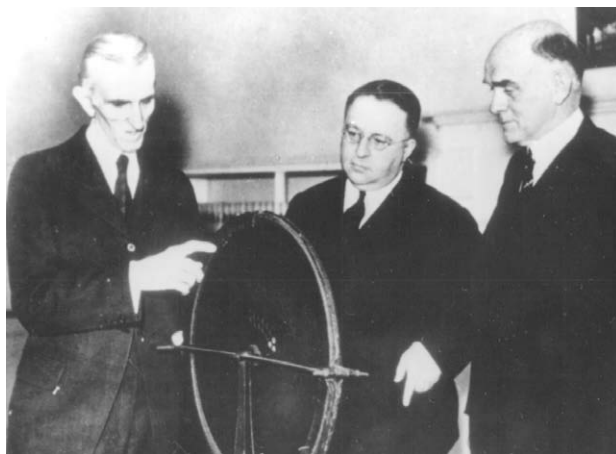
Since the terms “wireless” and “radio” are used interchangeably today, I should point out that “radio” is defined here as wireless communications by means of radio waves, which in Tesla’s time were often called “Hertzian waves.” Consequently, the earth conduction system that

Tesla proposed was wireless, but not radio. Historians sometimes confuse Tesla’s system with radio, but Tesla himself was not confused. In a patent application he wrote:

It is to be noted that the phenomenon here involved in the transmission of electrical energy is one of true conduction, and is not to be confounded with the phenomena of electrical radiation which have heretofore been observed, and which, from the very nature and mode of propagation, would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance.¹

Tesla’s philosophy might have been summarized as: “Why bother with wireless communication by means of radio waves, which weaken as they spread out from their source, when the Earth itself provides a good electrical conductor between any two points on its surface?” The trick of course is how to coax current to flow be-

tween the two points without a return conductor to complete the circuit.



This 1938 photograph shows Nikola Tesla (left) at age 82 examining one of his early alternators with Westinghouse Company officials. It had been lent to the Westinghouse Company, thereby escaping a fire that destroyed Tesla’s laboratory in New York City. The other men are left to right: Victor S. Beam, patent counsel for the company, and Henry Herman Westinghouse, Director. (Photo courtesy Tesla Wardencllyffe Project).

Tesla's solution, which dated back to lectures that he gave in 1893, was to apply a very high voltage e.m.f. from a generator or oscillator between the ground and an elevated conductor, referred to here as the transmitter sphere. Due to the self-capacitances of the earth and the sphere, the alternating e.m.f. would transfer charge back and forth between them. This charging current would also flow in the earth or water surrounding the transmitter's ground terminal, as it does around the ground terminal of a radio transmitter, and would be used to convey signals and perhaps useful amounts of electric power to remote points on the globe.

Figure 1a shows the basic transmitter configuration that Tesla probably would have used at his Wardenclyffe station; Figure 1b shows the configuration of a contemporary low frequency radio transmitter for comparison. The circuits look similar, but they had different purposes, and this affected the choice of parameters. The radio transmitter was designed to radiate maximum radio wave energy from its antenna, whereas the Tesla transmitter was designed to emit maximum current from its ground terminal.

In spite of the different intended modes of communication, the similarity of the basic arrangements of the transmitters and receivers was a factor in the decisions of the US Court of Claims in 1935 and the US Supreme Court in 1943 to invalidate the 1904 American patent of the Marconi Wireless Telegraph Company for a tuned spark radio system. These decisions were the culmination of unsuccessful efforts by the Marconi Wireless Telegraph Company of America to sue the United States government for the use of radio equipment circa World War I that was claimed to infringe on the 1904 patent.

The most obvious difference between Figures 1a and 1b is that where a radio transmitter uses an antenna, Tesla used a conducting sphere. (Tesla's sphere was sometimes confusingly

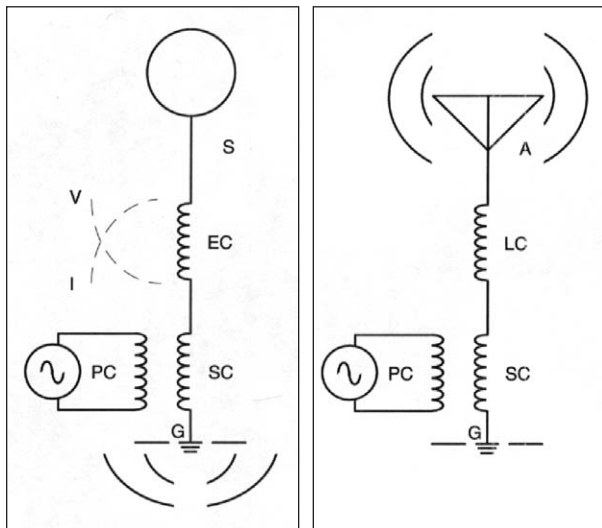


Fig. 1a. (left) Basic circuit of an early low-frequency radio transmitter. G—ground connection; PC—primary coil; SC—secondary coil; LC—loading coil; A—transmitting antenna.

Fig. 1b. (right) Basic circuit of the earth conduction transmitter that Tesla probably would have used at Wardenclyffe. G—ground connection; PC—primary coil; SC—secondary coil; EC—extra coil; S—transmitter sphere; V&I—standing waves.

called an antenna also, although it was intended only to act as a source or sink of charge). In contrast to low frequency radio antennas, which were made very tall to radiate efficiently, Tesla's sphere only needed to be elevated a distance equal to a few sphere radii, just enough to make its capacitance to ground small compared to its self-capacitance. This elevation typically was small enough compared to a wavelength to make the sphere and its vertical feedlines inefficient radiators of radio waves, which Tesla regarded as an energy loss. In a 1900 patent description Tesla proposed a similar sphere and ground arrangement for reception.

The Tesla transmitter circuit shown in Figure 1b is based on experimental arrangements that he used at his Colorado Springs laboratory, and the successful replica of the Colorado Springs transmitter constructed by Robert Golka in the 1970s.² This probably is the arrangement that Tesla referred to as his "magnifying transmitter." Although the radio and Tesla circuits look alike, the roles and parameters of the coils LC

and EC are quite different. LC is a “loading coil” which is used to tune the radio antenna circuit to the frequency of the transmitter. When tuned, the inductive reactance of LC and the transformer PC, SC cancels the capacitive reactance of the antenna, permitting a maximum amount of current to flow in the antenna. i.e., all of these components behave as “lumped” circuit elements in a series resonant circuit.

On the other hand, the “extra coil” EC was a “Tesla coil,” a special type of coil developed by Tesla to generate very high voltages at high frequencies (high relative to a.c. power frequencies). What distinguishes the Tesla coil from an ordinary air-core coil is that the great length of wire on it makes it act more like a transmission line than a simple lumped inductance.³ (The length of wire on Tesla’s extra coils at Colorado Springs was roughly one-quarter wavelength.) This allows standing waves like those sketched in Figure 1b to be set up on the coil if the bottom of the coil is at or near ground potential. These standing waves are like those on a quarter-wave vertical antenna, having a potential maximum at the top and a current maximum at the bottom. Tesla claimed that the potential generated at the top of such a coil greatly exceeded the voltage step-up that could be obtained in a conventional series resonant circuit, and the spectacular electrical discharges that he achieved with these coils seem to bear him out.

Both the potential (or voltage with respect to the ground) and current standing waves in Figure 1b tend to maximize the ground current, which was the end product of Tesla’s transmitter. The potential standing wave magnifies the e.m.f.

from the secondary coil SC, and applies it to the transmitter sphere. The resulting charging current at the sphere is magnified by the current standing wave to produce a ground current that is larger. The net effect is to transform the relatively large capacitive reactance of the sphere at frequencies of tens of kilohertz into a relatively low impedance as seen by the e.m.f. from SC, resulting in a large ground current. Although a simple series resonant circuit like that of the radio transmitter in Figure 1a also has minimum impedance at the resonant frequency, there is no current magnification, and the ground current is the same as the antenna current. It probably was the voltage and current magnifications, vital in producing a large ground current in a Tesla transmitter, that inspired Tesla to call this arrangement a “magnifying transmitter,” and to describe it as “a peculiar transformer specially adapted to excite the Earth.”

The Tesla magnifying transmitter appears to be an ingenious means of injecting a large current into the ground from a single terminal. The key question was (and still is) how far from the ground terminal this current and its associated electrical disturbance can be detected at frequencies high enough for practical communications—a few metres, a few wavelengths, around the world? Although the same phenomenon occurs at the ground terminals of radio transmitters, the answer is not known because radio engineers assume it to be of no practical interest.

At frequencies much smaller than the lowest whole earth resonant frequencies of several Hertz to several tens of Hertz, the charge from the ground terminal would obey the laws of elec-



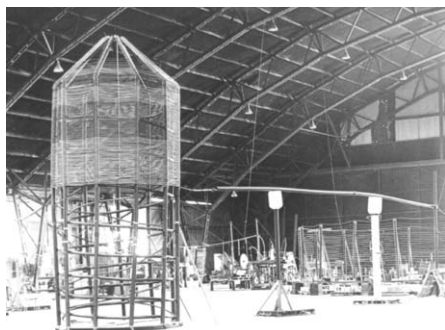
“Magnifying transmitter” constructed by Robert Golka, following the specifications of Tesla’s 1899 apparatus at Colorado Springs. See Fig. 1b for circuit diagram. Energized, as shown, it produced electrical discharges estimated at 12.5 million volts. Note that the extra coil is located at the centre of the excitation transformer. (Photo courtesy Tesla Wardenclyffe Project).

trostatics and spread uniformly over the surface of the whole earth. The current caused by the flow of this charge would decrease with distance, but its extent also would be worldwide. At the lower earth resonant frequencies, which Tesla calculated, one would expect global oscillations and standing waves as he described, if the resistance losses in the earth were small enough. These oscillations likely would be modified somewhat by interaction with the spherical cavity between the earth and the ionosphere. At much higher frequencies, the charge would still tend to flow to the surface of the earth, but the current would be confined to within tens or hundreds of metres of the surface by the “skin effect,” and the range of the disturbance would be reduced by I^2R losses.

Tesla obviously believed that the current would still travel a very long distance at frequencies as high as tens of kilohertz. He was so confident about the superiority of his earth conduction mode of transmission that as late as 1916 he claimed that signals transmitted across the Atlantic Ocean by commercial low frequency radio stations were being received in the form of earth conduction signals, not radio waves.⁴ Of course Tesla was unaware that reflection of radio waves from the ionosphere made long distance radio possible.

Tesla had however touched on a critical point. Radio transmitters with good antennas and real ground connections, not just ground screens or counterpoises, radiate both radio waves from their antennas and Tesla-type earth currents from their ground terminals. They provide a useful means of comparing the effectiveness of the two types of wireless signal produced by the same source, provided that the signals can be distinguished from one another. In particular, they raise the question: if earth current signals travel far enough to have practical value, why have they not been received from the ground terminals of radio transmitters—or have they?

The answer may depend on which type of electrical disturbance associated with the earth current is being received. (Tesla was never very clear about this aspect of his proposed receiver.) For example, if it is the vertical electric field of the charge on the surface of the earth that flows from the transmitter’s ground terminal, then either the sphere and ground of a Tesla receiver or the aerial and ground of a radio receiver should respond to it. At frequencies above about 30 kilohertz, radio signals can be distinguished from possible earth signals because of the difference between day and night reception and other ionospheric effects. In the very low fre-



The Golka “Magnifying Transmitter” replica under construction in a hangar at Wendover Air Base, Utah. The “extra coil” is in the left foreground, and the transformer that excited it is in the right background. This hangar once housed the Enola Gay, the B29 that dropped the atomic bomb on Hiroshima. (Photo courtesy Tesla Wardenclyffe Project)

quency range the differences may not be so obvious, but we will assume here for purposes of discussion that over the years constant major deviations from expected radio signal strengths and characteristics would have been noted. This implies that at large distances from low frequency radio transmitters the vertical electric fields of their radio waves are stronger than those generated by the surface charge from their ground terminals.

In addition to the vertical electric field of the surface charge, the current from the ground terminal would produce a horizontal potential gradient or electric field due to the resistance of the soil or water. At the receiver, this field would be parallel to the great circle joining the transmitter and receiver. This is the direction in which James H. Rogers apparently obtained the best reception in experiments with underground antenna wires.⁵ The underground antennas were intended to improve the signal-to-noise ratio by reducing atmospheric interference, and according to documented reports of long distance reception of low frequency radio stations around the time of World War I, they were quite successful. The signals detected by these antennas may be evidence of a practical Tesla earth current mode of communications at low frequencies. However, it should be noted that radio waves travelling over a conducting soil induce currents and voltages in the same direction.

Another component of radio and earth current signals that can be compared is their magnetic fields above ground. My calculations indicate



This building at Shoreham, Long Island, New York, housed Tesla's laboratory, workshops, and presumably the power plant for the transmitter. In the early 1900s, a large tower stood behind the building (see the OTB, February, 1999). It is the goal of the "Tesla Wardencliff Project" to preserve this building and utilize it to commemorate Tesla's work. (Photo courtesy Maxine Hicks, all rights reserved).

that the magnetic field of the earth current from the ground terminal of a typical low frequency radio transmitter might be much larger than the magnetic field of the radio wave from its vertical antenna. The question once again is whether such an effect could long go unnoticed. If the magnetic field of the earth current is in fact relatively large, it suggests that a loop antenna might be the best way to detect a Tesla earth current signal.

The foregoing discussion treats radio signals



Plaque at Wardencliff station building reads: "In this building designed by Stanford White, architect, Nikola Tesla—born Smiljan, Yugoslavia 1856—Died New York 1943—constructed in 1901-1905 Wardencliff—huge radio station with antenna tower 187 feet high/destroyed 1917, which was to have served as his first world communication system—In memory of 120th anniversary of his birth and 200th anniversary of the US independence—July 10, 1976." (Photo courtesy Maxine Hicks, all rights reserved).

and earth current signals as separate phenomena. Nevertheless, it is reasonable to ask whether they are not just different aspects of the same phenomenon. After all, radio waves induce surface charges and currents in the earth, and earth currents from ground terminals should produce electric and magnetic fields in the air above of the type previously discussed. Was Tesla simply focussing his attention on the subterranean component of the low frequency radio mode of propagation?

As we have seen, Tesla's sphere and ground combination could generate earth currents at a low frequencies without radiating much energy as radio waves. Conversely, radio transmitters and antennas can generate radio waves without using ground connections. This implies that, close to the transmitters at least, the radio wave in the air and the "Tesla current" signal in the ground are two distinct phenomena. However, the fact that they have field and current components in the same directions suggests that the two modes might become the same at a long distance from the source. If so, the relevant question would be whether Tesla's sphere and ground or a conventional radio transmitting antenna is the better method of generating a low radio frequency mode of propagation.

This is about as far as we can go on the basis of speculations. What is needed is a complete mathematical theory of the spreading of the current from a transmitter (radio or Tesla) ground terminal versus frequency, together with its associated electric and magnetic disturbances and the means of detecting them. I regret that I cannot offer such a solution, but I would encourage any engineer or physicist with the mathematical aptitude to take up the challenge. It would not only settle historical questions about the validity of Tesla's concepts, but it might reveal applications that are useful today.

Even if Tesla's earth conduction mechanism proved to be inadequate for a world wireless system, it seems likely in retrospect that if J.P. Morgan had financed the Wardencliff project to completion, it would have worked well enough as a radio transmitter to have provided a transatlantic service. As it was, the failure of working relations between inventor and investor brought an end to Tesla's great wireless project, as it did also to the transatlantic radio ambitions of his contemporary, Reginald Fessenden. These disappointing conclusions to their efforts left commercial transatlantic wireless as the domain of European interests until World War I.

(continued on page 35)



Fig. 4. Here's the interpanel set I hinted at in my first column. It's grown to three panels and I'll soon be adding a Fleming valve detector.

what effect the gridleak resistor value would have; I got best performance (best apparent gain) when the value was 2.7 Megohms. Either side of that value, output dropped off, and plate current rose with lower gridleak resistance.

Finally, I changed to a 1G4GT tube. It has lower μ ; only 8.8 versus 65 for the 1H5. That gave me less gain and a nasty "microphonic" noise caused by the vibration of the tube's innards.

Here's a challenge: build yourself a kluge breadboard like mine and see what you can learn by fooling with it. I've been an engineer for 38 years, and can't readily explain why the tube filament connection to ground makes such a difference. You would think that making the filament generally positive along its length would be the same as making the grid negative by a like amount and change the operating point only

slightly.

Try changing filament voltage—that used to be a crude technique for volume control. Try changing the plate load resistance—that will show you how get your triode's stage gain to approach the value of μ itself (but you'll never actually reach it!). The old Armstrong patent drawings show no grid resistor returning to ground—how did that affect his testing? Write or e-mail me with your ideas and test results!

Finally, a look at the "Interpanel" receiver I hinted at back in the first Breadboarding column. I started with the loose coupler, added a panel containing only a 23-plate tuning cap, and now I've added two more panels (Figure 4). One is a switching panel that mounts a catwhisker crystal detector from AES, a fixed crystal, and a pair of home-made coherers, one made with iron, one with brass filings.

The multipoint switch, scrounged from an old piece of test gear at a hamfest, selects which of these passive detectors does the work. Behind the switching panel is a triode detector like the one I've been describing. When completely hooked up, this receiver demonstrates PROGRESS IN DETECTOR INVENTION! If you'd like to have the schematic for the assemblage, write or email me at dparks@erols.com and I'll send you a drawing or an e-file. What fun this column has been! I will soon be adding a Fleming Valve detector, using a tube sent to me by a British reader, Mr Phil Taylor, of Billingshurst, Sussex. (BTW—he's looking for two 1000 v., 0.22 μ F Vitamin Q caps to rebuild an old oscilloscope)

TESLA'S DREAM, *continued from page 32*

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The letter "p" should not appear in the formula at the bottom, right, of page 29.